TM 9-2700

DEPARTMENT OF THE ARMY TECHNICAL MANUAL

PRINCIPLES OF AUTOMOTIVE VEHICLES

DEPARTMENT OF THE ARMY • NOVEMBER 1947

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For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price $1.50

DEPARTMENT OF THE ARMY
WASHINGTON 25, D. C., 18 November 1947

TM 9–2700, Principles of Automotive Vehicles, is published for the information and guidance of all concerned.

The information in this manual is correct as of 1 May 1947.

[AG 300.7 (21 Feb 46)]

BY ORDER OF THE SECRETARY OF THE ARMY:

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For explanation of distribution formula see TM 38–405.

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PART ONE

INTRODUCTION

CHAPTER 1

GENERAL

1. Purpose

This manual is published to disseminate basic descriptive information in the field, and in service and troop schools, to teach what the automotive vehicle is and how it works. It also contains information which makes the publication a convenient reference manual.

2. Scope

a. Subject Matter and Presentation. This text explains the automotive vehicle in general. The explanations avoid reference to any specific vehicle or unit wherever possible. Since existing publications cover operation and maintenance of vehicles, these subjects have been omitted. The flow of power is traced from its development in the engine to its final outlet at the wheels, the units being discussed in the order in which they contribute to the power flow. For this reason, the ignition system is treated separately from the rest of the electrical system. Diesel and gasoline engines, except for their fuel systems, are explained together, as are radial and in-line engines. After the flow of power is traced to the wheels, those chassis components, sometimes referred to as running gear, i.e., steering system, brakes, wheels and tracks and frames are explained; then hulls and bodies; and finally such miscellaneous items as special equipment and trailers.

b. Emphasis. Wheel vehicles have been emphasized for two reasons: first, tracklaying vehicles, in the main, employ in special adaptation the same fundamental principles of wheeled vehicles; secondly, instruction will be facilitated by the reference to wheeled vehicles because the parts are more accessible and more easily seen by the student than on tracklaying vehicles. Again to aid instruction, an attempt has been made to correlate the military vehicle with commercial vehicles that may be familiar to the student.

3. Characteristics of Military Vehicles

a. TERMINOLOGY. For a better understanding of the general sections to follow and of other references, the following terms are defined. Terms pertaining to the mechanics of the automotive vehicle are defined in the appropriate portion of the text.

(1) *All-wheel drive.* A drive in which all wheels receive power for propelling the vehicles.

(2) *Angle of approach.* The angle of the maximum grade that a vehicle can approach on the horizontal and start to climb with no part, except tires, coming into contact with the incline.

(3) *Angle of departure.* The angle of the maximum grade from which a vehicle can depart on the horizontal without any part, tires excepted, coming in contact with the grade.

(4) *Armor.* Armor is any type of enclosing structure used for the protection of military vehicles from gun fire.

(5) *Convertible.* A vehicle designed to be operated either as a track vehicle or as a wheeled vehicle.

(6) *Cross country.* Away from surface and improved roads. Over virgin terrain, dry and uneven, sand, rocks, hills, through water and/or swamp land.

(7) *Cruising range.* The total mileage a vehicle can operate on the contents of its fuel tanks or a filling of oil.

(8) *Drawbar pull.* The pull exerted at the pintle.

(9) *Flotation.* The amount of load carried by each square inch of projected contact area of the vehicle's tires or tracks. At zero penetration the flotation unit pressure for a wheeled vehicle is the same as the air pressure in the tires.

(10) *Fordability.* Expressed in inches of water that a vehicle can go through under its own power.

(11) *Grade ability.* The maximum grade that a fully loaded and equipped vehicle can climb at constant speed on a smooth concrete course when operating in a specified gear range.

(12) *Ground clearance.* The distance between level ground and the lowest point on the undercarriage of the vehicle.

(13) *Military characteristics.* The basic service requirements of a vehicle.

(14) *Payload.* The cargo carried by the truck or trailer.

(15) *Passenger capacity.* The passenger capacity is the number of passengers, including operating personnel, that a vehicle is designed to carry.

(16) *Stowage.* Equipment stowed with the vehicle.

(17) *Tractive factor.* The proportion of engine torque per pound

of vehicle weight that is available at the tire surface for moving the vehicle.

(18) *Turning radius.* The radius of the arc described by the center of the track made by the outside front wheel of a vehicle when making its shortest turn (S.A.E. definition).

(19) *Vehicle gross weight.* This value includes the weight of the chassis, cab body, cargo (payload), and unless otherwise specified, the operating personnel.

b. Transport Vehicles. Military transport vehicles are primarily commercial vehicles that have been modified to fulfill military needs. In some instances, the commercial product is used without modification. The dominant requirements of military transport vehicles over and above those demanded of similar commercial trucks are:

(1) All-wheel drive for maximum mobility.

(2) Constant velocity type universal joints at the outer ends of the front driving axles to provide maximum steering angle and better maneuverability over rough terrain without dangerous reactions being transmitted through the steering gear.

(3) Combat tires to eliminate emergency breakdown during operations due to tire punctures.

(4) Sturdy radiator and head lamp guards as protection from branches and brush in blackout operations in the field.

(5) Sturdy front and rear bumpers as protection against collision during blackout convoys (training and actual combat operations) and as an aid in assisting mired vehicles.

(6) Towing hooks and pintles for towing nonpowered vehicles and being towed.

(7) Front axle declutching unit for relieving tires and driving mechanism while operating on surfaced roads.

(8) Maximum angles of approach and departure to facilitate vehicle operation over uneven and rough virgin terrain.

(9) Deep fordability to enable vehicles to cross streams under their own power.

(10) Equal performance ability of all types and sizes of vehicles in order to realize maximum movement of convoys in a prescribed time period.

(11) Maximum ground clearance consistent with road stability to permit operation over virgin terrain and through marsh and mud.

(12) Clearance between the engine oil pan and the front propeller shaft sufficient to prevent contact under all conditions of operation.

(13) Flexible type of unit assembling mounting, particularly engine transmission and transfer case. Preferred type for power train unit is three-point suspension with circular trunnion as one support.

(14) Sloping engine hoods for close clear vision of roads and combat light during blackout driving either singly or in convoy.

(15) Combat lights, front and rear, for blackout driving.

(16) Scavenging oil circulating pump connected to the front and rear of the oil pan to return oil to the main oil pump where it can be circulated by the oil pump during steep slope operation.

(17) Auxiliary fuel filters. Necessary to eliminate water and sediment from fuel before it reaches the fuel pump. Accumulation of dirt and moisture is increased in military service because of the absence of protection from the elements during field fueling operations.

(18) Radio frequency interference suppression. Required to eliminate interference with military radio communication and informing enemy listening posts of vehicular movements.

(19) Crankcase ventilation. To reduce corrosion of reciprocating parts and maintain stable lubrication by removing fuel light ends and moisture of condensation from the crankcase.

(20) Arcticizing equipment. To provide easy starting of engines in subzero temperatures by heaters and insulating covers to batteries and engine compartment.

(21) Desertizing equipment. This equipment consists of large section, low inflation tires; auxiliary radiator tank to store main radiator overflow; pressure-type radiator cap to prevent coolant loss by evaporation and overflow loss when traveling down steep grades; fuel tank filler pressure caps to assist flow of fuel under vapor lock tendencies.

(22) Wheels. Demountable at the hub to permit quick changes without disturbing the wheel bearings, and in addition, to enable front wheels to be assembled in duals when required.

(23) Full-floating type axles. To insure against loss of wheels in the event of broken axle shafts.

c. Combat Vehicles. (1) So far as automotive design principles are concerned, it is to be noted that combat vehicles are in all respects subject to the same limitations as those of a more conventional type. In addition, designs must be such as to permit successful operation with one or more of the following features present:

(a) Power plant and power train fully enclosed by armor.

(b) Engine located at rear of vehicle.

(c) Mobility in temperatures from—40° F to 125° F.

(d) Operation in mud and under extreme dusty conditions.

(2) Tanks and armored cars are usually built on a hull fabricated of armor plate. Scout cars are usually of conventional basic design with armored bodies.

(3) Performance will generally include:

(a) 60 percent grade ability.

(b) Maximum drawbar pull at least 80 percent of gross weight.

(c) High gear drawbar pull at least 8 percent of gross weight.

(d) Minimum speed 3 miles per hour or less.

(4) In addition to satisfying the military need for which the combat vehicle may have been designed, crew comfort and safety must be provided by:

(a) Adequate ventilation.

(b) Padding of interior surfaces.

(c) Careful attention to seating.

(d) Adequate design of drivers' turret and escape hatches and locks for same.

(e) A fire extinguisher installation adequate as to coverage and controls.

(f) Avoidance of overly restricted interior dimensions.

4. History of Military Vehicles

In 1912, four commercial trucks were purchased by the U. S. Army for experimental purposes. Thus, motor vehicles were introduced as a means of transporting military personnel, supplies, and equipment. By 1916, when the Punitive Expedition was sent against the Mexican bandits, interest had been stimulated to the point that a fleet of trucks, absolutely unstandardized and of many different makes, was assembled at the Mexican Border and used in the campaign. It was discovered then that commercial transportation did not meet military requirements on operations over rough terrain and in the vital requirements of maintenance and repair. This discovery prompted the initiation of standardized designs of operating equipment and various modifications to meet military requirements. As a result, the thousands of vehicles used in World War I were to a great extent standardized and possessed a moderate degree of interchangeability. The slow, strangulating trench warfare of that war cause the development of an automotive vehicle used solely for combat purposes. As such, the tank was introduced by the British in France in 1916; subsequent American tanks were for the most part copies of British models. In the period between the two World Wars, American design and experimentation were carried on to develop a fleet of military wheeled vehicles that were entirely standardized and had a high degree of interchangeability. Under the program industry began to produce vehicles with both front and rear wheel drive. This was a feature that was required of a military vehicle for successful operation over any terrain, and found only in special commercial equipment. After German tanks and combat vehicles proved so tragically successful against the Polish, French, and British armies in 1939 and 1940, American tank development was necessarily accelerated. In the race to develop superior combat vehicles, the United States equalled and, in some instances, surpassed the Axis powers; in the race of production, the United States was eminently successful and was able to send overwhelming quantities of automotive materiel against the enemy to help bring about his defeat.

CHAPTER 2

ORGANIZATION OF THE MANUAL

5. Major Components

There are many different ways to group vehicle units and assemblies. The method employed in this text has been chosen because it more readily lends itself to a logical and simplified development of the material to be presented. In this grouping there are five major components:

a. POWER PLANT. The power plant consists of the engine, whether Diesel or gasoline, and attached fuel, ignition, cooling, and lubricating systems.

b. POWER TRANSMISSION SYSTEM. This system includes all mechanisms by which power is transmitted from the engine to the wheels. These mechanisms are the clutch, transmission, transfer assembly, propeller shafts, universal joints, final drive assembly, differential, and drive axles.

c. ELECTRICAL SYSTEM. The electrical system includes electrical attachments other than those in the ignition system, such as the battery and the generating, starting, and lighting systems.

d. CHASSIS. The units in this component are the frames, brakes, wheels, tires, tracks, suspension system, and steering system.

e. BODY. The cargo—or personnel-carrying portion of the vehicle; it includes hulls and bodies.

6. Classification of Vehicles

a. GENERAL. The term vehicle as used in the Army includes all wheeled, tracklaying, and combined wheeled and tracklaying vehicles with chassis powered by a self-contained power unit, and trailers and semitrailers towed by vehicles and bicycles.

b. CLASSIFICATION OF VEHICLES ACCORDING TO AR 850-15. (1) *General purpose vehicles* "are wheeled vehicles designed to be used interchangeably for movement of personnel, supplies, ammunition or equipment, or towing of guns, trailers, or semitrailers, and which are used without modification to body or chassis to satisfy general automotive needs." The 2½-ton cargo truck, 6 x 6, is a general purpose vehicle, for it is used as a general transport vehicle and has a standard, unmodified chassis.

(2) *Special equipment vehicles* "are vehicles the chassis of which are identical, except for minor alterations, to those used in general purpose vehicles, but which have a special body or special equipment mounted thereon." The ordnance shop truck (ordnance maintenance truck, 2½-ton, 6 x 6) is in this class because a special body to house the shop has been mounted on the chassis of a general purpose 2½-ton, 6 x 6.

(3) *Special purpose vehicles* "are vehicles, the chassis and body of which are designed or adapted for special purposes, and differ from those of general purpose or special equipment vehicles." Because it has been especially designed for use on any terrain and is not an adaptation of any other vehicle, the half-track is classed as a special purpose vehicle.

(4). *Combat vehicles* "are vehicles with or without armor and/or armament, which are designed for specific fighting functions. Armor protection or armament mounted as supplemental equipment on general purpose special equipment, or special purpose .vehicles will not change the classification of such vehicles to combat vehicles." The tank, of course, is the best example of a combat vehicle. That its purpose is solely for combat is reflected in its design and construction; both of which are different from those of any other vehicle.

c. Classification by Ground Contact. Under these general classifications vehicles may be further subclassified into wheeled, tracklaying, and half-track vehicles. Wheeled vehicles may be classified by the number of wheels and the number of driving wheels. This is found in the vehicular designation as 4 x 2 — 4 wheels, 2 driving — or 6 x 6 — 6 wheels, all driving. It should be noted that all 6-wheel vehicles have three axles—that is, wheels are considered a unit whether they are single, one tire, or dual, two tires. Tracklaying vehicles are so called because the tracks serve the purpose of providing a supporting platform of relatively large area under the bogie wheels of the vehicles, with rails or other guiding elements on the upper side. Half-track vehicles include all in which a portion of the vehicle weight is carried on wheels at the front, capable of being steered, the rear portion of the vehicle being carried on tracks.

PART TWO

ENGINES

CHAPTER 3

CHARACTERISTICS OF ENGINES

Section I. PRINCIPLES OF OPERATION

7. Definition of an Engine

An engine is defined simply as a machine that converts heat energy to mechanical energy. To fulfill this purpose, the engine may take any one of several forms.

a. INTERNAL COMBUSTION AND EXTERNAL COMBUSTION. Automotive engines, whether Diesel or gasoline; air-cooled or liquid-cooled; in-line, V-type, or radial; two-stroke cycle or four-stroke cycle, obtain heat energy from the burning of a fuel inside the confined space of a cylinder. Because burning takes place within the same cylinder that

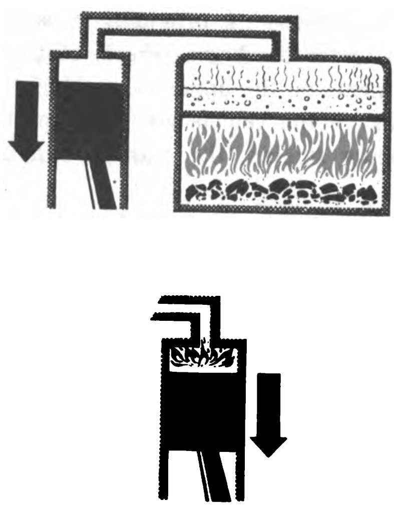

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Figure 1. Comparison of External Combustion and Internal Combustion Engines.

produces energy to turn the crankshaft, engines of this type are referred to as internal combustion engines (fig. 1). The steam engine is a common example of an external combustion engine. Fuel is burned outside the cylinder, and water is changed into steam which is directed into the cylinder to produce power. This text will be concerned only with internal combustion engines, and when the word "engine" is used it will be understood to refer to the internal combustion engine.

b. HEAT ENERGY AND MECHANICAL ENERGY. The transformation of heat energy to mechanical energy by the engine is based on a fundamental law of physics which states that gas will expand upon application of heat. If the gas is confined, however, with no outlet for expansion, then the pressure of the gas will be increased when heat is applied (as it is in an automotive cylinder). In an engine, this pressure acts against the head of a piston causing it to move away from the combustion chamber.

c. RECIPROCATING MOTION TO ROTARY MOTION. The downward movement of the piston is transformed into rotary motion through a connecting rod and crankshaft (fig. 2). The automotive cylinder is a hollow tube closed at one end. The piston, also cylindrical and designed to slide up and down in the cylinder, fits closely against the cylinder wall so that the open end is sealed. The connecting rod is straight, and its upper end is fastened or pivoted to the piston so that the lower end is free to swing. The motion of the piston is reciprocating, or up and down, whereas motion emerging from the engine is rotary. The necessary transformation is accomplished by the design of the crankshaft, which is mounted on bearings at both ends so that it can revolve freely. In the middle of the crankshaft there is an offset part known as the "crank" or "throw" to which the lower end of the connecting rod is

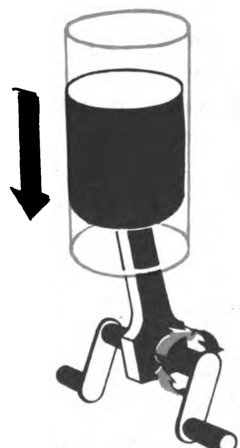

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Figure 2. Cylinder, Piston, Connecting Rod and Crankshaft for Simple One-cylinder Engine.

fastened. As the piston is forced down by the expanding gas, the connecting rod moves down also, but it must follow the circular path described by the throw of the crankshaft. Thus the reciprocating motion of the piston is transformed to rotary motion of the crankshaft.

d. THE CYCLE. To produce power for any length of time, an engine must accomplish a definite series of operations and perform them over and over again. The prescribed series is known as a "cycle" and must include these basic steps:

(1) The cylinder is filled with a mixture of fuel and air in the correct proportions.

(2) The mixture in the cylinder is compressed by the piston.

(3) The mixture is ignited and burns, and the expanding gas drives the piston down away from the combustion chamber.

(4) The burned gases are expelled from the cylinder.

e. AIR, FUEL, COMPRESSION AND IGNITION. Despite the intricate construction of modern engines, only four factors are necessary for proper engine functioning—air, fuel, compression and ignition. Fuel contains potential energy for operating the engine, air contains the oxygen necessary for combustion, and ignition starts combustion. All are fundamental, and the engine will not operate without any one of them. Any discussion of engines must be based on these three factors and the steps and mechanisms involved in delivering them to the combustion chamber at the proper times.

8. Otto Cycle

a. FOUR-STROKE CYCLE. Gasoline engines that need four strokes of the piston, two up and two down, to complete a cycle are known as four-stroke cycle engines. They are commonly referred to as four-stroke Otto cycle because they operate on principles first applied by Dr. N. A. Otto in 1876. Gasoline is not the only fuel used in Otto-cycle engines, but it is easily the most common. In any reference to the gasoline engine in this text, it will be understood that the engine operates on the Otto cycle (fig. 3).

(1) *Intake stroke.* The intake stroke is the first step in the cycle, and it begins with the piston at its topmost position, or "top dead center." The piston moves down, creating a difference in pressure between the upper part of the cylinder and the atmosphere. The result is a low-pressure area above the piston, allowing an air-fuel mixture to be forced through an opening into the cylinder. When the piston reaches the bottom of its stroke the opening closes, sealing the fuel mixture in the cylinder. This completes the intake stroke.

(2) *Compression stroke.* The compression stroke is the next step. The intake opening is closed, and the piston moves up until it reaches top dead center where the cycle started. The crankshaft now has made one revolution, and the air-fuel mixture is compressed in the small space

(combustion chamber) above the piston. There are two fundamental reasons for compressing the mixture:

(a) The heat of compression mixes air and fuel more thoroughly, making burning smoother and easier.

(b) The compressed mixture, when ignited, will expand with greater force than a mixture that is not under pressure.

(3) *Power stroke.* The third step of the cycle is the power stroke, the only one that contributes to the engine output. At this time, the compressed fuel mixture is ignited by an electric spark from a spark plug. The heat of combustion causes the burning gases to expand with extremely high pressure, forcing the piston down and producing mechanical energy to turn the crankshaft. Both openings into the combustion chamber remain closed.

(4) *Exhaust stroke.* The final step is to exhaust the burned gases in preparation for the beginning of another cycle. As the piston reaches bottom dead center, an opening at the top of the chamber is uncovered, immediately relieving the pressure on the piston; the port remains open while the piston moves up again. The piston forces the burned gases out as it once more moves back to top dead center. When the piston reaches top dead center again, the opening closes and the cylinder is then ready for another cycle. During the Otto four-stroke cycle the crankshaft revolved twice and the piston made four strokes. The same sequence of intake, compression, power, and exhaust must always occur in the same order and must be repeated again and again to operate the engine.

b. Two-stroke Cycle. (1) By modifying the four-stroke cycle, an engine can be made which operates on a two-stroke cycle and in which every other piston stroke is a power stroke. This is known as the two-stroke Otto cycle. Each time the piston moves down it is on the power stroke. Intake, compression, power, and exhaust still take place but are completed in just one-half the number of strokes. Working parts of the two-stroke cycle engine are shown in figure 4. Intake and exhaust ports are cut into the cylinder wall instead of in the top of the combustion chamber as they were in the four-stroke cycle engine. As the piston moves down on its power stroke, it first uncovers the exhaust port to let burned gases escape and then uncovers the intake port to allow a new air-fuel mixture to enter the combustion chamber. On the upward stroke the piston covers both ports and at the same time compresses the new mixture in preparation for ignition and another power stroke.

(2) Theoretically, the two-stroke cycle engine would put out twice as much power as a four-stroke cycle engine of the same size. This is not true, however, because fuel is wasted and power is lost when some of the incoming fuel mixture mixes with exhaust gases and goes out with them. The volumetric efficiency of the engine is thus reduced considerably (par. 9b (6)).

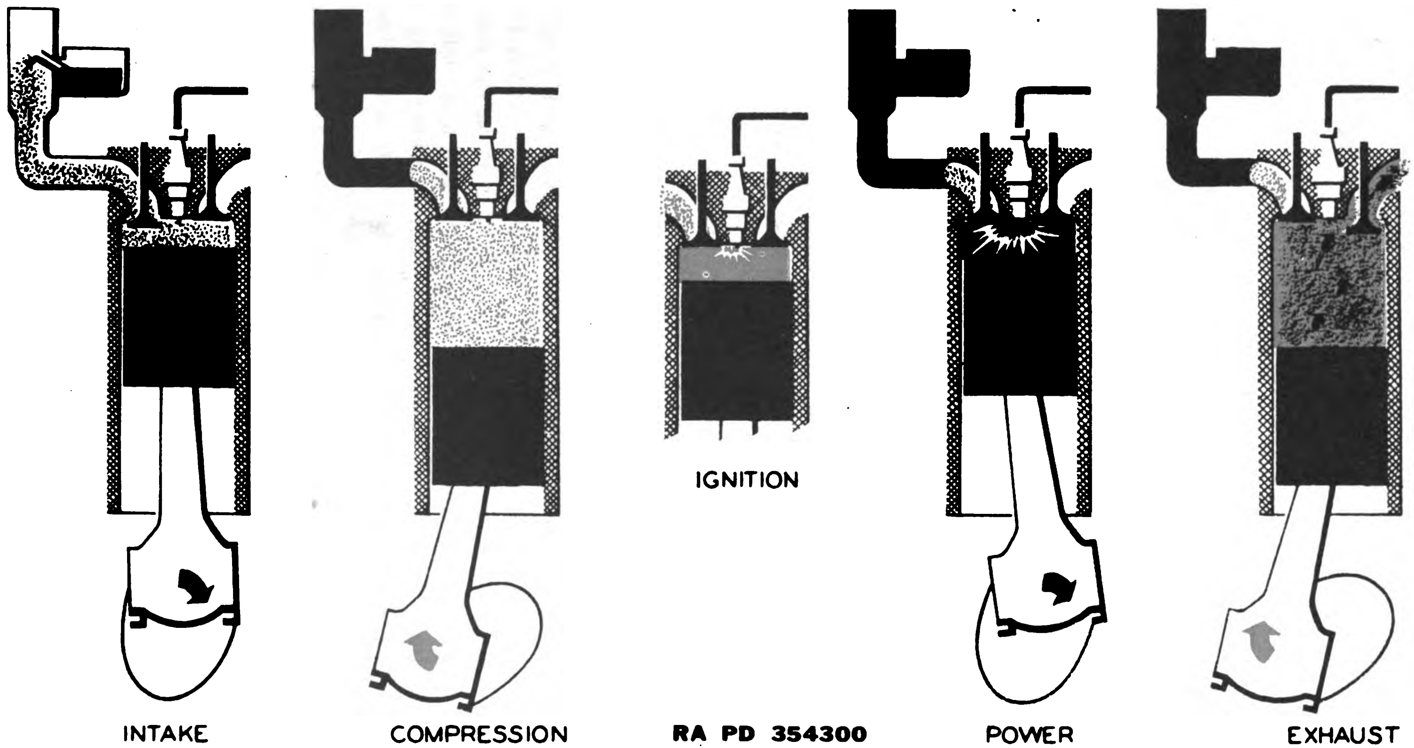

Figure 3. Four-stroke Otto Cycle.

9. Diesel Cycle

a. Diesel Development. The Diesel engine bears the name of Dr. Rudolph Diesel, a German engineer. He is credited with constructing, in 1897, the first successful Diesel engine using liquid fuel. His objective was an engine with greater fuel economy than the steam engine, which used only a small percentage of the energy contained in the coal burned under its boilers. Dr. Diesel originally planned to use pulverized coal as fuel, but his first experimental engine in 1893 was a failure. After a second engine also failed, he abandoned his plan and used liquid fuel, which proved successful.

b. Diesel Cycle vs Otto Cycle. (1) *Mechanical details.* The Diesel engine is mechanically similar to gasoline engines using the Otto cycle. Both depend for operation upon the four fundamentals of air, fuel, compression and ignition. Examination of the four-stroke and two-stroke cycles also will reveal definite similarity between the Otto and Diesel cycles. Intake, compression, power, and exhaust take place in the same order. Pistons move up and down in cylinders, and connecting rods are fastened to a crankshaft that transforms reciprocating motion into rotary motion. There is little difference in external appearances. Both types extract energy from the burning of an air-fuel mixture inside a cylinder.

(2) *Method of ignition.* (*a*) The main difference between engines operating on Otto and Diesel cycles is in the method of admitting and igniting the fuel (fig. 5). In the Otto-cycle engine, the fuel and air are mixed before they enter the cylinder. In the Diesel, fuel and air enter

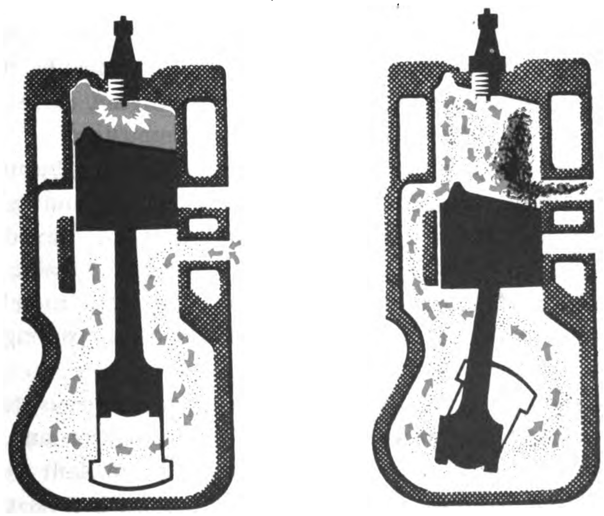

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Figure 4. Two-stroke Otto Cycle.

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separately and the mixing occurs within the cylinder. The Otto-cycle engine compresses a mixture of air and fuel which is ignited by an electrical spark, but the Diesel compresses air only. Diesel fuel is injected into the compressed air at about the same time that the spark would occur in a gasoline engine. The heat caused by compression of air in the cylinder is solely responsible for ignition in the Diesel. No spark plug is necessary.

(*b*) Pressure developed by the compression stroke is much greater in the Diesel engine, in which pressures as high as 500 pounds per square inch are common. For each pound of pressure exerted on the air, there will be a temperature increase of about 2° F. At the top of the compression stroke (when pressure is highest) the temperature in the chamber will be about 1,000° F. This heat ignites the fuel almost as soon as it is injected into the cylinder, and the piston, motivated by the expansion of burning gases, then moves down on the power stroke. In a gasoline engine the heat due to compression is not enough to ignite the air-fuel mixture and a spark plug is therefore necessary.

(3) *Control of speed and power.* (*a*) The speed and power output of Diesel engines are controlled by the quantity of fuel injected into the cylinder. This is opposed to the common gasoline engine, which controls speed and power output by limiting the amount of air admitted to the carburetor. The carburetor is the device that mixes air and fuel outside the cylinder (par. 52*a*). The simple difference is that the Diesel engine controls the quantity of fuel whereas the gasoline engine regulates the quantity of air.

(*b*) In the Diesel engine a varying amount of fuel is mixed with a constant amount of compressed air inside the cylinder. A full charge of air enters the cylinder on each intake stroke. Because the quantity of air is constant, the amount of fuel injected determines power output and speed. As long as the amount of fuel injected is below the maximum established by the manufacturer in designing the engine, there is always enough air in the cylinder to insure complete combustion.

(*c*) In the carburetor of a gasoline engine, there is a means of controlling the amount of air admitted. The amount of air and its velocity, in turn, control the quantity of fuel that is picked up and mixed with air to be admitted to the cylinder. The amount of mixture available for combustion determines power output and speed. It is apparent, therefore, that the controlling factor is the quantity and velocity of air passing through the carburetor.

(4) *Combustion process.* In the Diesel engine, there is continuous combustion during the entire length of the power stroke, and pressure resulting from combustion remains approximately constant throughout the stroke. In the gasoline engine, however, combustion is completed while the piston is at the upper part of its travel. This means that the volume of the mixture stays about the same during most of the combustion process. When the piston does move down and the volume increases,

there is little additional combustion to maintain pressure. Because of these facts, the cycle of the gasoline engine is referred to as having constant-volume combustion whereas the Diesel cycle has constant-pressure combustion.

(5) *Thermal efficiency.* The Diesel engine is economical because it uses a low-cost fuel and obtains more power output per gallon. The latter advantage is due to the higher compression ratio of the Diesel, which increases its thermal efficiency (par. 19*a*). Because the air has been under such high compression pressure, it expands more when fuel is injected and combustion occurs. The Diesel engine converts more heat energy to mechanical energy because combustion is more prolonged and therefore force is applied to the head of the piston for a longer time.

(6) *Volumetric efficiency.* It was pointed out that there are no major mechanical differences between gasoline and Diesel engines. However, the Diesel two-stroke cycle engine does use a device for raising volumetric efficiency (par. 19*c*), which is not found on two-stroke Otto-cycle engines. This device is a blower which forces air into the combustion chamber to hasten the movement of burned gases out through the exhaust ports. As a result, the piston compresses a charge of air that has very little exhaust gas remaining in it and consequently, has sufficient oxygen to burn the fuel when it is injected. In the gasoline two-stroke cycle engine, part of the incoming air-fuel mixture went out with the exhaust gases. The volumetric efficiency gained by using the blower is partially offset, however, by the power needed to turn it.

Section II. PRACTICAL APPLICATION

10. Mechanical Details

The one-cylinder engine which was the example used in descriptions of the Otto and Diesel cycles consisted merely of a cylinder, piston, connecting rod, crankshaft, flywheel and spark plug or some other means of igniting the fuel. To explain the practical applications of this engine it is necessary to add some more parts, a practice that will continue as the explanation of the engine progresses.

a. The first step in engine operation is the admitting of the air-fuel mixture, or air alone in the Diesel, to the cylinder. An intake valve controls the opening for admitting the mixture, and an exhaust valve controls the opening for expelling exhaust gases from the cylinder. Both valves are held closed by springs and are opened mechanically at the proper time by the valve-operating mechanism linkage (fig. 6), which is activated by the camshaft.

b. The camshaft (fig. 7), turned by the crankshaft through gears or a chain, opens the valves by the mechanical lift of its cams acting against the tension of the valve springs.

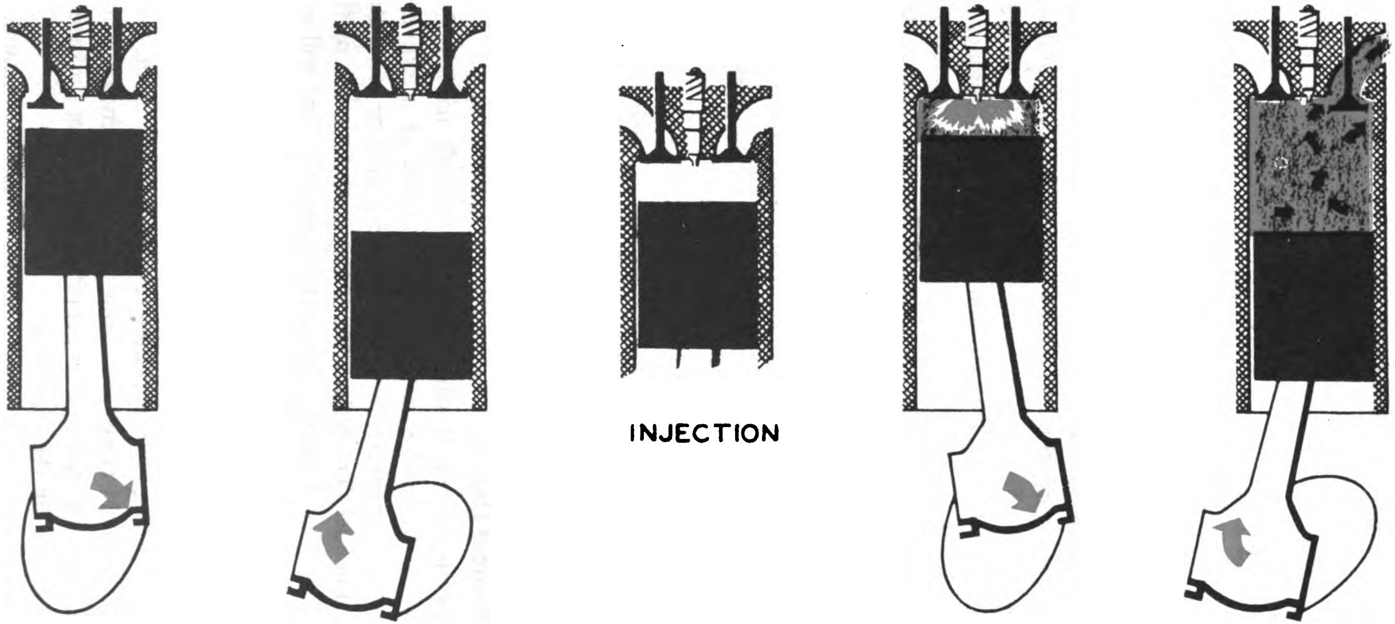
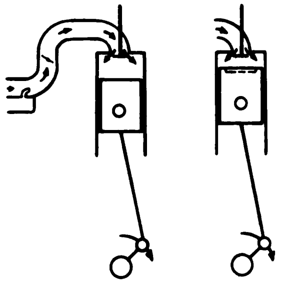


Figure 5a. Four-stroke Diesel Cycle.

GASOLINE | **DIESEL**

INTAKE STROKE

Gasoline: On downward stroke of piston, intake valve opens and atmospheric pressure forces air through carburetor where it picks up a metered combustible charge of fuel. The mixture goes past the throttle valve into cylinder-space vacated by the piston.

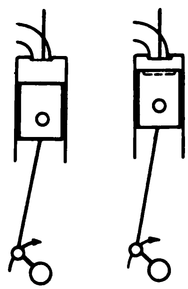


Diesel: On downward stroke of piston, intake valve opens and atmospheric pressure forces pure air into the cylinder-space vacated by the piston, there being no carburetor or throttle valve. Cylinder fills with same quantity of air, regardless of load on engine.

• • •

COMPRESSION STROKE

Gasoline: On upstroke of piston, valves are closed, and mixture is compressed usually to from 70 to 125 lbs. per sq. in., depending on anti-knock characteristics of the fuel.

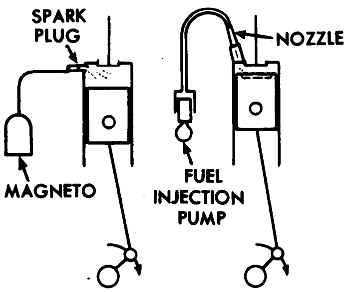


Diesel: On upstroke of piston, valves are closed, and air in International Diesels is compressed to approximately 500 lbs. per sq. in.

• • •

POWER STROKE

Gasoline: Compressed fuel-air mixture is ignited by electric spark. Heat of combustion causes forceful expansion of cylinder gases against piston, resulting in power stroke.

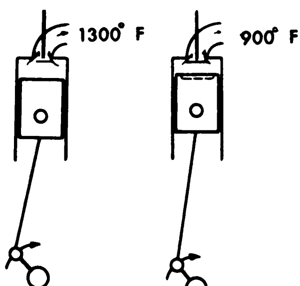


Diesel: High compression produces high temperature for spontaneous ignition of fuel injected near end of compression stroke. Heat of combustion expands cylinder gases against piston, resulting in power stroke.

• • •

EXHAUST STROKE

Gasoline: Upstroke of piston, with exhaust valve open, forces cylinder gases out, making ready for another intake stroke.



Diesel: Upstroke of piston, with exhaust valve open, forces cylinder gases out, making ready for another intake stroke.

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Figure 5b. Comparison of Gasoline and Diesel Engine Cycles.

11. Air-fuel Ratio

a. Fuel for the theoretical engines discussed in the preceding paragraphs could be any combustible substance, but the fuels most widely used in automotive engines today are gasoline and Diesel fuel. The characteristics which make these fuels desirable will be covered later in this text. However, a discussion of the problems involved in the use of a liquid fuel is necessary to better understand the intake systems.

b. Oxygen must be present if combustion is to occur, and inasmuch as air is the source of supply of oxygen used in an automotive engine, the problem becomes one of getting enough air into the cylinder to support combustion of the fuel. The commonly accepted ratio of air to fuel for combustion in a gasoline engine is 15 to 1. This may vary somewhat either way, depending on whether power or fuel economy is desired. For every pound of gasoline used, 15 pounds of air must be supplied. Gasoline weighs approximately 600 times as much as air, which means that 600 x 15 or 9,000 times as much air must be furnished if a volumetric comparison is made. To put it another way, ½ teaspoon of gasoline must be mixed with 1 cubic foot of air to obtain a 15 to 1 ratio by weight.

12. Valve Timing

a. RELATION BETWEEN PISTON AND VALVES. A new mixture must be trapped in the cylinder at the proper time during each cycle, and, after combustion, the exhaust gases must be allowed to flow out of the cylinder. Valve timing refers to the exact times in the engine cycle at which the valves trap the mixture and then allow the burned gases to escape. The valves must open and close so that they are constantly in step with the piston movement of the cylinder which they control. The position of the valves is determined by the camshaft; the position of the piston is determined by the crankshaft. Correct valve timing is obtained by providing the proper relationship between the camshaft and the crankshaft. When the four strokes of an engine were discussed, it was assumed that the valves opened and closed at top or bottom dead center and remained open or closed for 180° of crankshaft rotation. In actual operation, the time at which the valves operate will vary, as shown in the typical valve-timing diagram (fig. 8).

b. EXHAUST VALVE. The exhaust valve opens before the piston reaches the end of the power stroke so that the pressure remaining in the cylinder will cause the exhaust gases to rush out of their own accord. If the valve did not open before the end of the power stroke, this pressure would impede the upward movement of the piston during the exhaust stroke. Even though some of the force of the expanding gases is wasted, gases rushing out the exhaust port create a turbulence which aids scavenging. This, together with the freedom afforded the piston in beginning the exhaust stroke, results in greater power output.

c. "Rock" Position. When the piston is at top or bottom dead center, the crankshaft can move 15° to 20° without causing the piston to move up or down any perceptible distance. This is called the "rock" position (fig. 9). When the piston moves up on the exhaust stroke, considerable momentum is imparted to the exhaust gases as they pass out through the exhaust-valve port, but if the exhaust valve closes at top dead center a small amount of the gases will be trapped in the combustion chamber and the incoming air-fuel mixture will be diluted. Since the piston has little downward movement while in the rock position, the exhaust valve can remain open during this period and thereby permit a more complete scavenging of the exhaust gases.

d. Intake Valve. Very little vacuum is created in the combustion chamber as the piston passes through the rock position at top dead center. The exhaust gases, however, because of their momentum in passing through the exhaust-valve port, create an air current in the chamber. This air current is sufficient to cause a new mixture to start moving into the combustion chamber if the intake valve is open. For this reason, the intake valve opens slightly before top dead center. As the piston goes down on the intake stroke, the rapid decrease in pressure in the cylinder enables atmospheric, or outside, pressure to impart considerable momentum to the incoming mixture. If the piston moves slowly, the mixture will be able to enter fast enough to keep the pressure in the combustion space equal to that outside. At high speed the piston will reach the end of its downward stroke before a complete charge has had time to enter, thereby causing the pressure in the combustion space to be below that of the atmosphere. The intake valve is allowed to remain open until the piston reaches a point in its next upward stroke at which the pressure in the cylinder equals the outside pressure. The momentum of the incoming mixture builds up the pressure faster than the upward movement of the piston through the rock position would build it up if the valve were closed. The point at which the pressure of the incoming mixture equals the pressure caused by the upward movement of the piston varies in different designs.

13. Compression Ratio

a. Definition. To develop the highest power output from the mixture after it is trapped in the cylinder, the mixture must be compressed as high as practicable. As previously stated, the higher the pressure in the cylinder after the compression stroke the greater the power output. The compression pressures of an engine are indicated by the compression ratio, which is the ratio of the total volume of a cylinder to its clearance volume. A study of figure 10 will show the relationship between these two volumes. The volume above the piston at top dead center is the clearance volume. The displacement volume is the increase as the piston moves down to bottom dead center. It must be remembered that although

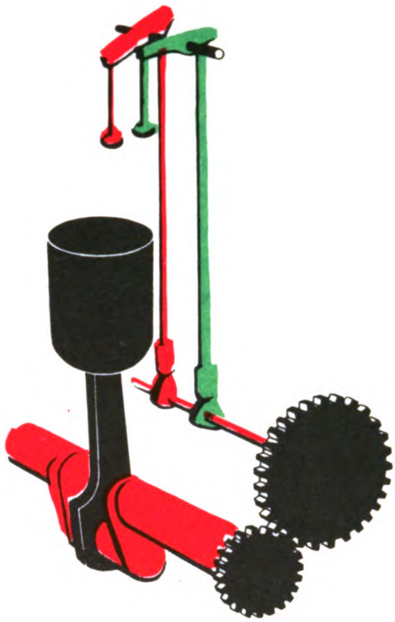

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Figure 6. Valve Linkage including Camshaft.

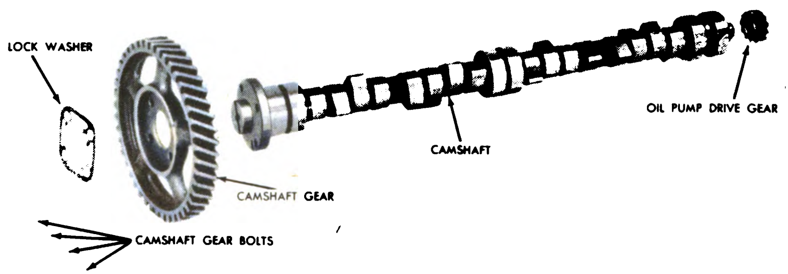

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Figure 7. Camshaft and Related Items.

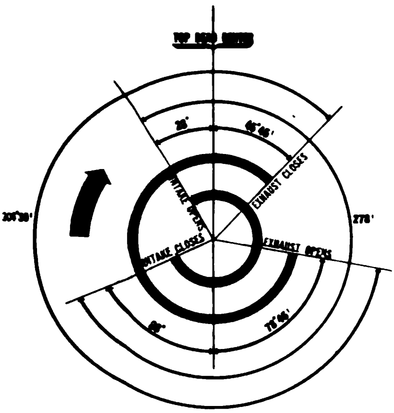

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Figure 8. Valve Timing Diagram.

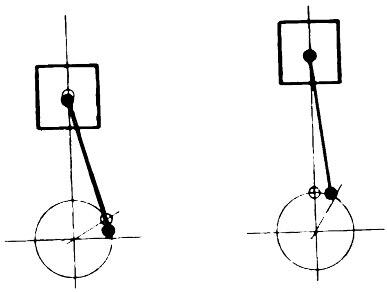

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Figure 9. Rock Position.

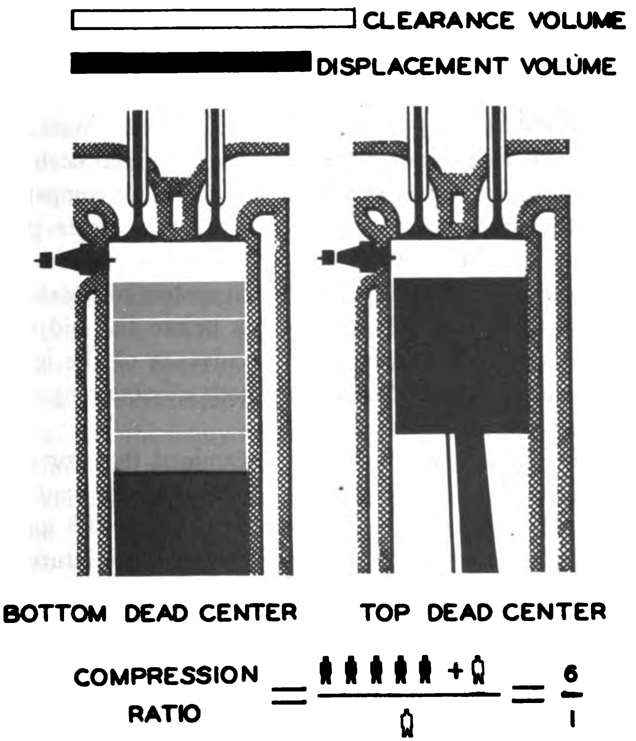

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Figure 10. Compression Ratio.

the compression ratio is an indication of pressure, volumes and not pressures are considered when calculating the compression ratio.

b. LOW-AND HIGH-COMPRESSION ENGINES. In the gasoline engine, where fuel is present with the air during compression, the highest practical pressure is determined by the characteristics of the fuel. Early makes of gasoline engines used compression ratios of 3 or 4 to 1 and were known as low-compression engines. High-compression engines were not used, because the gasoline available would have caused detonation or "pinging." Later, it was found that certain chemicals added to the gasoline would eliminate detonation caused by high compression ratios. This discovery together with improved refining methods led to the modern engines with compression ratios as high as 7.5 to 1. In Diesel engines, where air alone is compressed, the only limitation on compression is the ability of the engine to withstand the heavy strains produced by high compression pressures. The fact that Diesel engines will "knock" is not due to the high compression ratios but rather to the fact that the fuel does not burn fast enough. The characteristics of gasoline and Diesel fuel which lead to detonation or knocking are inherent in the fuel and the designers have taken them into consideration in the development of the engines. These characteristics together with the burning process for gasoline and Diesel fuel will be discussed in paragraphs 40 and 43.

14. Ignition Timing

The time at which ignition of the fuel charge should occur is dependent upon the speed of the engine, type of fuel used, compression ratio, and several other factors. It will be necessary to cover gasoline and Diesel ignition factors separately because factors which aid Diesel ignition may be undesirable in the spark ignition system of a gasoline engine. Both types of engines provide for ignition before the end of the compression stroke, and both provide for the advance of the ignition point with increasing engine speed, but the methods of obtaining these results differ.

a. GASOLINE ENGINE. It has been determined that for gasoline engines, maximum power is obtained when the maximum combustion pressure occurs while the piston is at a point between 10° and 20° past top dead center on the power stroke. Even though the mixture burns very rapidly, it burns slowly enough to make ignition necessary before the end of the compression stroke if combustion is to be nearly completed by the time the piston reaches the maximum-power position. For any given compression ratio and gasoline, the time required to complete the combustion process does not change regardless of engine speed. However, as the engine speed increases, the strokes of the cycle take place in a shorter time. When cycle time shortens, combustion must begin earlier in order to be completed at the same point in the cycle that it was before the engine speeded up. Therefore, there must be a means of varying the time of the spark throughout the engine speed range. If the spark is too far advanced, combustion will be completed before the piston has reached the end of its compression stroke, and the flywheel must force the piston upward against the resulting pressure in order to get it into position to move downward on the power stroke. Even if the momentum of the flywheel is sufficient to overcome the pressure, there will be a noticeable loss of power and an excessive amount of detonation. If the spark is retarded, the combustion will be completed too long after the piston has begun to move downward on the power stroke, and the pressure will then be reduced because the combustion will have taken place in a larger space.

b. DIESEL ENGINE. The fuel in a Diesel engine is ignited solely by the heat of compression of air. Shortly after the injected fuel reaches the hot compressed air it is ignited, regardless of how little or how much is injected. Therefore, the time of ignition is governed by the time of fuel injection. The pressure begins to rise as the first droplets of fuel entering the cylinder begin to burn, and the rate and amount of fuel injected determine the maximum pressure obtained as well as the speed of the engine. More fuel is added as the combustion progresses, thereby maintaining almost constant pressure on the piston as it moves downward. In the gasoline engine the amount of spark advance was governed by the piston speed and load. In the Diesel engine, the start of injection usually is constant and the end of injection is varied. As the amount of fuel injected determines engine speed, the longer the period of injection the greater the engine speed. At high engine speeds the operation tends to approach the constant-volume process of the gasoline engine.

15. Multicylinder Engines

a. POWER INCREASE. The principles discussed in the previous paragraphs considered the operation of one cylinder only. In the early automotive vehicles, one-cylinder, two-cylinder, and some three-cylinder engines were used, but the many advantages of a larger number of cylinders soon led to their adoption. Although the power stroke of each piston theoretically continues for 180° of crankshaft rotation, it has been discovered that best results can be obtained if the exhaust valve is opened when the power stroke has completed about four-fifths of its travel. Therefore, the period that power is delivered during 720° of crankshaft rotation, or one four-stroke cycle, will be 145° multiplied by the number of cylinders in the engine. If an engine has two cylinders, power will be transmitted for 290° of the 720° of travel necessary to complete the four events of the cycle. The flywheel must supply power for the remaining 430° of crankshaft travel.

b. POWER OVERLAP. As cylinders are added to an engine, each one must complete the four steps of the cycle during two revolutions of the crankshaft. The number of power impulses for each revolution also

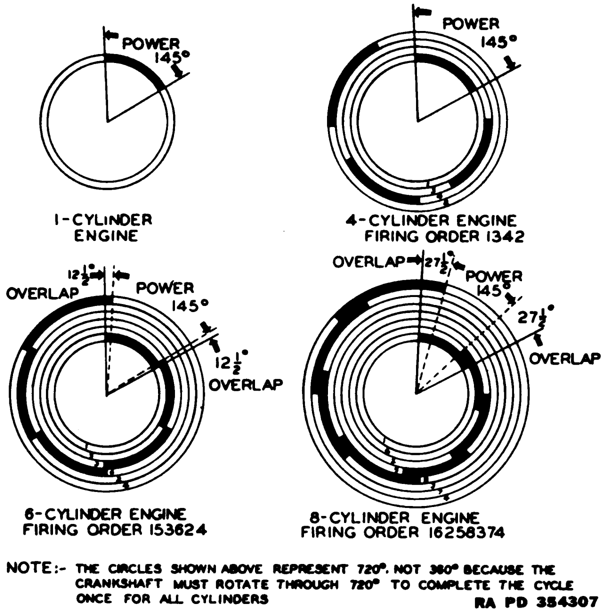

Figure 11. Power Overlap of Four-stroke Cycle Engine.

increases, producing smoother operation. If there are more than four cylinders, the power strokes overlap, as shown in figure 11. It can be seen that the length of overlap increases with the number of cylinders. The diagram for the six-cylinder engine shows a new power stroke starting each 120° of crankshaft rotation and lasting for four-fifths of a stroke, or 145°. This provides an overlap of 25°. In the eight-cylinder engine, a power stroke starts every 90° and continues for 145°, resulting in a 55° overlap of power. Because the cylinders fire at regular intervals the power overlap will be the same regardless of firing order and will apply to either in-line or 90° V-type engines.

16. Classification of Engines

Automotive engines may be classified according to the type of fuel they use, type of cooling employed, or valve and cylinder arrangement. They all operate on the internal combustion principle, and the application of basic principles of construction to particular needs or systems of manufacture has caused certain designs to be recognized as conventional. The most common method of classification is by type of fuel used, that is, whether the engine burns gasoline or Diesel fuel. This method has been covered in previous pargaraphs, so classification by type of cooling, valve arrangement, and cylinder arrangement will be discussed here.

a. Cooling. Engines are classified as to whether they are air- or liquid-cooled. All engines are cooled by air to some extent, but air-cooled engines are those in which air is the only external cooling medium.

Lubricating oil and fuel help somewhat to cool all engines, but there must be an additional external means of dissipating the heat absorbed by the engine during the power stroke.

(1) *Air-cooled.* Air-cooled engines are used in motor vehicles but their most extensive use is in aircraft. This type of engine is used where there must be an economy of space and weight. It does not require a radiator, water jacket, coolant, or a pump to circulate the coolant. The cylinders are cooled by the conduction of heat to metal fins on the outside of the cylinder wall and head. To effect the cooling, air is circulated between the fins. When possible, the engine is installed so that it is exposed to the air stream of the vehicle and has baffles to direct the air to the fins. If the engine cannot be mounted in the air stream, a fan is employed to force the air through the baffles.

(2) *Liquid-cooled.* Liquid-cooled engines require a water jacket to hold the coolant around the valve ports, combustion chambers, and cylinders; a radiator to dissipate the heat from the coolant to the surrounding air; and a pump to circulate the coolant through the engine. Liquid-cooled engines also require a fan to draw air through the radiator because the speed of the vehicle does not always force enough air through the radiator to provide proper dissipation of heat.

b. VALVE ARRANGEMENT. Engines may be classified according to the position of the intake and exhaust valves, that is, whether they are in the cylinder block or in the cylinder head. Various arrangements have been used, but the most common are "L-head" and "I-head" (fig. 12). The letter designation is used because the shape of the combustion chamber resembles the form of the letter identifying it.

(1) L-*head.* In the L-head, both valves are placed in the block on the same side of the cylinder. The valve-operating mechanism is located directly below the valves, and one camshaft actuates both the intake and exhaust valves. This type has supplanted the "T-head," where both

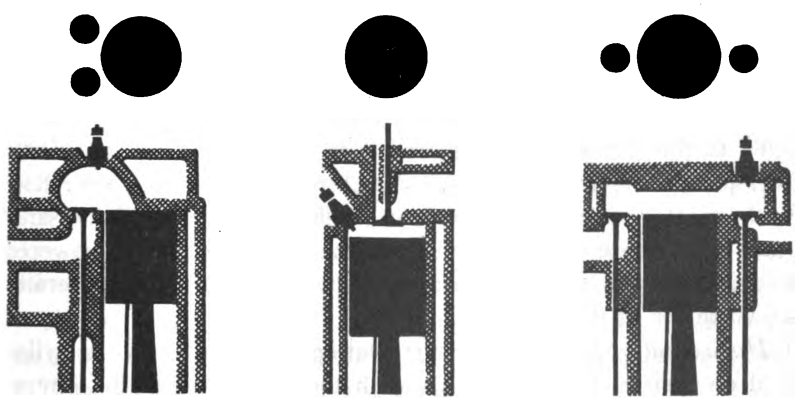

Figure 12. L, I and T Arrangement of Valves.

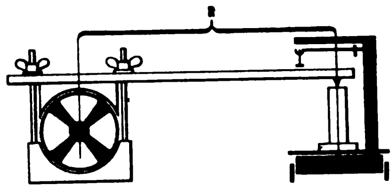

Figure 13. Prony Brake.

valves were in the block but on opposite sides of the cylinder. The disadvantage of the T-head was that it required two complete valve-operating mechanisms.

(2) *I-head.* Engines using the I-head construction are commonly called "overhead valve" engines because the valves are mounted in the cylinder head above the cylinder. This arrangement requires a lifter, a push rod, and a rocker arm above the cylinder to reverse the direction of valve movement, but only one camshaft is required for both valves.

c. Cylinder Arrangement. Automotive engines also vary in the arrangement of cylinders in the block, depending on the engine use. Cylinder arrangement in liquid-cooled engines is usually in-line or V-type; in air-cooled engines it is radial or horizontal opposed.

(1) *In-line.* The vertical in-line cylinder arrangement is one of the most commonly used types. All the cylinders are cast or assembled in a straight line above a common crankshaft which is immediately below the cylinders. A variation is the inverted in-line type.

(2) *V-type.* In the V-type engine two "banks" of in-line cylinders are mounted in a V-shape above a common crankshaft. This type is designated by the number of degrees in the angle between the banks of cylinders. Usually the angle of the V is 90° for 8-cylinder engines; 75, 60, or 45° for 12-cylinder engines; and 45 or 135° for 16-cylinder engines. Crankshafts for V-type engines generally have only half as many throws as there are cylinders, as two connecting rods (one from each bank) generally are connected to each throw.

(3) *Radial.* The radial engine has cylinders placed in a circle around the crankshaft. The crankshaft has only one throw, and one piston is connected to this throw by a "master" rod. The connecting rods from the other pistons are fastened to the master rod, making the power flow first to the master rod and then to the crankshaft. The result is the same as if each rod were connected directly to the crankshaft. High-powered radial engines may have two rows of cylinders in which each row operates on its own throw of the crankshaft.

(4) *Horizontal opposed.* The horizontal-opposed engine has its cylinders laid on their sides in two rows with the crankshaft in the center. This type is often found in passenger busses; because of its low over-all height, it can be mounted under the body of the vehicle.

Section III. PERFORMANCE

17. Measurement of Horsepower

The horsepower of an engine may be expressed in several ways, depending on how it is measured.

a. "INDICATED" HORSEPOWER. "Indicated" horsepower is the power calculated by formula and is used for experimental and laboratory purposes. It is based on the pressure exerted on the piston during the power stroke, obtained from the indicator card, area of the piston head, length of the stroke, and the number of power strokes in a given period.

b. "BRAKE" HORSEPOWER. The "brake" horsepower usually will be 70 to 85 percent lower than indicated horsepower, the difference resulting from consideration of the power lost in friction and the driving of the auxiliary units of the engine—the water pump, oil pump, and camshaft. When horsepower is mentioned in this text, it will be assumed to be brake horsepower unless otherwise stated.

c. "SAE" HORSEPOWER. A third expression is "SAE" horsepower, developed by the Society of Automotive Engineers. Calculated by formula, it is used for commercial licensing of vehicles.

d. MEASUREMENT DEVICES. Horsepower which actually does work is of primary interest. Two of several ways to measure it are described below.

(1) *Prony brake.* A very simple way to determine usable horsepower is to cause the flywheel of an engine to rotate against a braking device. One of the earliest of these devices was introduced by Baron de Prony, a French engineer, and is known as the Prony brake, illustrated in figure 13. Wooden blocks, cut to fit the radius of the flywheel, are fastened to a frame attached to an arm. One end of the arm rests on a knife edge on the bed of a scale. Adjusting screws regulate the tightness of the blocks against the flywheel. The heat generated by the flywheel as it turns under the pressure of blocks is absorbed by a stream of water applied to the flywheel rim. To measure the horsepower, the engine is operated at full throttle without load to permit it to reach its maximum speed. When the adjusting screws are tightened, the pressure of the blocks against the flywheel adds load and causes the speed of the engine to decrease. The pressure of the blocks tends to make the arm rotate with the flywheel and exert a force on the scale.

Note. The net force is the force on the scale when the flywheel is running, minus the dead-weight force of the arm when the flywheel is not running.

The net force indicated on the scale is multiplied by the length of the arm measured along the line (R). A simple calculation is necessary to show the horsepower for any given speed.

(2) *Dynamometer.* A more modern and more accurate method of measuring the power delivered by an engine makes use of a device

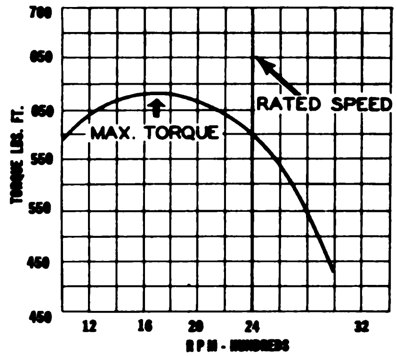

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Figure 14. Relationship between Torque and Speed.

called a "dynamometer." This machine absorbs the power of the engine by one of several means, and tells all details of the engine's performance through its gages and dials. The means employed to absorb the power of the engine include hydraulic friction and magnetism. In the former, the power of the engine drives a fluid through a system designed to offer enough resistance to absorb all the power furnished. In the magnetic system, commonly called "electric dynamometer," magnets energized by the flow of electricity furnish the "drag" and the overcoming of this "drag" absorbs the entire power output of the engine. The dynamometer may be used to drive the engine for purposes of measuring the friction of the engine itself or of the various accessories. It should be pointed out that in connection with such tests for measuring horsepower the words "net" and "gross" are sometimes used. Net brake horsepower is the measurement of the power output of an engine with all its accessories. Gross brake horsepower is the measurement of the power when the engine has been stripped of such accessories as the pump, fan, and generator.

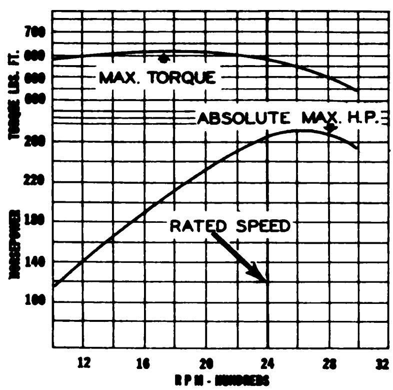

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Figure 15. Typical Horsepower Curve.

18. Horsepower vs. Torque

a. Since horsepower is a product of torque and rotation speed, the horsepower at any given r. p. m. (revolutions per minute) will vary directly with the torque. For example, if engine speed is constant and the torque is doubled, the horsepower output will be doubled. Actually, however, the torque does not remain the same throughout the various speeds of an engine.

(1) The relationship between torque and speed is shown in figure 14, which is a typical torque curve for a gasoline engine which reaches its maximum rated horsepower at 2,400 r. p. m. It will be noted that torque increases and then decreases as the speed of the engine passes 1,800 r. p. m. The reason for this curve is that at very low speeds the engine cannot draw full charges into the cylinders because of the relatively low air velocity, and at high speeds the charges cannot move fast enough to fill the cylinders.

(2) If the horsepower curve for the same engine is plotted, as in figure 15, we find that the horsepower rises rapidly and then, as the torque begins to fall, the horsepower tapers off. The torque curve is the same as that shown in figure 15 except that smaller units have been used for the vertical scale in order to place both curves on the same graph. A closer examination of the horsepower curve shows that it rises most sharply between 1,000 and 2,000 r. p. m., rises less sharply to about 2,400 r. p. m., and finally drops at 2,650 r. p. m. Note that although the engine is rated at 2,400 r. p. m., overspeeding will increase the horsepower a certain amount. This practice should be discouraged because it will harm the engine if done frequently.

b. When comparing the torque and horsepower of two engines, the r. p. m. at which the torque and horsepower are measured must be considered. Maximum torque throughout the speed range is produced at wide-open throttle. The load being carried by the engine will govern the

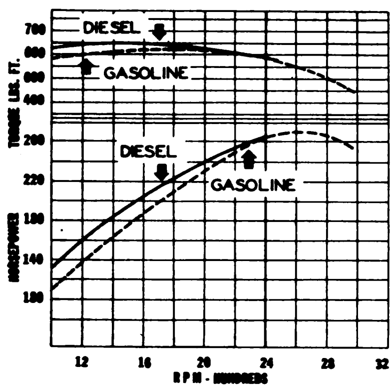

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Figure 16. Typical Torque and Horsepower Curves (Gas. and Diesel Engines).

speed. The torque will increase as the load increases until the speed of the engine drops to the point at which the engine can no longer draw full charges into the cylinders. This point is variable and is determined by the design and the volumetric efficiency of the engine.

(1) From the formulas for horsepower and torque, we know that if two engines develop the same torque at the same speed, they must develop the same horsepower at that speed, although the horspower and torque of the two engines may vary at other speeds. This is illustrated in figure 16, which shows the torque and horsepower curves for a Diesel and a gasoline engine. Both engines develop 265 hp. at 2,400 r. p. m.; therefore, the torque for each engine at that speed is the same. However, as the speed of the two engines decreases, owing to load, the two torque curves diverge. The torque curve of the gasoline engine rises slowly and then falls off; the Diesel curve, on the other hand, rises more rapidly and does not fall off as sharply. It will be noted that the torque curve of a Diesel engine is relatively flat and that there is a wider range of speeds through which high torque is obtained.

(2) An engine which can maintain high torque throughout the upper range of speeds will propel a vehicle with a minimum of gear shifting, since low gears in a transmission act simply as "torque multipliers" to increase the power going to the wheels or tracks of a vehicle. It should be remembered, however, that additional torque is not gained without sacrificing something. If torque can be increased only by shifting into a lower gear, speed is lost. Thus the advantage of using an engine with a "flat" torque curve is that more power is obtained in the higher gears, permitting heavier loads to be moved at higher rates of speed.

19. Efficiencies

In reference to the internal combustion engine, the word "efficiency" is frequently mentioned; consequently the meaning of this term as applied to the design and operation of an engine should be understood. In general, efficiency is used to designate the relationship between the result obtained and the effort expended to produce this result.

a. THERMAL EFFICIENCY. The overall thermal efficiency of an engine is the relationship between the fuel input and the power output. This relationship is expressed in heat units called "British thermal units" (B. t. u). One B. t. u. also equals 778 ft.-lb. of work; therefore the horsepower output of an engine can be readily converted into B. t. u. The source of power in an engine is fuel, and the B. t. u. content of regularly used fuels has been determined by laboratory analysis:

$$\text{Thermal Efficiency} = \frac{\text{power output in B. t. u.}}{\text{fuel input in B. t. u.}}$$

Example. An engine delivers 85 brake horsepower for a period of 1 hour, and in that time consumes 50 lb. (approximately 7½ gallons) of gasoline. Assuming that the gasoline has a value of 18,800 B. t. u. per lb. find the thermal efficiency of the engine:

Power delivered by engine 85 hp. for 1 hour, or 85 hp.-hours

1 hp.-hour = 2,545 B. t. u.[1]

85 hp. x 2,545 B. t. u. per hp.-hour = 216,325 B. t. u. output (per hour)

50 lb. x 18,800 B. t. u. per lb = 940,000 B. t. u. input (per hour)

$$\text{Overall thermal efficiency} = \frac{216{,}325}{940{,}000} = 0.230, \text{ or } 23 \text{ percent}$$

b. Mechanical Efficiency. The mechanical efficiency is the rating that shows how much of the power developed by the expansion of the gases in the cylinder is actually delivered to the flywheel. The factor which has the greatest effect on mechanical efficiency is friction within the engine. The friction between moving parts in an engine remains practically constant throughout the engine's speed range. Therefore the mechanical efficiency of an engine will be highest when the engine is running at the speed at which maximum brake horsepower is developed. The power output at the flywheel is brake horsepower, and the maximum horsepower available is indicated horsepower; therefor:

$$\text{mechanical efficiency} = \frac{\text{brake horsepower}}{\text{indicated horsepower}}$$

c. Volumetric Efficiency. Power output of a gasoline engine depends on how much fuel is burned within the cylinder. It is not difficult to get enough fuel into the cylinder, but it is a problem to get enough air in with the fuel to insure complete combustion. The ability of an engine to take in air is expressed as volumetric efficiency. An engine would have 100-percent volumetric efficiency if at atmospheric temperature and pressure it could take in an amount of air exactly equal to the piston displacement. However, this is not possible without the use of a supercharger, because the passages through which the air must flow offer a resistance, the force pushing the air in is only the atmosphere, and the air absorbs heat during the process. Therefore the designer determines volumetric efficiency by measuring the amount of air-fuel mixture taken in by the engine, converting it to the volume it would occupy if it were at atmospheric conditions, and comparing it to the piston displacement. Thus:

$$\text{volumetric efficiency} = \frac{\text{volume of mixture forced in}^{2}}{\text{piston displacement}}$$

[1] $\frac{33{,}000 \text{ ft.-lb. per minute} \times 60 \text{ minutes}}{778 \text{ ft.-lb.}} = 2{,}545$ B. t. u. per hp.-hour

[2] The volume of mixture must be corrected to standard atmospheric pressure and temperature. Although gasoline is present in the mixture, it occupies such a small volume that its effect is negligible.

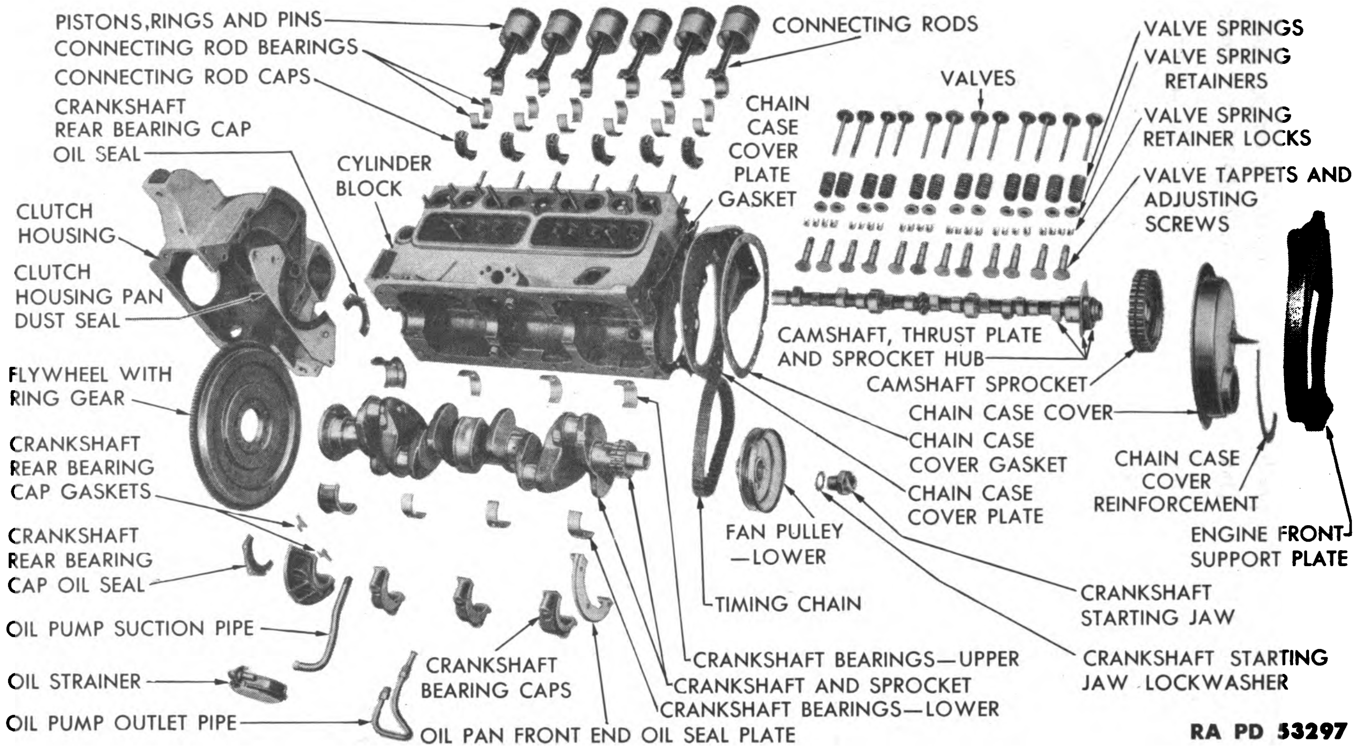


Figure 17. Cylinder Block and Components Disassembled.

CHAPTER 4

CONSTRUCTION OF ENGINES

20. General

This chapter will be concerned with describing the basic components of engines. The parts of in-line and V-type engines are similar and may be described together. Most radial engine components, however, differ substantially and require separate explanations. These include cylinders, crankcase, camshaft, connecting rods, and gear train. The various parts which make up the cooling, fuel, ignition, and lubrication systems will be described in other chapters.

21. Cylinder Block

a. The cylinder block of in-line and V-type engines contains the cylinders in which the pistons move, the valve ports, and the passages through which the coolant flows. It also includes the upper part of the crankcase and, as such, acts as the base of the engine.

b. The cylinders and crankcase are cast "in-block," that is, in one piece called the cylinder block. The advantages of the in-block method are so many that it has become almost universal. Casting cylinders in-block produces more compact, shorter, and more rigid construction at less cost than casting cylinders singly or in pairs; assembly is simplified, and valve-operating mechanisms are easier to inclose.

c. The cylinders of a liquid-cooled engine are surrounded by jackets through which the liquid circulates. These jackets are cast integral with the cylinder block, as shown in figure 17. Communicating passages permit the coolant to circulate around the cylinders and through the head.

d. Cylinders must be absolutely round and true, and the surfaces must be highly finished. These surfaces are obtained in manufacturing by boring, grinding, and/or honing (in that order), and the final result is a precision finish which offers little resistance and assures a uniform seal between cylinder and piston rings.

e. Cylinder blocks were formerly made of gray cast iron, but wearing qualities of this metal were not adequate. The material now used in cylinder blocks is a special iron alloy containing nickel, chromium, and molybdenum. Cylinder liners or sleeves are bcoming more common in large motor-vehicle engines. Liners are made of alloys specially treated to give greater wearing qualities; their outside diameters are as large as the openings into which they fit. The "wet" type of liner comes in direct contact with the coolant and is sealed at the top and bottom by a rubber sealing ring; the "dry" type of liner does not contact the coolant directly. Liners have two advantages: they usually wear longer, and, after they have been worn beyond the maximum oversize, can be replaced with new liners, avoiding the replacement of the entire block.

22. Cylinder Head

On in-line and V engines, the cylinder head, a separate casting which contains the combustion chamber, is bolted to the top of the cylinder block to close the upper ends of the cylinders (fig. 18). It contains passages which match those of the cylinder block and allow the coolant to circulate in the head. To retain compression in the cylinder, a metal cylinder-head gasket is placed between the head and the block. Holes are cut in this gasket for the bolts holding the cylinder head to the block, for the passage of coolant from the block to the head, and for the combustion chamber. All cylinder heads were formerly made of cast iron, but many engines now are being built with cylinder heads of cast aluminum alloy because it is a better conductor of heat and therefore aids in cooling.

23. Cylinders, Radial Engine

One of the most important parts of the radial engine is the cylinder assembly, consisting of the barrel and the head (fig. 19). The barrel of the radial-engine cylinder differs from that of the in-line engine in that it is made individually, not cast in-block (par. 21). The arrangement of cylinders separately and radially places them all in the open so that an even flow of air can be directed to all. As the radial engine is air-cooled, closely spaced fins surround the barrel to make more surface available for the radiation of heat. This is in contrast to the conventional in-line liquid-cooled engine, which has a water jacket around its cylinders.

a. Even the normal process of combustion generates high temperature and comparatively high pressure in the radial engine. If low-grade fuel is used or if the engine is operated at too high a temperature, either condition resulting in detonation (par. 40*b*), the pressure of normal combustion will be multiplied several times. This made it necessary for metallurgists to develop materials that retain their strength under high temperature and are resistant to repeated stresses. Cylinder barrels are made of either cast nickel iron or forged steel. Because it is heavy and comparatively weak under high temperature, cast iron is not used on large engines. However, it can be used on small engines where high strength and light weight are not important. Forged steel is far more satisfactory and is the prevalent material for cylinder barrels. The fins are machined on the outside of the barrel. The bearing surface on the inside is ground accurately and nitrided (toughened by exposure to an ammonia process under high temperature) to provide a hard, smooth, wear-resisting surface and to reduce the possibility of distortion under high operating temperatures. A cylinder hold-down flange is machined on the lower end of the barrel, where it is fastened to the main crankcase section by studs, nuts, and lock wires or lock nuts.

b. Early radial engines were manufactured with the cylinder barrel and the head cast integrally of nickel iron. The recent trend has been to make the head separately of an aluminum alloy. Aluminum is adaptable to the casting of deep, closely spaced fins, has high strength, and is a ready conductor of heat. The alloy head is screwed and shrunk on the barrel. The cylinder is not disassembled except by the manufacturer.

(1) One of the most common head designs is the "pompadour" type with fins running parallel to the air stream (fig. 19). The inner part of the head where the combustion chamber is located is dome-shaped and almost spherical. A spherical combustion chamber has little surface exposed to heat for a given volume of intake charge. This reduces heat loss through the cylinder head and makes the cylinder more efficient. Two spark plugs also are located in the head to give uniform flame propagation and combustion.

(2) Intake-valve seats and guides are usually made of aluminum-bronze alloy. On the exhaust side of the head, a high-temperature non-corrosive steel is used which is tough enough to resist wear and the high temperatures of the exhaust gases. The guides are readily replaceable, but the seats usually are not replaced except in a major overhaul.

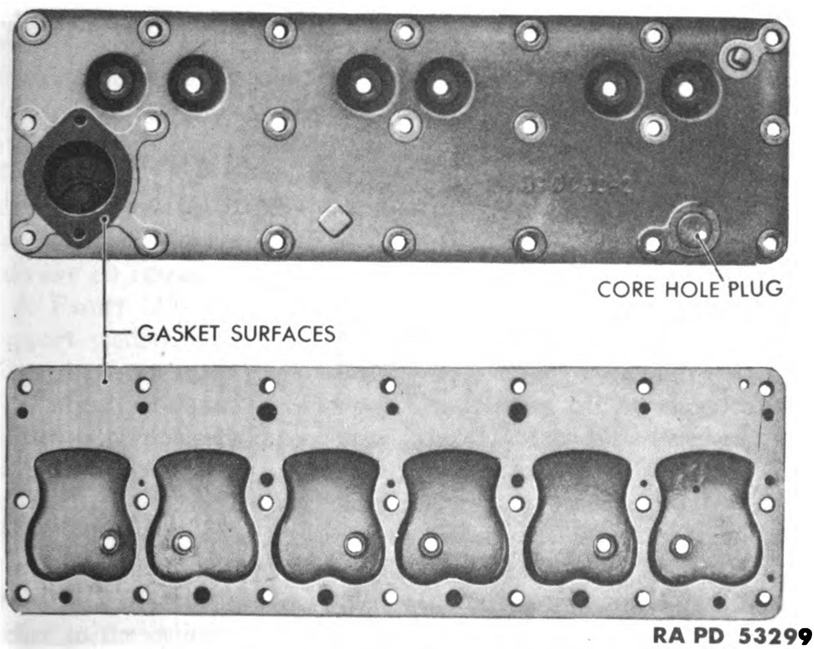


Figure 18. Cylinder Head.

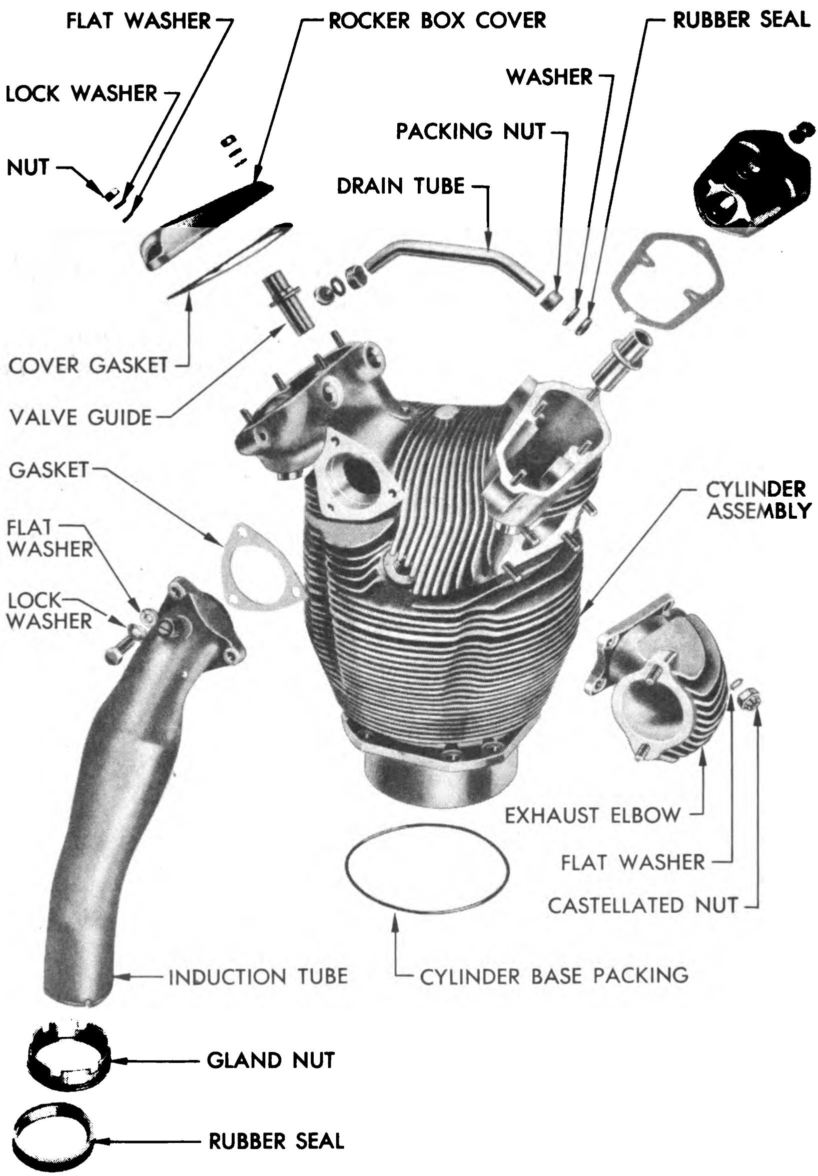


Figure 19. Radial Engine Cylinder Assembly.

24. Crankcase

a. The crankcase is that part of the engine which supports and incloses the crankshaft, provides a reservoir for the lubricating oil, and acts as a support for the oil pump, oil filter, and some of the other accessories. It is common practice to cast the upper part of the crankcase as part of the cylinder block. The lower part of the crankcase is the oil pan, which is bolted to the bottom of the block. It is made of pressed or cast metal (fig. 20).

b. The crankcase also supports the engine on the vehicle frame or on a subframe constructed for that purpose. The engine supports are an integral part of the crankcase or are bolted to it in such a way that they support the engine at three or four points. The points of contact with the frame are usually cushioned on rubber. The rubber insulates the frame and body of the vehicle from engine vibration and noise and prevents damage to the engine supports and transmission from engine twisting and frame distortion.

25. Crankcase, Radial Engine

Whereas the in-line engine crankcase consisted of an upper and a lower part, the radial engine crankcase is composed of five aluminum-alloy castings fastened together with studs through flanges (fig. 21). The crankcase forms the foundation on which the entire engine is assembled and is composed of the front section, the front main-bearing section, the main crank section, the diffuser section, and the accessory or rear crankcase section.

a. Front Section. The front section is the part which would be nearest the propeller in an airplane and nearest the flywheel in an automotive vehicle. Its design and construction are considered important in airplane use because of the varied forces and vibrations caused by the propeller; but in automotive use the principal concerns are that it is oil-tight and gives rapid, uniform heat conduction. It houses the ball thrust bearing (par. 33*c*) and the crankshaft-driven front scavenger pump, which picks up oil from the front of the sump and directs it into the oil reservoir.

b. Front Main-bearing Support Section. The front main-bearing support section is simply a cast aluminum-alloy diaphragm which supports the front main roller bearing.

c. Main Crankcase Section. Construction of the main crankcase section is particularly important as it holds the cylinders and is subjected to considerable stress, especially if the engine is detonating. On the main crankcase section are the cylinder pads, machined surfaces upon which the cylinder flanges are mounted.

d. Diffuser Section. The rear side of the diffuser section forms the front wall of the diffuser, which deflects the air stream from the impeller to the cylinders (par. 50*a*). The impeller is also mounted on the

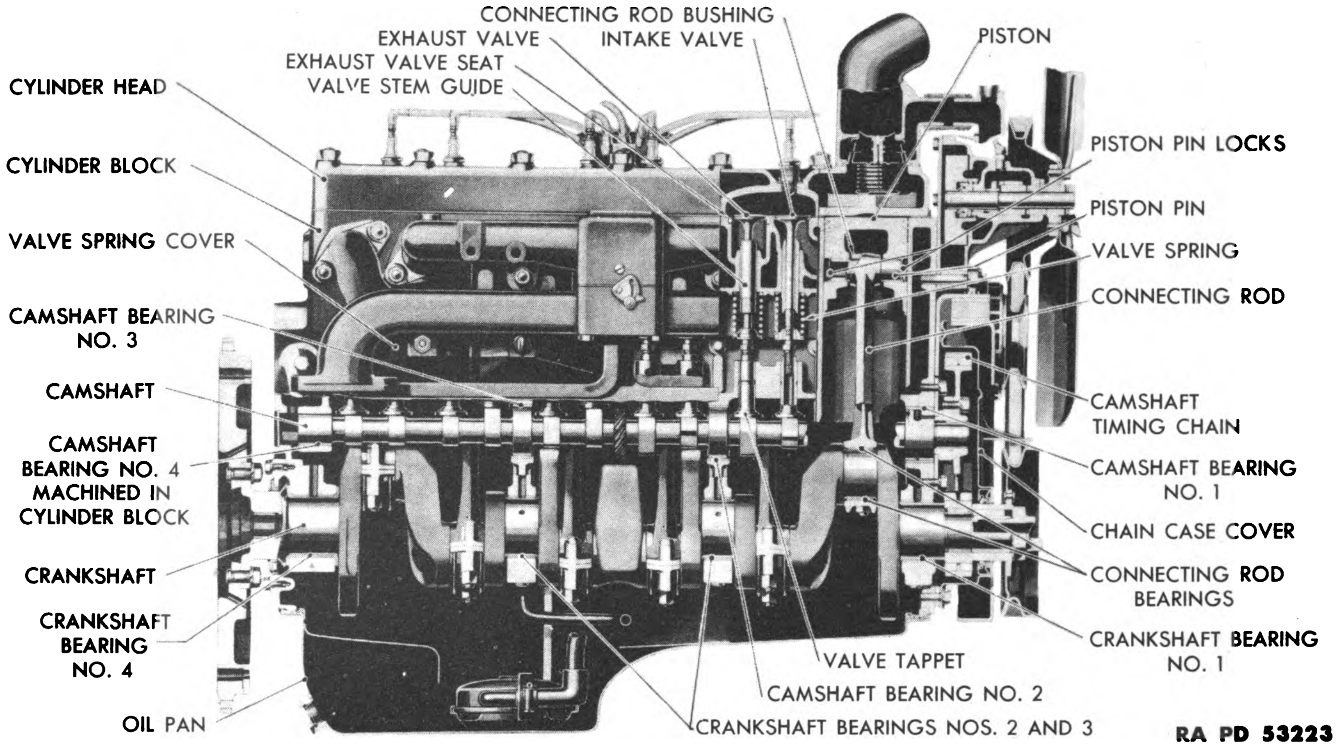


Figure 20. Engine Cross-section.

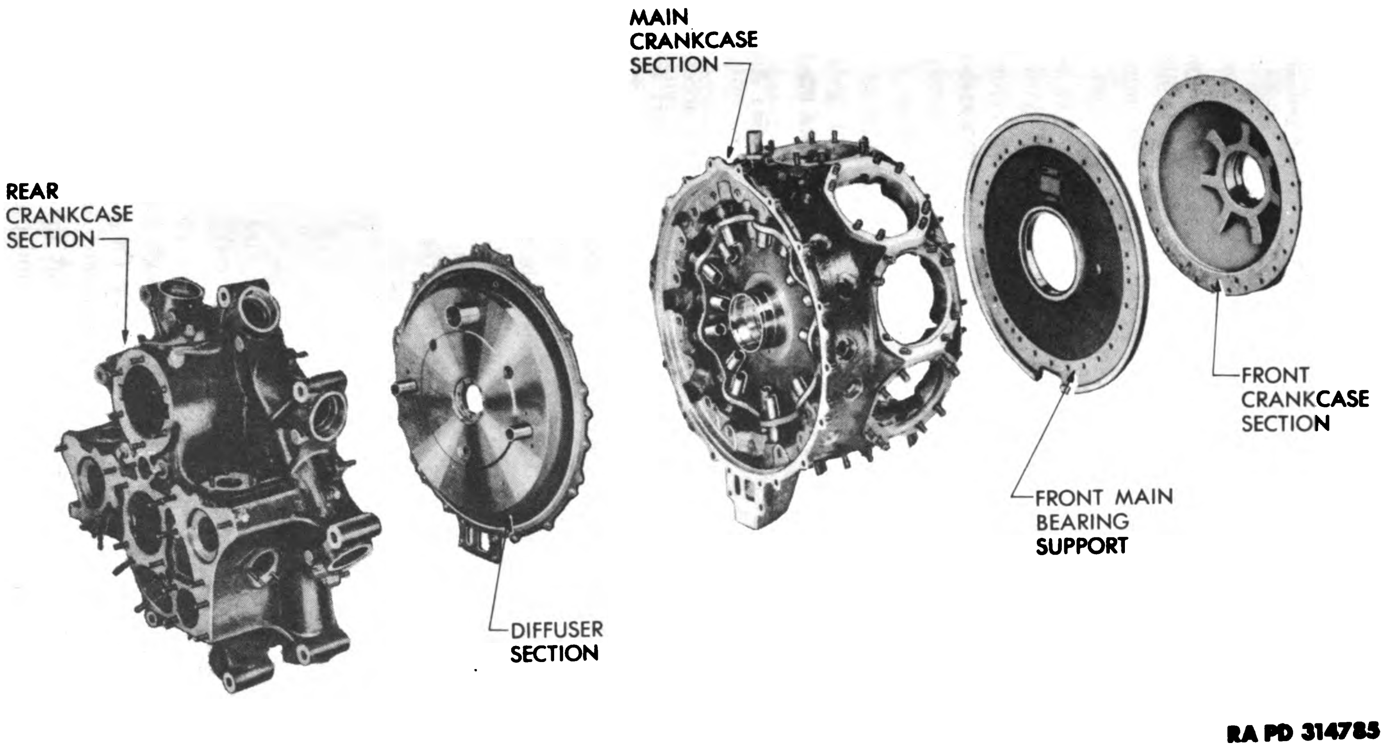


Figure 21. Radial Engine Crankcase Sections.

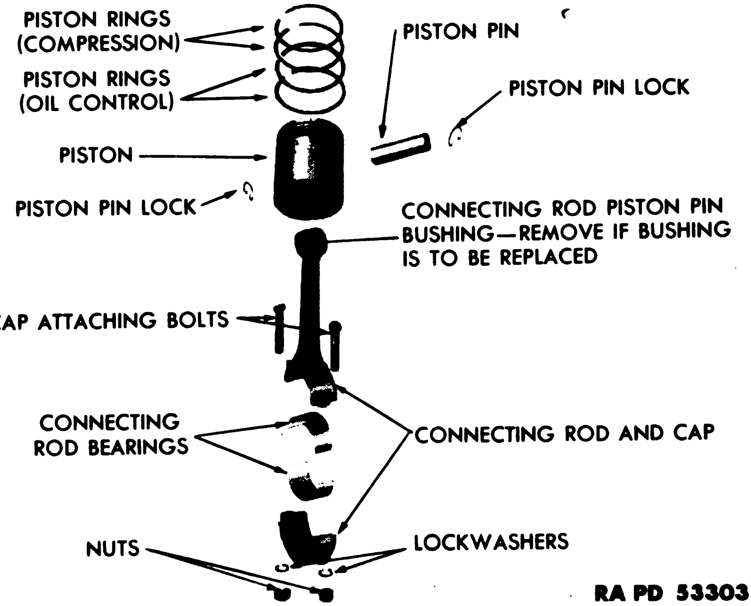


Figure 22. Piston, Piston Rings, Connecting Rod, and Connecting Rod Bearings.

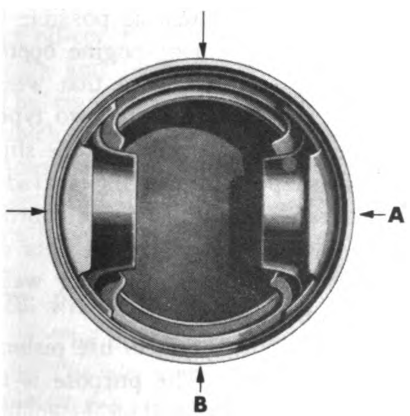
diffuser section. It supports the impeller drive and two accessory-drive idler gears. Three bushings in the diffuser section support the forward ends of the starter shaft and two accessory drive shafts. These shafts extend through the diffuser chamber to the accessory section.

e. ACCESSORY SECTION. The accessory or rear crankcase section supports the accessory drives and provides pads for mounting the various accessories — magnetos, carburetor, starter, generator, fuel pump, tachometer drive, and oil pump. The forward end of the section forms the rear wall of the diffuser and provides the intake-pipe connections (par. 47).

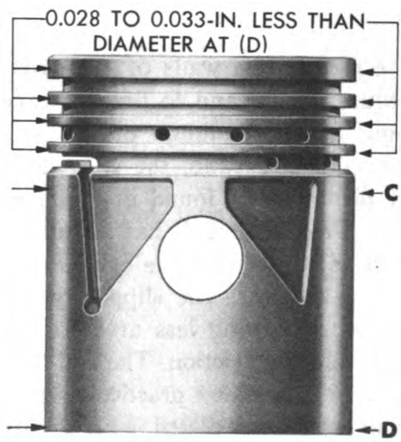
26. Pistons

a. Fitted into the bore of the cylinder is a moveable piston which receives the energy of force of combustion and transmits that energy to the crankshaft through the connecting rod (fig. 22). Automotive pistons ordinarily are made of cast iron or a steel or aluminum alloy. They must be light, wear well, and have high tensile strength. At the top and bottom of the strokes of the cycle the piston must come to a complete stop and start again in the opposite direction. Considerable energy is required to overcome the inertia of the piston when it stops and starts, and as the weight of the piston and the length of the stroke affect the inertia, it is desirable to keep both factors as low as possible. In order to reduce weight, the head and skirt of the piston are made as thin as is consistent with the strength required. Ribs are used on the underside of the piston to reinforce the head; they also assist in conducting heat from the head of the piston to the piston rings and out through the cylinder walls. Special ribs are used to reinforce the piston-pin "bosses." The radial-engine piston varies only slightly in construction from the one used in the in-line or V-type engine. These variations exist only because the radial-engine piston must have greater cooling capacity and less weight and yet retain its strength. Because of this, aluminum alloy is the favored material for radial-engine pistons. Besides its rapid heat-conducting and strength characteristics, aluminum is adaptable to several manufacturing processes as it is readily machinable. The forged piston is preferable for radial-engine pistons as it is made of denser metal, which is less subject to warpage and better able to withstand considerable stress and strain.

b. The piston is kept in alinement by the skirt, which is usually cam ground, i.e., oval in cross section (fig. 23). This oval shape permits the piston to fit the cylinder, regardless of whether the piston is cold or at working temperature. Its narrowest diameter is at the piston-pin bosses, where the metal is thickest. At its widest diameter, the piston skirt is thinnest. The piston is fitted to close limits at its widest diameter so that piston "slap" will be prevented during engine warm-up. As the piston is expanded by the heat generated during operation, it becomes round because the expansion is proportional to the amount of heat in



THE ELLIPTICAL SHAPE OF THE PISTON SKIRT SHOULD BE 0.010 TO 0.012-IN. LESS AT DIAMETER (A) THAN ACROSS THE THRUST FACES AT DIAMETER (B).



THE SKIRT OF THE PISTON SHOULD TAPER SO THAT THE DIAMETER AT (C) IS FROM 0.0005 TO 0.0015-IN. LESS THAN AT (D).

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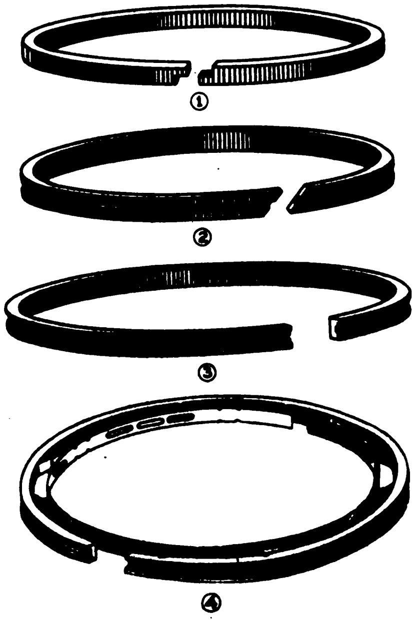
Figure 23. Cam-ground Piston.



① *Compression ring with step joint.*
② *Oil-regulating ring with diagonal joint.*
③ *Double-duty oil-regulating ring with butt joint.*
④ *Flexible ring with expander.*

Figure 24. Piston Rings.

the metal. The walls of the skirt are cut away as much as possible to reduce weight and to prevent excessive expansion during engine operation. Many aluminum pistons are made with split skirts so that when the pistons expand, the skirt diameter will not increase. The two types of piston skirts found in radial engines are the full trunk and the slipper. The full trunk has a full cylindrical shape with bearing surfaces parallel to those of the cylinder, giving more strength and better control of the oil film. The slipper type has considerable relief on the sides of the skirt, leaving less area for possible contact with the cylinder walls and reducing friction. The full-trunk skirt is more widely used.

c. It is common practice today for some manufacturers to use pistons that have been plated with a soft material like tin. The purpose is to have the tin work into and fill the pores of the cylinder wall as the engine is broken in. The result is a more perfect fit between the piston and cylinder wall and a shorter breaking-in period. Aluminum pistons are often "anodized" to make the outside surface harder.

Anodizing is a process whereby the piston is oxidized by electrolysis. It produces an aluminum-oxide coating over the entire surface of the piston. This coating is very hard and highly resistant to wear.

Because of the softness of aluminum, pistons made of this material, unless properly treated, may pick up gritty particles which will become embedded in the piston, causing scratches and wear in the cylinder walls.

27. Piston Rings

Piston rings are used on pistons to maintain gastight seals between the pistons and cylinders, to assist in cooling the piston, and to control cylinder-wall lubrication. About one-third of the heat absorbed by the piston passes through the rings to the cylinder wall. Although piston rings have been made from many materials, cast iron has proved the most satisfactory, as it withstands heat, forms a good wearing surface, and retains a greater amount of its original elasticity after considerable use.

More recently, piston rings are being plated with various metals to produce better wearing qualities.

There are two types of piston rings: compression rings and oil-control rings. These types of piston rings are shown in figure 24.

a. Compression Ring. The principal function of a compression ring is to prevent gasses from leaking by the piston during the compression and power strokes. All piston rings are split to permit easy assembly to the piston and to allow for expansion. When the ring is in place, the ends of the split joint do not form a perfect seal; therefore it is common practice to use more than one ring and to stagger the joints around the piston. If cylinders are worn, expanders are sometimes used to insure a perfect seal.

b. Oil-control Ring. The lowest ring about the piston pin is usually an oil-control ring. This ring scrapes the excess oil from the cylinder walls and returns some of it through slots to the piston-ring grooves. The ring groove under an oil ring is provided with openings through which the oil flows back into the crankcase. In some engines, an additional oil ring is in the skirt below the piston pin, thus providing better control of the oil. Steel side plates are sometimes used on two-and three-section oil-control rings.

28. Piston Pins

a. The piston is attached to the connecting rod by means of the piston pin. The pin passes through the piston-pin bosses and through the upper end of the connecting rod, which rides within the piston on the middle of the pin. Piston pins are made of alloy steel with a precision finish and are case-hardened and sometimes chromium-plated to increase their wearing qualities. Their tubular construction gives them a maximum of strength with a minimum of weight. They are lubricated by splash from the crankcase or by pressure through passages bored in the connecting rods.

b. There are three methods of fastening a piston pin to the piston and connecting rod (fig. 25).

(1) An anchored or "fixed" pin is attached to the piston by a screw running through one of the bosses; the connecting rod oscillates on the pin.

(2) A "semifloating" pin is anchored to the connecting rod and turns in the piston-pin bosses.

(3) A "full-floating" pin is free to rotate in the connecting rod and in the bosses but is prevented from working out against the sides of the cylinder by plugs or snap-ring locks.

29. Connecting Rods

a. The connecting rods connect the pistons with the crankshaft (fig. 22). They must be light and yet strong enough to transmit the thrust of the pistons. Automotive connecting rods are drop-forged from a steel alloy capable of withstanding heavy loads without deflection, i.e., bending or twisting. The connecting rod itself generally is made in the form of an I-beam for lightness with maximum strength. Holes at the upper and lower ends are machined to permit accurate fitting of bearings. It is very important that these holes be parallel.

b. The upper end of the connecting rod is connected to the piston by the piston pin. If the piston is locked in the piston-pin bosses or if it floats in both piston and connecting rod, the upper hole of the connecting rod will have a solid bearing (more commonly called a bushing) of bronze or similar material. As the lower end of the connecting rod revolves with the crankshaft, the upper end is forced to rotate on the piston pin. Although this movement is not great, the bushing is necessary because the temperatures and unit pressures exerted are high. If the piston pin is semifloating, i.e., anchored to the connecting rod, a bushing is not needed.

c. The lower hole of the connecting rod is split to permit it to be clamped around the crankshaft. The bottom part, or cap, is made of the same material as the rod and is attached by two or more connecting-rod bolts. The surface which bears on the crankshaft is generally a bearing material in the form of a separate split shell although, in a few cases, it may be spun or die-cast in the inside of the rod and cap during manufacture. The two parts of the separate bearing are positioned in the rod and cap by dowel pins, projections, or short brass screws. The shell may be all bronze or of Babbitt metal face-spun or die-cast on a backing of bronze or steel. Split bearings may be of the precision or semi-precision type.

(1) The precision type is accurately finished to fit the crankpin and does not require further machining during installation. It is positioned by projections on the shell which match reliefs in the rod and cap. The projections prevent the bearings from moving sideways, but they per-

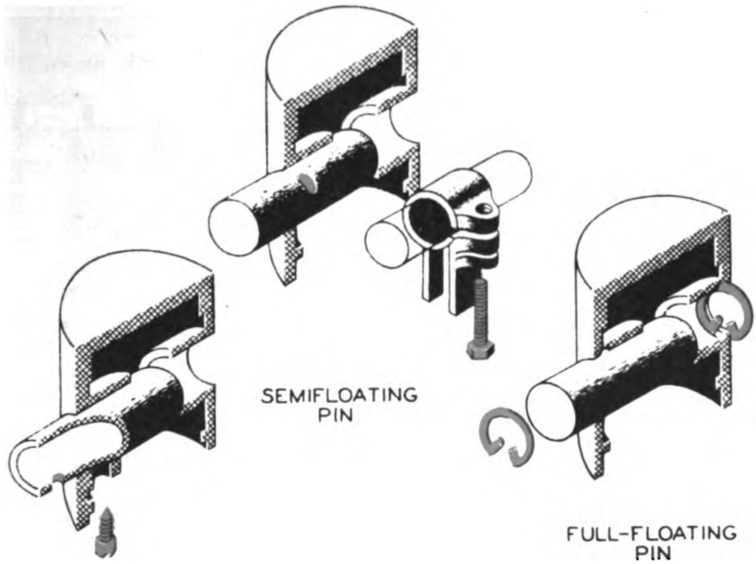


Figure 25. Piston Pin Arrangements.

mit rotary movement after the bearing cap is removed, thus making it possible to replace the bearing without removing the connecting rod from the engine.

(2) The semiprecision type is usually fastened securely to the rod and cap. Prior to installation, it is machined to the proper inside diameter with the cap and rod bolted together.

30. Crankshaft

a. FUNCTION. The crankshaft might well be called the "backbone" of the engine, as it ties together the reaction of all the pistons, transforms the reciprocating motion of the pistons and connecting rods into rotary motion, and transmits the resulting torque to the flywheel and clutch. The crankshaft is a shaft with one or more throws along its length (fig. 26). The arrangement of the throws along the crankshaft is determined by the desired firing order of the engine cylinders. The desired firing order is regulated by the relationship of the camshaft and the crankshaft.

b. CONSTRUCTION. Crankshafts are first forged or cast from an alloy of steel and nickel. The rough casting or forging is then machined. When all the rough machining is completed, the nonbearing surfaces are plated with a light coating of copper. When the plating process is completed, the whole crankshaft is placed in a carburizing oven or an electro-induction furnace, where surfaces of the crankshaft not coated with copper become alloyed with the carbon, producing a thin, hard surface or bearing area. This process is known as "case-hardening." The crankshaft is completed by grinding the case-hardened surfaces.

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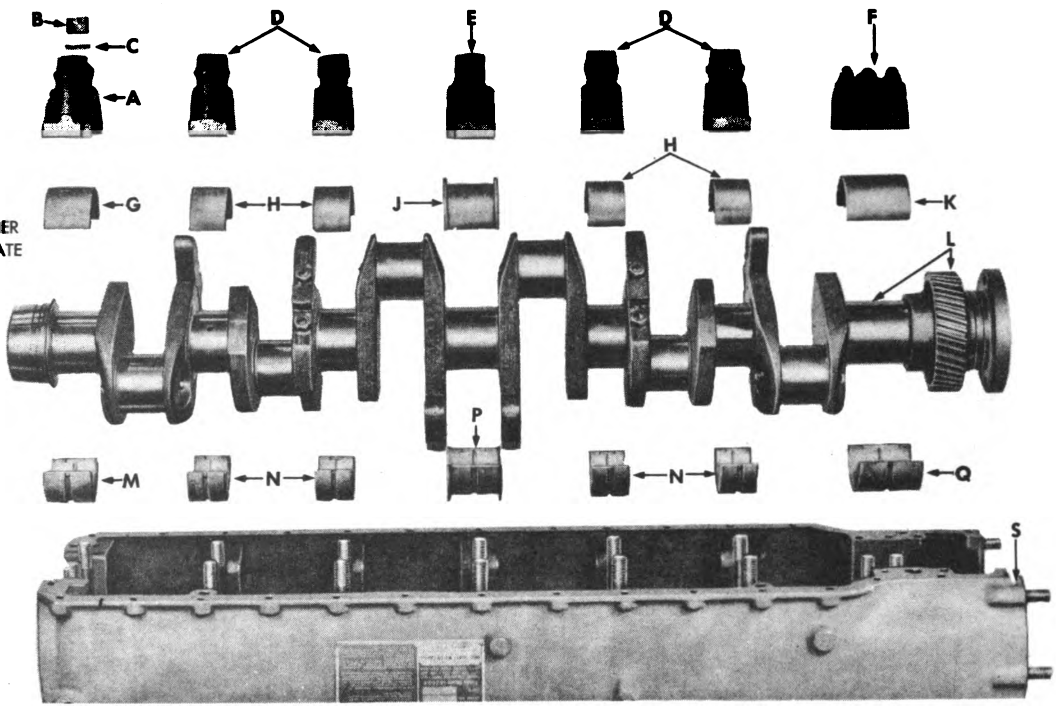

A—MAIN BEARING CAP—FRONT
B—MAIN BEARING STUD NUT
C—MAIN BEARING STUD NUT WASHER
D—MAIN BEARING CAP—INTERMEDIATE
E—MAIN BEARING CAP—CENTER
F—MAIN BEARING CAP—REAR
G—MAIN BEARING SHELL—FRONT (CAP HALF)
H—MAIN BEARING SHELL—INTERMEDIATE (CAP HALF)
J—MAIN BEARING SHELL—CENTER (CAP HALF)
K—MAIN BEARING SHELL—REAR (CAP HALF)
L—CRANKSHAFT ASSEMBLY
M—MAIN BEARING SHELL—FRONT (CASE HALF)
N—MAIN BEARING SHELL—INTERMEDIATE (CASE HALF)
P—MAIN BEARING SHELL—CENTER (CASE HALF)
Q—MAIN BEARING SHELL—REAR (CASE HALF)
R—MAIN BEARING STUD
S—CRANKCASE ASSEMBLY—UPPER

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Figure 26. Crankshaft and Bearings.

c. Throw Arrangement. Most crankshafts are similar in design. Crankshafts for four-cylinder engines have either three or five points of support (fig. 27). The four throws are in one plane, the throws for cylinders No. 2 and No. 3 being advanced 180° over the throws for cylinders No. 1 and No. 4. A crankshaft for an eight-cylinder V-type engine would be of the same basic design. For better balance and smoother operation, a variation of the V-type eight-cylinder crankshaft has two throws on each bank advanced 90° over the other two throws. Crankshafts for eight-cylinder in-line engines follow two general designs (fig. 27). The first design has two identical four-throw arrangements positioned end to end, with one set advanced 90° over the other. This is known as a 4-4 shaft. In the other design, the 2-4-2 shaft, a set of four throws is positioned between two sets of two throws each. The end cylinders are advanced 90° over the center group. Crankshafts for six-cylinder engines have either three, four, or seven points of support. The throws for the connecting-rod bearings are forged in three planes 120° apart, with two throws in each plane. Throws No. 1 and No. 6 are in the first plane, Nos. 2 and 5 are in the second, and Nos. 3 and 4 are in the third (fig. 27). The crankshafts for 12-cylinder V-type engines are basically the same as the shafts for 6-cylinder engines.

d. Crankshaft Stress. Any piece of rotating machinery has a certain definite speed at which it will vibrate. In designing a crankshaft it is sometimes possible to place this critical speed outside the speed range of the engine. If not, the crankshaft must be heavy enough to withstand the vibration. In severe cases of vibration, the crankshaft may break. In order to run smoothly, a crankshaft must be statically and dynamically balanced. Crankshaft deflection, caused by load stresses, will often throw a shaft out of balance, especially at high speeds. To overcome vibration, uneven balance, and load deflection, crankshafts are balanced by use of weights. These weights may be forged as part of the shaft, as shown in figure 26, or they may be bolted on.

e. Torsional Vibration. Torsional vibration is a twisting vibration. It usually is noticeable in in-line six- and eight-cylinder engines with long crankshafts. Assume that the crankshaft is made of rubber. When the front cylinder is fired, it would tend to turn the crankshaft very rapidly, but the inertia of the flywheel would tend to prevent this rapid increase in speed at the rear of the crankshaft. The result is a "winding up" of the "rubber" crankshaft. As the force exerted by the front cylinder decreases, the rubber crankshaft will "unwind" again. This repeated winding and unwinding sets up a twisting or torsional vibration. Naturally, a steel crankshaft will not distort like rubber, but it distorts enough to have torsional vibration.

(1) The slipping-flywheel type of vibration damper is a device developed to overcome torsional vibration (fig. 28). It consists of a small flywheel which runs loosely on the front of the crankshaft. A friction clutch,

having a slipping torque of about 150 lb-in., tends to make this flywheel rotate with the crankshaft. Normally, torsional vibration would result, but the damper's flywheel slips, preventing the winding up. When the speed of rotation of the crankshaft and main flywheel is steady, the clutch grips the flywheel, and both flywheel and crankshaft revolve together. When the speed of rotation of the crankshaft is reduced, as it is by the intake stroke, the crankshaft will tend to lag behind the main flywheel and thus cause torsional vibration. In this case the flywheel again slips, and the friction disks in the clutch will exert a force on the crankshaft and help to bring it up to speed.

(2) Another type, known as a harmonic balancer, has a flywheel or inertia weight mounted by means of leaf springs on the fan-drive pulley. When the crankcase begins to vibrate torsionally, the weight also will vibrate but, because of its inertia and type of mounting, its motion will be out of phase with the crankshaft and will reduce the intensity of vibration.

31. Crankshaft, Radial Engine

The crankshaft construction offers one of the pronounced differences between radial and in-line engines. Radial-engine crankshafts are classified as to whether the crank-throw section is solid or of two-piece construction and as to the method of holding the sections together. There are three distinct types of crankshafts: solid crankpin or throw, split-clamp crankshaft, and split-spline crankshaft. The split-clamp type,

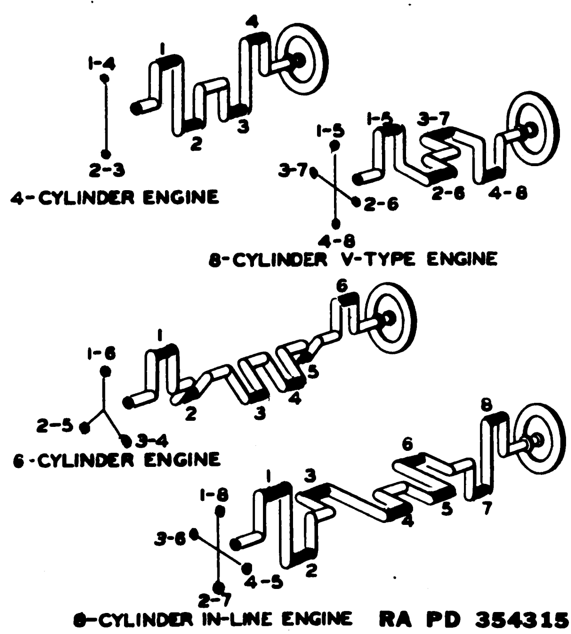

Figure 27. Crankshaft and Throw Arrangements.

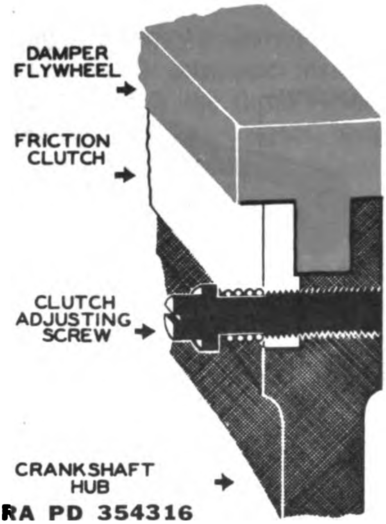

Figure 28. Vibration Damper.

which permits use of a solid big-end master-rod bearing designed to minimize distortion under heavy load, is the most common of the three and will be described in more detail. It is a single-throw counterbalanced assembly machined from steel forgings.

a. The split-clamp type has rear and forward sections (fig. 29). The forward section consists of the shaft proper, the front crankcheek with its counterweight, and the crankpin. The rear section of the shaft consists of the rear crankcheek with its counterweight and the rear main-bearing journal. The sections are alined during assembly by means of a special alining bar, which is inserted through holes in the counterweight section. The front and rear shanks are extensions of the rear and forward sections of the crankshaft. The rear shank provides a place for installing a main bearing to support the rear end of the crankshaft. It is extended into a tail shaft for driving the accessories which are attached to the rear section of the engine. The tail shaft is splined into the rear shank.

This set-up is varied in other crankshafts, such as the one in figure 29, where there is no tail shaft.

The rear main bearing is the plain or friction type with a gear mounted on it for driving the accessories. The gear is made in two parts, the inside part being bolted to the crankshaft (fig. 30). Engagement with the outer part is through springs which smooth out the power flow. The front shank is integral with the front section and forms a single-piece unit which includes the crankpin journal. The front shank is practically uniform in section; it is provided with a spline for connection with the flywheel. The front main bearing is mounted close to the crankcheek; the thrust bearing is mounted on the forward end of the crankcase front section and as near the flywheel as possible.

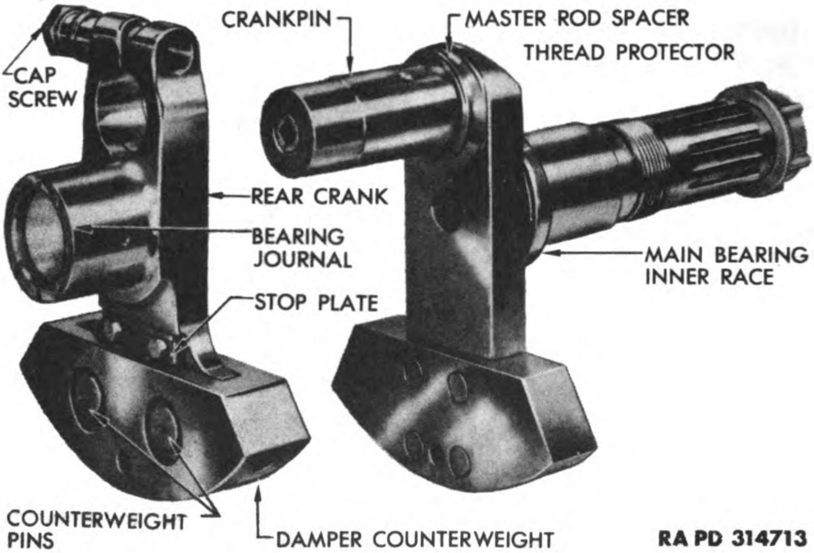

Figure 29a. Radial Engine Crankshaft Sections.

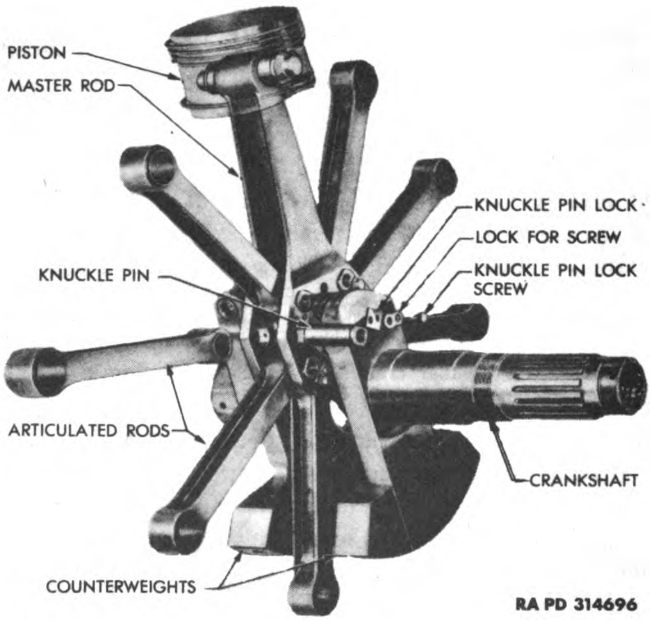

Figure 29b. Radial Engine Crankshaft, Connecting Rods and Piston.

b. Radial-engine firing impulses are heavy, and the connecting rods are concentrated on one throw. To counteract these heavy firing impulses, weights must be located opposite the throw where the forces of the connecting rods are exerted. Counterweights, forged as a unit with crankshaft sections or manufactured separately, provide the necessary opposing force, easing the load on the bearings. If the weights are detachable, they may be made of either bronze or steel. Bronze, because of its greater weight, is preferable where space within the crankcase is limited. Bronze also is supposed to have a greater dampening effect on the engine impulses. If not integral parts of the sections, the counterweights are riveted or bolted to the counterweight cheeks. They should be removed only under direction of the manufacturer.

c. As the power impulses in a radial engine occur several degrees apart, torsional vibration is set up in the engine. In order to dampen these vibrations, the rear crankshaft counterweight is suspended on the crankcheek so that it acts as a free-swinging pendulum moving in the plane of crankshaft rotation. A typical damper consists of a movable slotted-steel counterweight attached to the crankcheek (fig. 31). Two spool-shaped pins extend into the slot and pass through oversized holes in both the weight and the crankcheek. This difference in diameter between the pins and the holes allows for the pendulum effect. The radius of the pendulum is so short that its frequency corresponds to that of the power impulses. The power impulses try to move the pendulum sideways in the plane of rotation, independently of the cheek; but this tendency is counteracted by centrifugal force due to crankshaft rotation. Centrifugal force moves the pendulum outward to the limit allowed by the difference in diameter between the pins and holes, and restores it to this position when the engine impulses try to move it sideways. The pendulum counterweight, therefore, applies counter-torque to each torque fluctuation caused by an engine impulse.

32. Flywheel

a. The purpose of the flywheel is to store up energy necessary to keep the crankshaft turning when it is not receiving power impulses from the pistons. The size of the flywheel required, therefore, varies with the number of cylinders and the general construction of the engine. The flywheel rim carries a ring gear, either integral with the flywheel or shrunk on, which meshes with the starter driving gear for cranking the engine (fig. 32). The rear face of the flywheel is usually machined and ground and acts as one of the pressure surfaces for the clutch, becoming part of the clutch assembly.

b. When used in aircraft, a radial engine does not require a flywheel because the propeller serves this purpose; when installed in an automotive vehicle, a flywheel is very necessary. It is of cast-iron construction like that used in the in-line or V-type engine; but on the circumference,

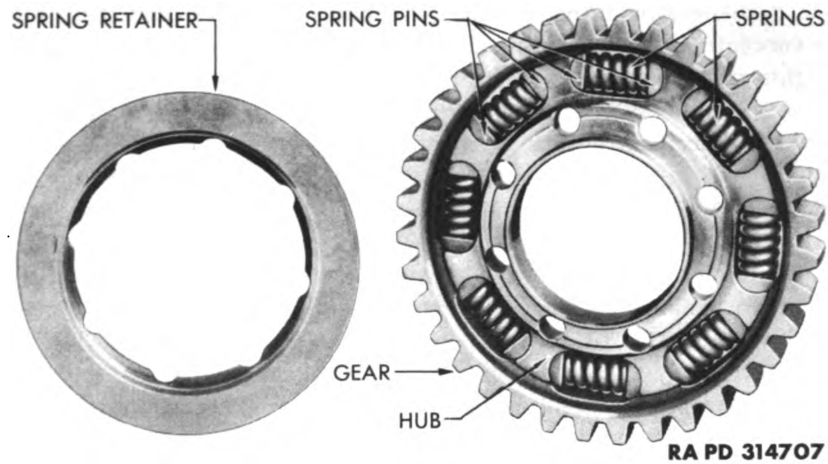

Figure 30. Radial Engine Crankshaft Gear.

where the in-line engine has a ring gear to engage with the starter motor, the radial-engine flywheel has a cooling fan connected (fig. 33). The flywheel itself is splined on the crankshaft where the propeller would be if the engine were in an airplane. There is no flange connecting the crankshaft and flywheel as in the conventional types. The splines act as a means of driving the flywheel. Longitudinal positioning of the flywheel on the crankshaft is accomplished by two cones, one on either side of the flywheel. The flywheel also acts as a housing for the clutch (if the vehicle has one) rather than employing a separate housing as the in-line engine does. Because the radial-engine clutch is subjected to such high temperature in operation, there are holes in the flywheel to help in cooling the clutch.

33. Main Bearings

a. The crankshaft of an engine rotates in "main" bearings. These bearings are located at both ends and at a few intermediate points along the crankshaft. In in-line engines, they are supported by "webs" in the crankcase and, in high-speed automotive engines, are of the thin-shell bronze- or steel-backed type (fig. 6).

b. One-half of the shell is fastened to the bottom or cap part of the bearing in the same way that a connecting-rod bearing is fastened to the connecting-rod bearing cap. The two-part precision shell bearing is highly desirable because it can be easily replaced and does not require scraping and fitting. It has one principal disadvantage, however, in that it cannot be line-bored or reamed to allow for warpage of the crankshaft or block; if there is warpage, certain bearing areas are subjected to excessive wear. The precision bearing also is more expensive, but its advantages more than offset its disadvantages. The principal load on the

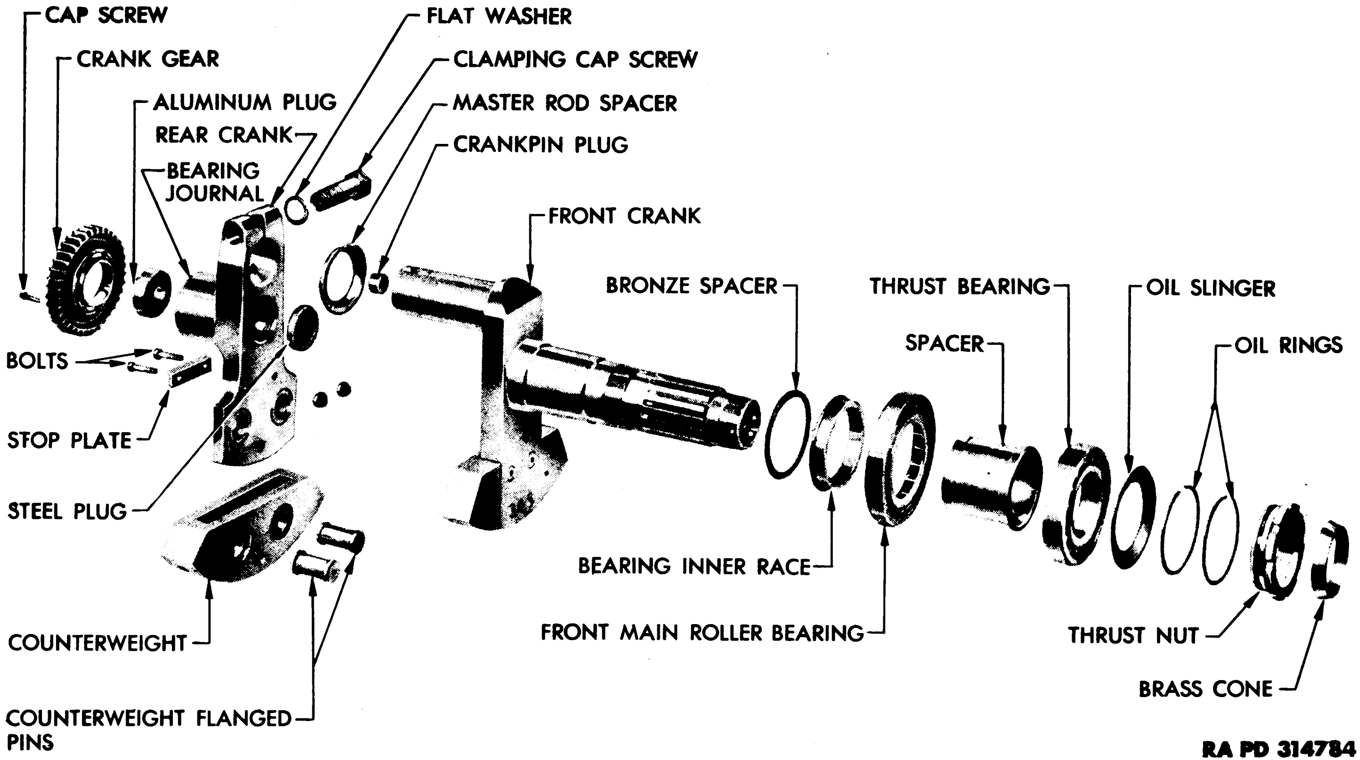

Figure 31. Radial Engine Crankshaft Disassembled, Showing Counterweights.

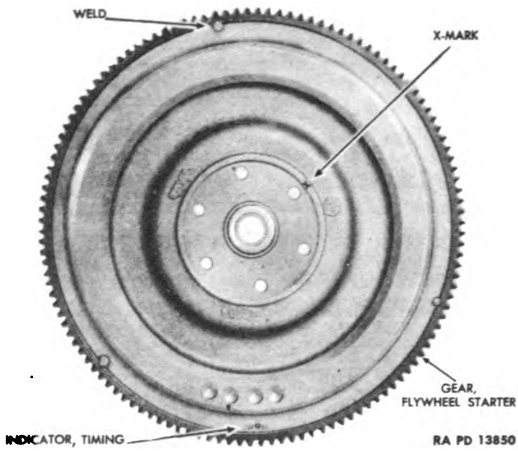

Figure 32. Flywheel.

main bearings is radial, but the small end-thrust load on the crankshaft is taken up by a main bearing which is provided with lip or thrust faces and acts as a combination radial and thrust bearing. The main bearings are often channeled for oil distribution and may be lubricated with crankcase oil by pressure through drilled passages or by splash. To prevent loss of engine lubricating oil, oil seals are placed at the main bearings where the crankshaft extends through the crankcase.

c. Various combinations of main bearings have been used to support the crankshaft in a radial engine. However, the arrangement common to radial engines in the automotive field makes use of two main bearings, one on either side of the crankshaft throw, and a third bearing located in the front section of the crankcase. The first main bearing is a roller bearing in the main-bearing support section of the crankcase, where it takes the radial load produced by engine power impulses. The other main bearing is in the main crank section and is of the plain type. It also takes the radial load caused by engine impulses. Both main bearings are placed as near the crankshaft cheeks as possible to reduce chances of crankshaft deflection during operation. If the shaft were supported improperly and excess deflection occurred, dynamic unbalance would result. The third bearing is a ball thrust bearing designed to take the longitudinal thrust of the crankshaft.

34. Valve and Valve Seats

a. VALVES (figs. 34 and 35). Every cylinder of any four-stroke cycle engine must have at least one intake valve to permit the mixture to enter the cylinder and one exhaust valve to allow the burned gases to escape.

The type of valve usually used in automotive engines is called a poppet or mushroom valve (fig. 34). The word "poppet" is derived from the popping action of the valve, and the word "mushroom" from its general shape. The valves usually are made in one piece from special alloy steels. The intake valves ordinarily are made of chromium-nickel alloy and the exhaust valves of silichrome alloy because of the extremely high temperatures that they must withstand. In some engines, especially the air-cooled types, the exhaust valve contains sodium in a sealed cavity extending from the head through the stem (fig. 35). The sodium conducts heat away from the head to the stem, from where it is conducted to the valve guide, thus aiding in cooling. When worn out, sodium-filled valves should be disposed of in accordance with existing regulations.

b. Valve Seats. The valve seat is the face of the circular opening leading into the combustion chamber of the cylinder (fig. 34). There are at least two such openings or ports in each cylinder, to which are connected the intake and exhaust manifolds. Since exhaust-valve seats are subjected to intense heat, valve grindings and reseatings are necessary from time to time to renew the seating surfaces. Regrindings can be minimized by using nickel-chrome cast-iron alloy in the cylinder castings or by using valve-seat inserts. These inserts are rings of special alloy fitted into place in the cylinder block or cylinder head. Inserts can be used with both exhaust and intake valves but are more frequently used with exhaust valves only.

c. Valve Guides. Valve stems are ground to fit the guides in which they operate. The reamed hole in the guide must be alined and square with the valve seat to insure proper seating of the valve face (fig. 34).

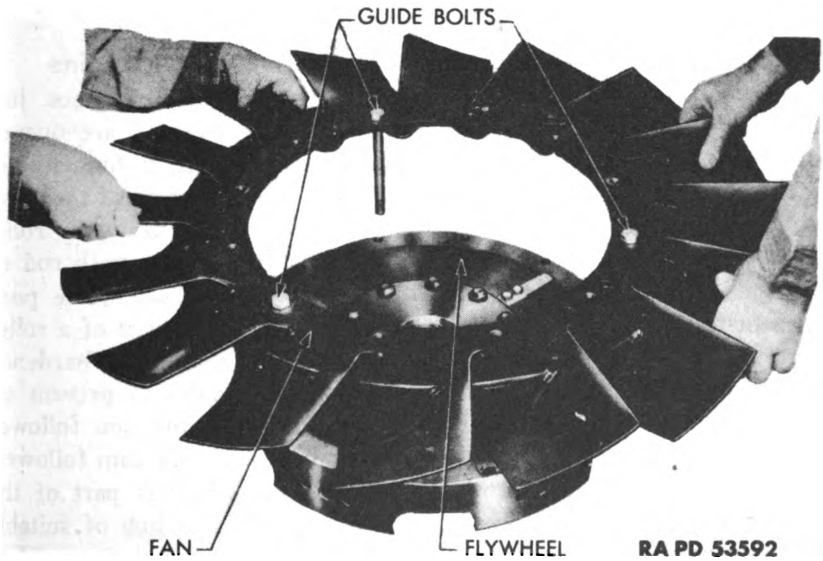

Figure 33. Radial Engine Flywheel with Cooling Fan.

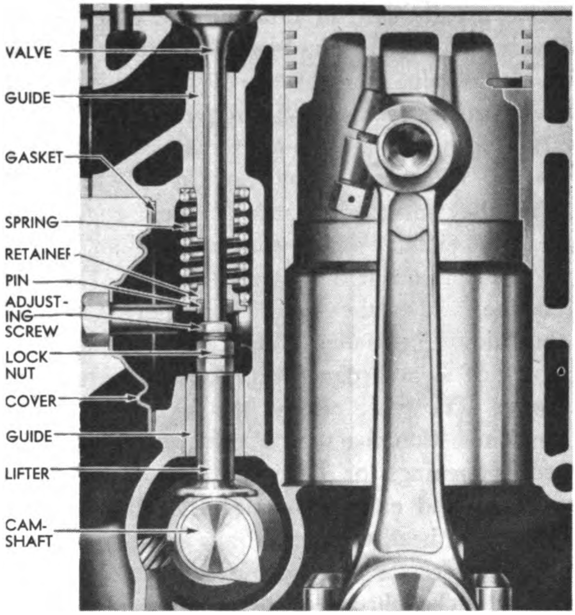

Figure 34. Valve Operating Mechanism.

The guides may be integral parts of the cylinder block or cylinder head, depending on the type of valves used, or they may be removable sleeves which can be replaced when worn. Removable valve guides are usually made of cast iron. Valve heads and seats are cooled by the transfer of heat to adjacent metals, which are cooled by the surrounding water.

35. Valves and Valve-operating Mechanism, Radial Engine

The poppet-valve system is the prevalent type in radial engines, just as it is in in-line engines. The valves of a radial engine are opened positively by a cam ring instead of a camshaft as in the in-line engines and are closed by spring action (figs. 36 and 37). The flow of the force opening the valves is as follows: the cam lobe works against a roller on the cam follower; the cam follower, in turn, forces the push rod up through a ball socket which fits in the top of the follower; the push rod actuates the rocker arm, which opens the valve by means of a roller acting on the tip of the valve stem. The cam followers are of hardened steel and are a close sliding fit in the follower guides to prevent oil leakage. The ball socket is also a close sliding fit in the cam follower and is held against the pushrod and by a coil spring in the cam follower.

a. The cam ring may be mounted on a shelf which is part of the crankcase construction or on a sleeve which contains a hub of suitable bearing material. It is a unit made up of a hardened-steel ring with a double row of cam lobes, one for intake valves and one for exhaust, and either an external or internal spur gear. All parts of the unit are fixed and do not change position relative to each other. The number of lobes is determined by the number of cylinders and the direction of rotation of the cam ring. The spur gear is not connected directly to the crankshaft gear but is driven from a pinion on the starter shaft (fig. 36). In a nine-cylinder engine, the cam ring operates at about one-tenth or one-eighth crankshaft speed, the speed of rotation being determined by the direction of rotation of the cam ring in relation to the camshaft and the number of lobes on the cam ring. The cam-ring lobes have a ramp on each side to take up clearance in the push-rod assembly and to reduce the shock which occurs when the cam follower contacts the lobe. The clearance is caused by the elongation of their air-cooled cylinders due to the high temperatures of operation. As the cylinders elongate, they move the rocker boxes farther from the crankcase but the length of the push rod increases only a small amount. The difference accounts for the clearance that is built up when the engine is hot. This, of course, must be taken into consideration in setting valve clearances and explains why a radial engine must be warmed up properly before a load is applied. Otherwise the valve timing would vary considerably from the specified requirements.

b. Except for size, radial-engine valves are basically the same as those used in in-line engines. They are made of nickel-steel alloy forgings (fig. 35). The intake-valve stem usually is much smaller than the exhaust-valve stem and is solid. Because it is exposed to large quantities

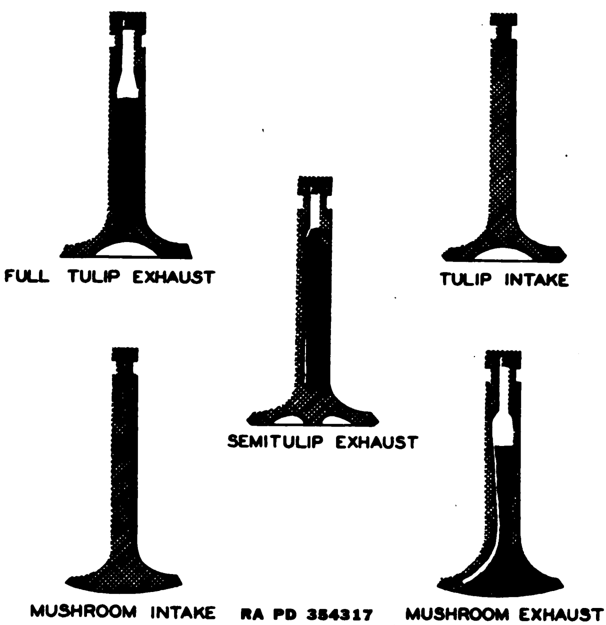

Figure 35. Valve Types.

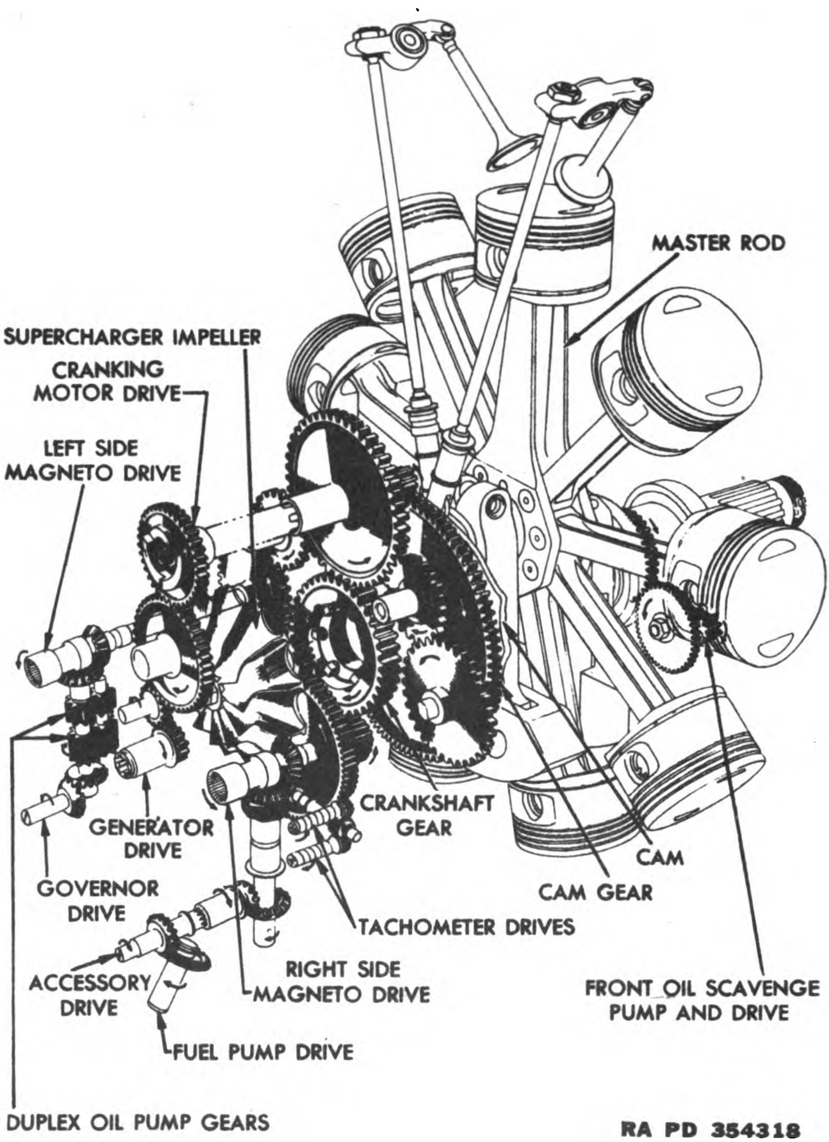

Figure 36. Radial Engine Gear Trains.

of high-temperature gases, the exhaust valve is heavier; its stem is hollow and usually is filled with metallic sodium for cooling. The valves in a radial engine open and close rapidly and with more force than the ordinary in-line engine valves, so the mating surfaces on the valve faces and seats must resist more pounding. For these reasons, the seats are much wider than those of the in-line engine. In addition, the exhaust-valve faces usually have a coat of stellite, a material highly resistant to

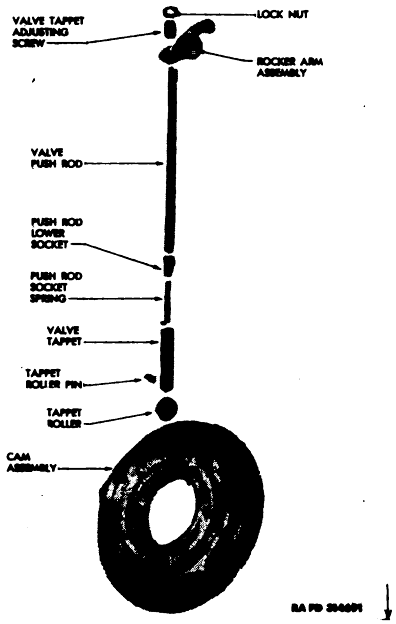

Figure 37a. Radial Engine Valve Operating Mechanism.

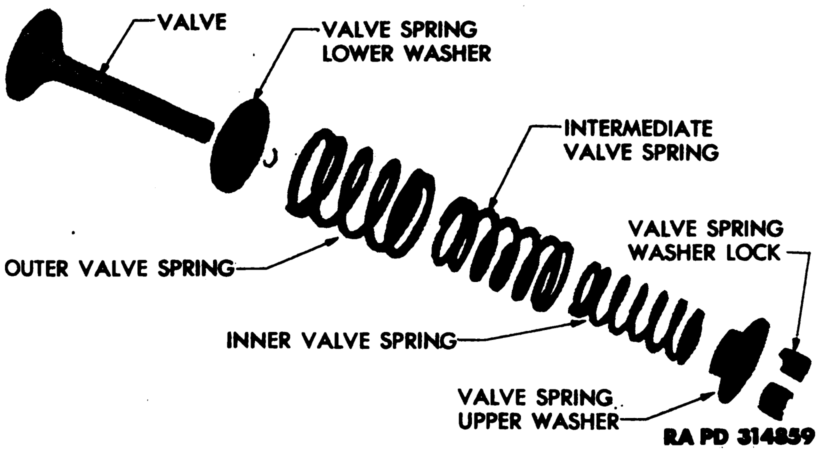

Figure 37b. Radial Engine Valve and Valve Springs.

heat and wear. A layer of stellite also is used on the tip of the valve stem where it contacts the rocker-arm roller. Most radial-engine valves are of the "tulip" type, so-called because of their tulip shape (fig. 35). The neck section is heavy, an aid in resisting higher temperatures, and the head is shaped so that stresses are more tensile. It uses a 45° face angle, which gives the advantage of better seating and heat-conducting qualities. Another recent type is the hollow-head mushroom valve. Its construction is supposed to eliminate any tendency of the valve to bounce, and it uses a 30° face angle, which gives better air-flow efficiency.

c. The valve springs are made of high-grade steel wire. They are wound in a helical shape with a flat coil on each end bearing against retaining washers. Two or three springs are used to close the valves although one would be enough if that were their only purpose; the additional springs prevent harmonic vibrations and bouncing of the valve and are a safety factor (fig. 37).

36. Radial Engine Gear Train

A gear attached to the rear end of the crankshaft drives all engine accessories, including the valve-operating mechanism, impeller, and starter (fig. 36). The various gear trains are protected against the shock of sudden acceleration by a flexible-spring drive between the crankshaft and its gear. The crankshaft gear, impeller drive pinion, and the starter drive gear, all house between the diffuser section and the main crankshaft section, mesh directly. The so-called accessories, which include the magnetos, fuel pump, oil pump, tachometer, governor and generator, are driven through idler gears that mesh with the starter drive gear. The shafts for these gears and the starter shaft extend rearward through the diffuser section to the rear or accessory section.

a. The starter gear is splined on the starter shaft. Gear and shaft are clamped together in most models by the starter-shaft bolt which carries the cam drive pinion on its forward end and passes through the entire length of the shaft. A spur gear at the rear of the starter shaft meshes through an idler gear with the generator drive.

b. The accessory drive shafts are of two-piece construction, consisting of a separate shaft and separate magneto coupling which is a spline fit on the shaft. A screw through the center of the coupling is used for retaining it on the shaft. The magnetos are driven directly from these shafts. The right-hand accessory drive shaft drives the tachometer drives, fuel-pump drive, and right-hand magneto drive. The left-hand accessory drive shaft drives the oil pump and the left-hand magneto drive. A three-way accessory drive may be mounted on the engine accessory section in place of the fuel pump. On an airplane it would be used for the fuel pump, vacuum pump, and propeller governor drives. However, only the fuel pump is required in automotive usage.

CHAPTER 5

GASOLINE FUEL SYSTEMS

Section I. CHARACTERISTICS OF GASOLINE

37. Source

Petroleum is the most common source of fuel for modern internal combustion engines. It contains two important elements (carbon and hydrogen) in such proportions that they will burn freely in the presence of oxygen and will liberate heat energy. Petroleum actually contains more potential energy than dynamite. A gallon of dynamite would drive an automobile 3 miles; the same amount of gasoline would drive it 18 miles. Gasoline is the most popular petroleum-base engine fuel because it is best suited to engine operation. It has many advantages, two of which are better rate of burning and easy vaporization to give quick starting in cold weather. Second in quantity used is Diesel fuel, which will be described in another chapter. The major characteristics of gasoline are volatility, purity, and antiknock quality. They are all worth consideration, as any one of them will affect the efficiency of engine operation.

38. Volatility

Volatility, as applied to gasoline, is its tendency to change from liquid to vapor at any given temperature. The volatility of gasoline affects ease of starting, length of warming-up period, and engine performance during normal operation. All liquids tend to vaporize at atmospheric temperature, but their rates of vaporization vary. Rate of vaporization increases as the temperature rises and as pressure goes down, temperature being the more important factor. For practical consideration, it may be stated that a highly volatile fuel will vaporize at atmospheric temperatures whereas a fuel of low volatility will vaporize at high temperatures. To understand volatility, it is advisable to study its automotive applications with regard to starting ability, vapor lock, crankcase dilution, and fuel distribution.

a. Starting Ability. To start readily, an engine must have a burnable fuel mixture in the combustion chamber at the moment of starting. Ordinarily, the proper mixture is about 15 parts of air to 1 part of fuel by weight, but when an engine is cold some of the vaporized fuel condenses and collects in the manifold. More fuel must be added to make

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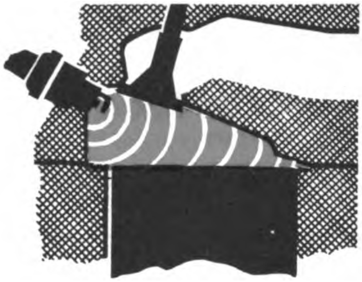

RA PD 354319

Figure 38. Normal Burning Process.

RA PD 354320

Figure 39. Detonation or "Knocking."

RA PD 354321

Figure 40. Preignition.

enough fuel available for starting and operation until the engine reaches operating temperature. The air-fuel ratio must actually be about 1¼ to 1 in order to obtain 15 parts of air to 1 part of combustible fuel. This change in ratios is accomplished by the choke in the carburetor. Starting in cold weather is facilitated by using fuels of higher volatility.

b. Vapor Lock. One of the difficulties experienced in using highly volatile fuels, especially in hot weather, is vapor lock. When a fuel has a tendency to vaporize at normal atmospheric temperatures, it forms so much vapor in the fuel lines that action of the fuel pump results impulsation of the vapor rather than flow of fuel. To avoid vapor lock, heat-insulating materials or baffles are often placed between the carburetor and manifold or between the exhaust pipe and fuel lines. Hot-weather grades of gasoline are blended from low-volatility fuels to lessen the tendency toward vapor lock.

c. Crankcase Dilution. When cold weather or overchoking leaves an excessive amount of fuel unvaporized, another undesirable condition results. The fuel that is not vaporized seeps by the piston and piston rings and into the crankcase during the warming-up period. This dilutes the oil in the crankcase and destroys its lubricating qualities; the condition is known as crankcase dilution. It can be overcome if engine operating temperatures are high enough to cause the gasoline to be vaporized in the crankcase, the vapors being withdrawn through a ventilating system (par. 104).

d. Fuel Distribution. When fuel is not distributed evenly to all cylinders, the engine will run unevenly and power output will decrease. To insure good distribution, the fuel must be completely vaporized and mixed with air in the manifold before entering the cylinders. Quick, smooth acceleration also depends on a fully vaporized fuel mixture entering the combustion chamber.

39. Purity

Petroleum contains many impurities that must be removed during the refining process before gasoline suitable for automotive use is produced. At one time considerable corrosion was caused by the sulfur inherent in petroleum products, but modern refining procedure has made it almost negligible. Another problem was the tendency for the hydrocarbons in gasoline to oxidize into a sticky gum when exposed to air, which resulted in clogged carburetor passages, stuck valves, and other operational difficulties. Chemicals that control the gumming tendency are now added to the gasoline. Dirt grease, water, and various other chemicals also must be removed to make gasoline an acceptable fuel.

40. Antiknock Quality

a. Combustion Process. In order to appreciate the contribution that antiknock quality makes toward an effective fuel, it is necessary to understand certain fundamentals of combustion. The burning or combustion process can be divided into three stages (fig. 38): nucleus of flame, hatching-out, and propagation.

(1) *Nucleus of flame.* As soon as a spark jumps the gap of the spark-plug electrodes, a small ball of blue flame develops in the gap. This ball is the first stage, or "nucleus of flame." It enlarges very slowly and, during its growth, there is no measurable pressure created by heat.

(2) *Hatching-out*. As the nucleus enlarges, it develops into the "hatching-out" stage. The nucleus is torn apart so that it sends fingers of flame into the mixture in the combustion chamber. This causes enough heat to give just a slight rise in temperature and pressure in the entire air-fuel mixture. Consequently, a lag still exists in the attempt to raise pressure in the entire cylinder.

(3) *Propagation*. It is during the third, or propagation, stage that effective burning occurs. The flame now burns in a "front" which sweeps across the combustion chamber, burning rapidly and causing great heat with an accompanying rise in pressure. This pressure causes the piston to move downward. The burning during normal combustion is progressive. It increases gradually during the first two stages, but during the third stage the flame is extremely strong as it sweeps through the combustion chamber. However, there is no violent or explosive action such as when detonation, ordinarily responsible for "pinging" or "knocking", occurs.

b. DETONATION. If detonation takes place it occurs during the third stage of combustion. The first two stages of burning are normal; but in the propagation stage, flame sweeps from the area around the spark plug toward the walls of the combustion chamber. Parts of the chamber that the flame has passed contain inert nonburnable gases, but the section not yet touched by the flame contains highly compressed heated combustible gases. As the flame races through the combustion chamber, the unburned gases ahead of it are further compressed and are heated to high temperatures. Under certain conditions, the extreme heating of the unburned part of the mixture may cause it to ignite spontaneously and explode. This rapid uncontrolled burning in the final stage of combustion is detonation (fig. 39). It is caused by the rapidly burning flame front compressing the unburned part of the mixture to the point of self-ignition. The wave front of the mixture collides with the normal wave front and makes an audible knock.

(2) Detonation may harm an engine or hinder its performance in several ways. It is, in effect, an uncontrolled explosion, causing the confined gases in the combustion chamber to rap against the cylinder and head walls. "Knock" or "ping" results. In extreme cases, pistons have been shattered, rings broken, cylinders burst, or heads cracked. Other effects of detonation may be overheating, broken spark plugs, overloaded bearings, high fuel consumption, loss of power, and frequent need for overhaul.

c. OCTANE RATING. (1) The ability of a fuel to resist detonation is measured by its octane rating. The octane rating of a fuel is determined by matching it against mixtures of normal heptane and iso-octane in a test engine and under specified test conditions until a mixture of the pure hydrocarbons is found which gives the same degree of knocking in the engine as the gasoline being tested. The octane number of the gasoline is, then, the percent of the iso-octane in the matching iso-octane normal-heptane mixture. For example, a gasoline rating 75 octane is equivalent in its knocking characteristics to a mixture of 76 percent iso-octane and 25 percent normal heptane. Thus, by definition, normal heptane has an octane number of zero and iso-octane has an octane number of 100.

(2) It should be understood that the tendency of a fuel to detonate varies in different engines and in the same engine under different operating conditions. Octane number has nothing to do with starting qualities, potential energy, volatility, or other major characteristics. Engines are designed to operate within a certain octane range. Performance is improved with the use of higher octane fuel within that range if the spark setting is changed accordingly. However, if an engine operates satisfactorily at the upper limit of its fuel's octane-rating range, it will not improve its performance if fuel that exceeds the designed octane range is used.

(3) Tetraethyl lead is the most popular of the compounds added to gasoline to suppress knocking. Improved refining methods also have produced fuels of greater antiknock quality. Tetraethyl lead and other antiknock compounds are effective because they reduce the rate of burning of the fuel thus tending to prevent explosive burning or detonation. It takes only a small amount to produce the desired results. Most automotive fuels contain tetraethyl lead in amounts varying up to 3 cubic centimeters per gallon.

d. OTHER CAUSES FOR KNOCKING. (1) Low-octane fuel is not the only reason for detonation. Anything which adds "heat" or pressure to the last part of the mixture to burn within a cylinder will aggravate detonation. That is why the compression ratio of a gasoline engine has an upper limit. When the ratio is raised too high, the immediate result is detonation due to the excessive heat caused by additional compression. Under certain conditions, preignition, excessive spark advance, lean fuel mixture and defective cooling systems are a few of the many causes of detonation.

(2) Detonation is not to be confused with preignition (fig. 40). Detonation takes place late in the burning process after the spark has occurred. Preignition, however, is an igniting of the fuel mixture during compression before the spark occurs and is caused by some form of hot spot within the cylinder, for example, an overheated exhaust-valve head, hot spark plug, or an incandescent piece of carbon. Preignition may lead to detonation, but the two are separate and distinct events.

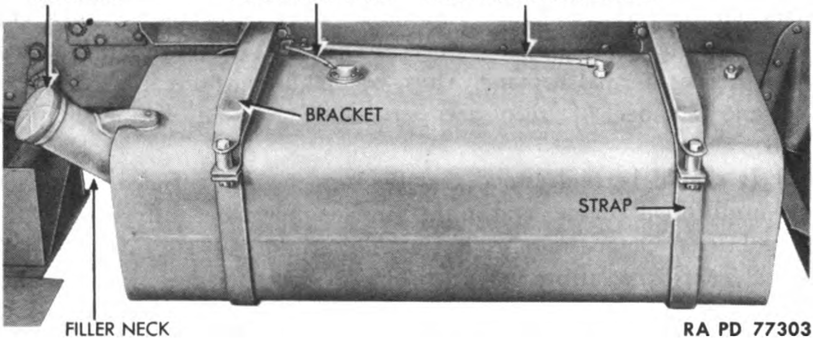

Figure 41. Fuel Tank.

Section II. FUEL-SYSTEM COMPONENTS

41. Fuel System

A gasoline-engine fuel system consists of a storage tank for fuel, a mechanism for delivering the fuel from the tank to the carburetor, a carburetor to mix the fuel with air before entry into the engine, an intake manifold to distribute the air-fuel mixture to the cylinders, and an exhaust manifold to dispose of exhaust gases after combustion. Also included in the system are the fuel gage, filter, air cleaner, and tubing. Because of the many variations in the Diesel engine, especially in connection with the fuel injector system, Diesel fuel systems will be described separately (see chapter 6). The radial-engine fuel system differs little from the in-line and V-type engine systems. The basic components of the two systems are the same. The radial-engine vehicle has a storage tank for the fuel and a pump for delivering it to the carburetor. The carburetor does not have a choke circuit as described for the in-line engine, but the radial-engine has a primer system, which is not part of the carburetor, to perform the same function. Intake pipes, rather than a manifold, distribute the air-fuel mixture to the cylinders, and the distribution is aided by an impeller unit. The fuel gage, air cleaners, filters, and necessary tubing make up the rest of the system.

42. Fuel Tanks and Gages on Tanks

The fuel tank (fig. 41) may be located at any convenient point on the vehicle. As fuel is supplied to the carburetor at pressure above atmospheric, the position of the tank has little effect upon the quantity of fuel forced into the carburetor. The tank, usually made of thin-gage metal, is covered with terneplate (lead and tin alloy) to prevent corrosion. It has an inlet for refilling the tank and an outlet in the top or side leading to the fuel pump. The outlet pipe, fitted for the fuel-line connection, extends down into the tank to about one-half inch from the bottom. This prevents sediment that may accumulate in the bottom of the tank from being drawn into the fuel line. Baffle plates in the tank serve more than one purpose. They reinforce the sides and bottom; and they prevent fuel from surging or splashing, which would hasten evaporation, break the fuel down chemically, and produce static electricity. Notches or perforations in the baffle plates permit fuel to flow freely through the compartments. There is a drain plug for draining and cleaning the tank. Several fuel tanks (usually four) comprise the conventional arrangement in automotive vehicles equipped with radial engines. If the vehicle is a tank or a gun motor carriage, two vertical fuel tanks are in the front corners of the engine compartment and two horizontal tanks are in the sponsons, one on either side of the engine compartment. Their combined capacity is about 175 gallons. The fuel-tank body, top and bottom, is made of 12-gage (0.019") copper bearing steel with a basic welded construction. Internal baffles serve the same purpose they do in ordinary tanks. The tanks are vented by a small hole in each filler cap. There are two main shut-off valves, each one controlling the flow of fuel from bulkhead to indicate the amount of fuel in all tanks. Early types of fuel gages were mechanically operated, and the indicator was incorporated as a single unit within the tank with the fuel-tank float and operating mechanism. The modern type has the operating mechanism and float within the tank, but the indicator is on the instrument panel. Most modern gages are electrically operated.

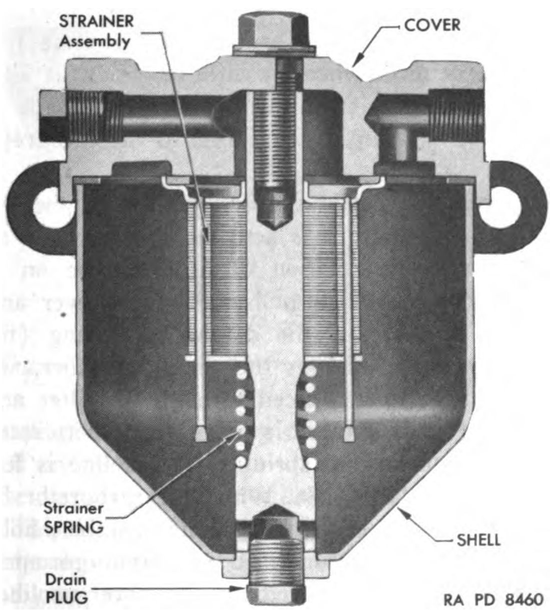

Figure 42. Fuel Filter.

43. Fuel Filter

The fuel filter may be located at any point between the fuel tank and the carburetor, but the most common type is usually located between the fuel tank and fuel pump.

a. The filter often is an integral part of the pump, especially if it is the sediment-bowl type. Fuel enters the glass bowl and passes up through the filter screen before flowing through the outlet; any water and solid matter caught by the screen falls to the bottom of the bowl, where it can be removed (fig. 43).

b. Another type of filter is made of a series of laminated disks placed within a large bowl which acts as a settling chamber for the fuel and incloses the disks or strainers (fig. 42). Fuel enters the filter at the top inlet connection and flows down, goes between the disks, and then up a central passage to the outlet connection at the top. Dirt and foreign matter cannot pass between the disks and are deposited at their outer rim. The clearance between the disks (0.003″) also is small enough to prevent the passage of water. This is possible because water, when present in gasoline, forms small globules that are too large to pass between the disks. Some commercial vehicles use a filter with a ceramic element, but the metal-disk type is the most common in Army vehicles.

44. Fuel Pump

The fuel pump must deliver sufficient fuel to supply the requirements of the engine under all operating conditions. It must also maintain enough pressure in the line between the pump and carburetor to keep the fuel from boiling and to prevent vapor lock. Fuel pumps usually are classified as positive or nonpositive. The positive type (par. 70) continues to pump fuel even when the carburetor bowl is filled; therefore, a method of bypassing the fuel back to the supply tank must be provided. The nonpositive pump delivers fuel to the carburetor only when it is required.

a. The pump ordinarily used on in-line gasoline engines is a diaphragm nonpositive type. Ordinarily, it is actuated mechanically although electricity may be used. The rotation of an eccentric on the camshaft actuates the rocker arm, which pulls the pump lever and diaphragm down against the pressure of the diaphragm spring (fig. 43). This creates a pressure differential in the pump chamber, which permits gasoline from the tank to be forced through the filter and inlet valve into the chamber. The diaphragm is moved up on its return stroke by the pressure of the diaphragm spring, and gasoline is forced through the outlet valve to the carburetor. When the carburetor bowl is filled, a back pressure is created in the fuel-pump chamber, holding the diaphragm down against the pressure of the diaphragm spring. It maintains this position until the carburetor needs more gasoline. The rocker arm and the pump lever are in two pieces which operate as a single

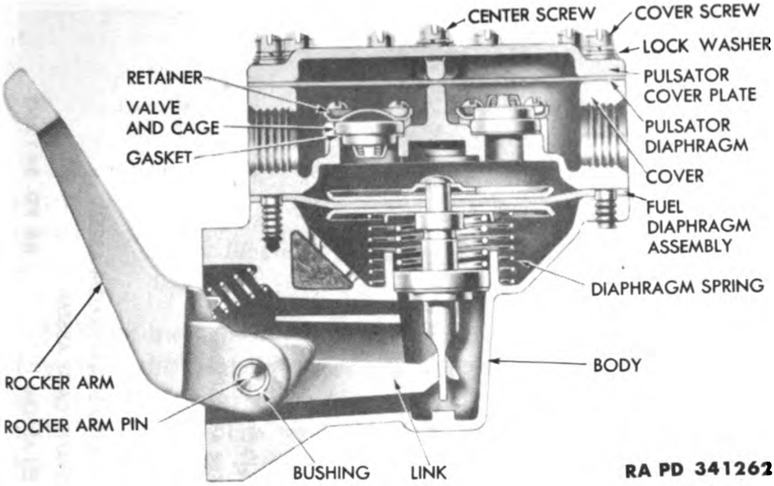

Figure 43a. Fuel Pump.

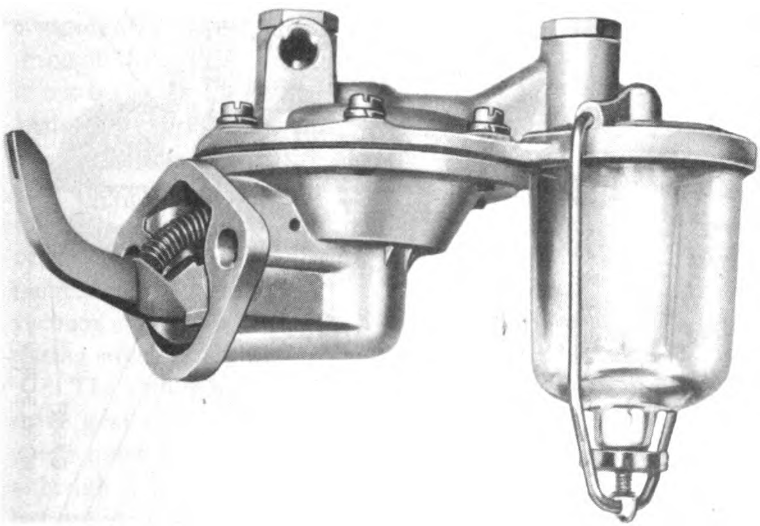

Figure 43b. Fuel Pump With Integral Filter Bowl.

part when the diaphragm is moving up and down. However, when fuel is not required and the lower part of the rocker arm is held down at one end by the diaphragm pull rod, only the upper part operates in the normal way. This is possible because the rocker arm operates against the lower part only in the downward direction. Upward movement of both parts is by spring pressure. It is this feature of operation which makes the pump nonpositive.

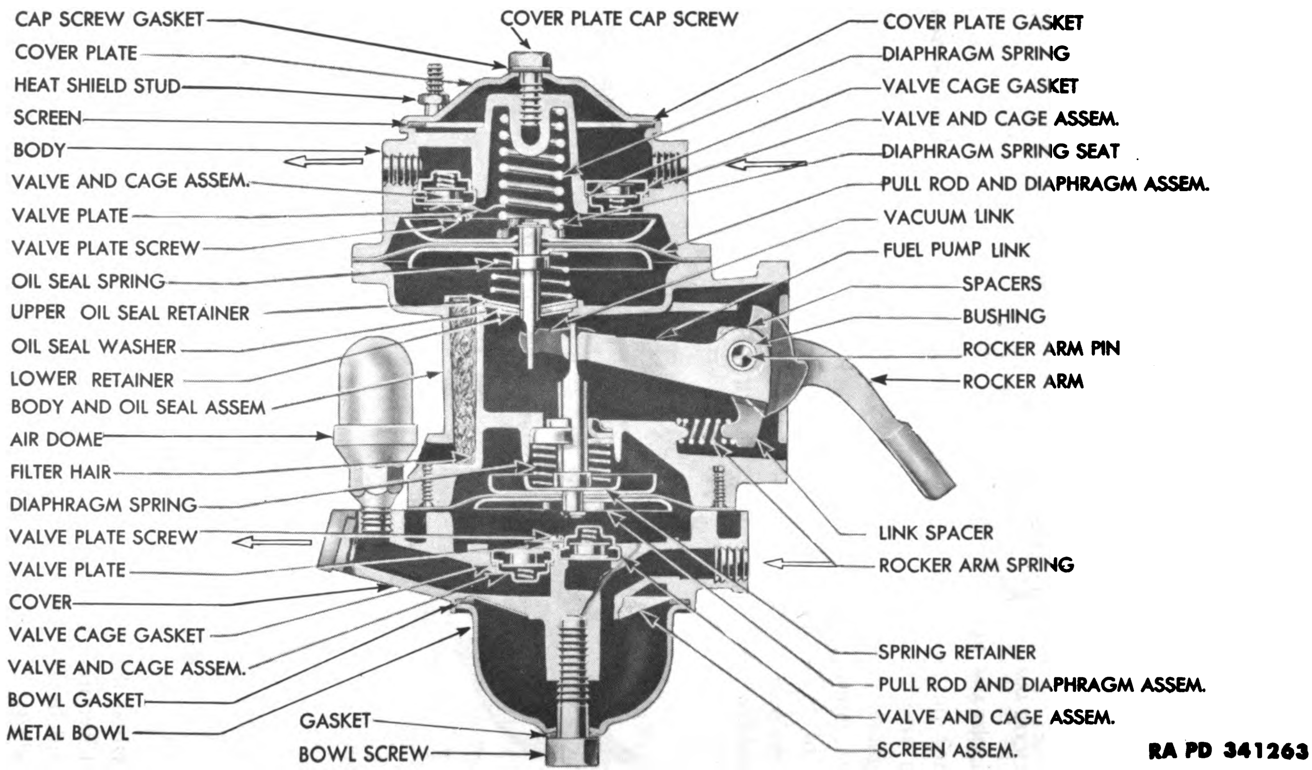

Figure 44. Fuel Pump With Vacuum Booster.

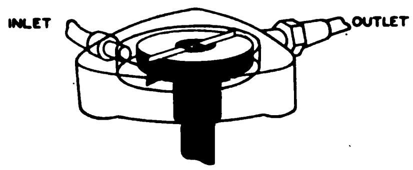

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Figure 45. Vane-type Fuel Supply Pump.

b. Some mechanically actuated pumps have a vacuum booster section (fig. 44) built in them to provide positive windshield-wiper operation at all times. This overcomes failure of the wiper on acceleration and under full throttle. The booster section operates the windshield wiper only; it has nothing to do with the fuel system except that it is operated by the fuel-pump rocker arm. The booster-unit diaphragm is pushed down when the rotation of the camshaft eccentric actuates the rocker arm. Movement of the diaphragm down expels air from the chamber through the exhaust valve which opens to the intake manifold. On the return stroke of the rocker arm, the spring moves the diaphragm up, creating a vacuum in the chamber and opening the intake valve. Air then comes through the inlet passage from the windshield wiper. When the wiper is not being used, the vacuum in the manifold holds the diaphragm down against spring tension. The diaphragm remains practically stationary, not making a complete stroke for every stroke of the rocker arm. When the intake-manifold vacuum is greater than the vacuum created by the pump, the air will flow from the windshield wiper through both valves of the pump. Operation of the wiper is the same as if there were no pump. It is when intake vacuum is low that the pump works. The vacuum it creates will then operate the wipers. This situation occurs during acceleration and at full-throttle speeds.

c. The radial-engine fuel pump is usually driven from the accessory-drive gear train but may be driven by any one of several methods. The pump most frequently used is the eccentric sliding-vane type (fig. 45). although a diaphragm type similar to that described in paragraph *70b* has appeared on some later models. The two-vane positive-displacement spring-loaded pump is the prevalent vane type. It consists of an eccentric rotor into which are inserted two vanes pressed against the walls of the pump bore by a spring between the vanes.

45. Air Cleaner

Air cleaners are placed at the air intake of carburetors to remove dust so that clean air is delivered to the cylinders. Dust is highly abrasive and can cause considerable damage to the pistons and the cylinder walls. Some air cleaners serve the additional purposes of arresting flames caused by carburetor backfire and preventing the hissing sound made by air entering the carburetor. Two types of air cleaners are used today—the wet type and the dry type.

a. WET TYPE. The most common wet type is the oil-bath cleaner, consisting of a main body, a unit filled with copper gauze, and a cover plate with a felt pad (fig. 46). Air entering the cleaner has to pass through small ports at the top of the main body and down between the main body and the copper gauze. Here the air makes a 180° turn and passes over a bath of oil. It then passes up through the oil-soaked copper gauze, where the fine particles are filtered out. The air itself soaks the copper gauze with the spray it picks up as it passes over the oil bath. After the air passes through the copper gauze, it hits the cover plate and is deflected down through a passage to the carburetor. If a backfire occurs, the flame is snuffed out by the felt pad before any damage results.

b. DRY TYPE. The ordinary type of dry air cleaner uses a filter (fig. 47). Others employ inertia and centrifugal principles. The dry air cleaner consists of a body, baffle plates to silence incoming air, loosely knitted copper gauze, and a cover plate with a felt pad. The incoming air passes through a series of baffles, where dust and dirt are removed, and then out into the carburetor.

c. The radial engine is equipped with two oil-bath type air cleaners similar to those described previously in this paragraph. Air enters the cleaners through the upper air-intake tubes, passes through a stationary

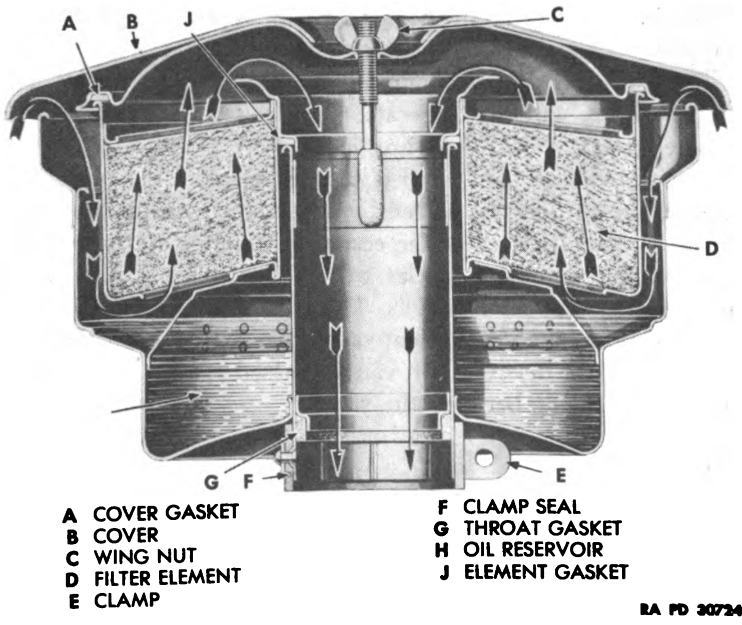

Figure 46. Wet-type Air Cleaner.

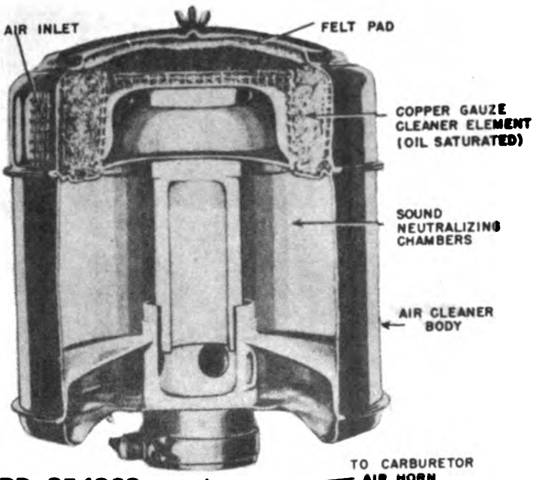

Figure 47. Dry-type Air Cleaner.

and a prefilter element, is cleaned by the oil in the oil cup, and is passed out through the lower intake tubes to the carburetor. The dirt collected drains to the bottom of the oil-cup.

46. Intake Manifold

a. The intake manifold distributes fuel as evenly as possible to each cylinder, prevents condensation, and assists in further vaporization of the fuel mixture. Smooth and efficient engine performance depends on whether or not mixtures that enter each cylinder are uniform in strength, quality, and degree of vaporization. That is partly the job of the intake manifold. The ideal fuel mixture is completely vaporized when it goes into the combustion chamber. Complete vaporization requires high temperature, and high temperature increases volume and decreases the volumetric efficiency of the engine. Therefore, the best alternative is to introduce a fuel mixture into the manifold that is vaporized above the point where fuel particles will be deposited and below the point where excess heat results in power losses. Intake manifolds must be designed carefully to help meet these requirements. When two cylinders fire consecutively, the intake manifold must prevent fuel from being cut off from the cylinder firing second. This cut-off would be caused by the pressure differential set up by the intake of the first cylinder that fired. The walls of the manifold must be smooth and offer no obstruction to the flow of the fuel mixture. Design also should prevent collecting of fuel at the bends in the manifold (fig. 48).

b. The intake manifold should be as short and as straight as possible to reduce the chances of condensation between the carburetor and cylinders. To assist in vaporization of fuel, some intake manifolds are

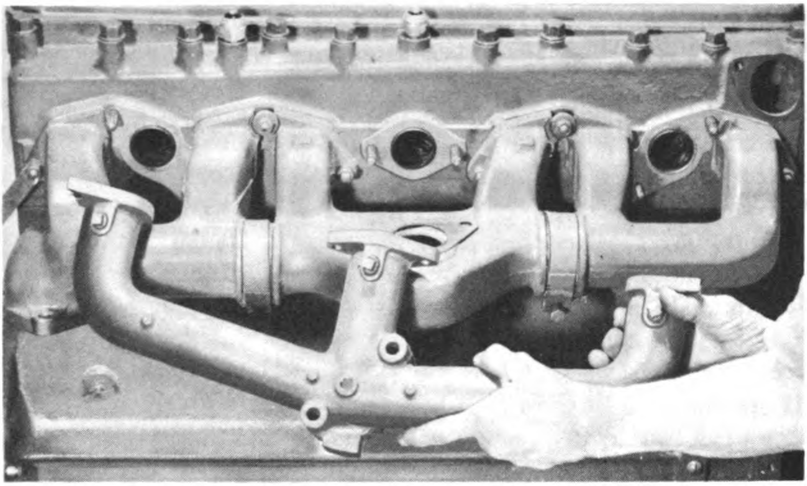

Figure 48. Intake and Exhaust Manifolds.

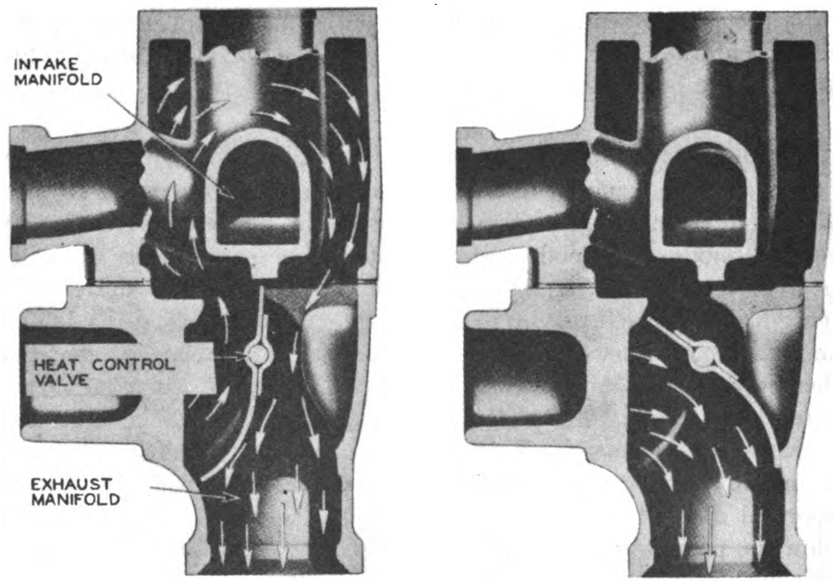

Figure 49. Operation of Intake Manifold Hot Spot.

constructed so that part of their surface can be heated by hot exhaust gases. A valve is placed in the exhaust manifold, which deflects the gases toward the hot spot in the intake manifold when the temperature around the engine is low (fig. 49). As the temperature rises, gases are passed directly through the exhaust manifold without coming in contact with the hot spot. All fuel in the intake manifold must pass over the hot spot before entering the cylinders. However, it does not contact the entire mixture at once, which helps keep the temperature down. Because of the hot spot, unvaporized particles that remain in the fuel mixture tend to vaporize instead of being carried into the cylinders as liquid particles. This additional vaporization of fuel is especially important during cold weather because it eliminates the need for excessive choking during the warm-up period.

47. Intake Pipes (Induction Tube), Radial Engine

In radial engines, individual intake pipes connect the diffuser section to the intake ports of the cylinders and are constructed of a thin light alloy or steel tubing. In figure 50 it will be noted that the intake-pipe cylinder end is a symmetrical curve to provide a minimum of restriction to the flow of the incoming fuel mixture. The lower end of the intake pipe is inserted into the tangential ports of the diffuser section and is made gastight by a rubber ring and a locking nut (fig. 19). This arrangement permits the intake pipe to move with the elongation and contraction of the cylinder. It prevents any distortion of the pipe. The intake pipes also function as vaporization chambers, and any fuel remaining in the liquid state vaporizes either in the pipes or the hot cylinders.

48. Exhaust Manifold

The exhaust manifold (fig. 48) carries waste products of combustion from the cylinders. This must be accomplished with as little back pressure as possible. Exhaust manifolds may be single iron castings or may be cast in sections. They should have smooth interior surfaces and no abrupt changes in size. The shape of the exhaust manifold has an appreciable effect on the scavenging action of the engine, and for best results no more than three cylinders should be connected to one manifold. On a radial engine, the exhaust manifold is in different form although serving the same purpose. The exhaust manifold usually is in two segments (fig. 51) installed on the rear of the engine. Tangential pipes lead from the exhaust ports of each cylinder to two main pipes which provide outlets, one on each side of the engine.

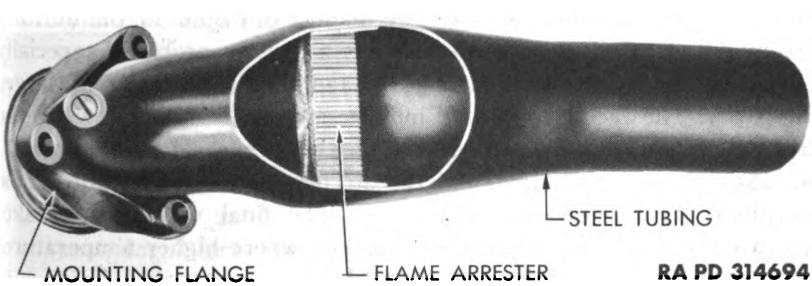

Figure 50. Radial Engine Intake Pipe.

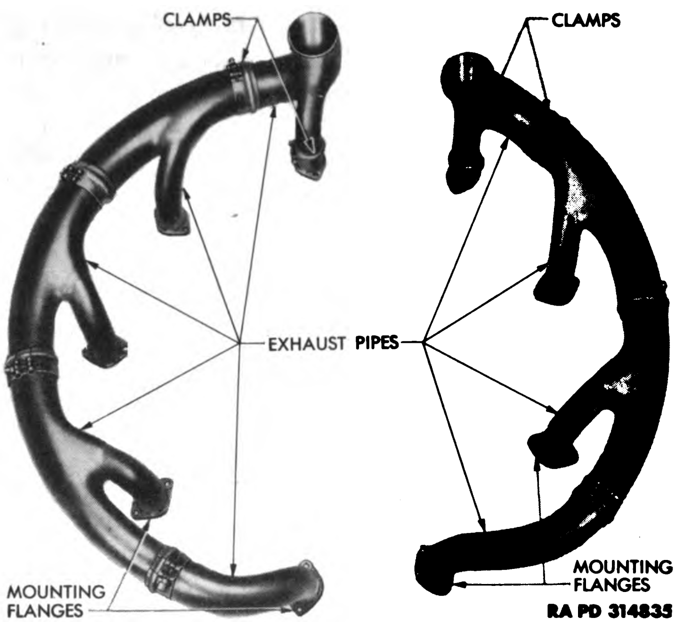

Figure 51. Radial Engine Exhaust Manifolds.

49. Muffler

The purpose of the muffler is to reduce the pressure of exhaust gases and to discharge them to the atmosphere with a minimum of noise. It is used near or at the end of the exhaust pipe (fig. 52). A typical muffler has several concentric chambers with openings between them. The gas enters the inner chamber and expands as it works its way through a series of holes into the other chambers and finally to the atmosphere. Mufflers must be designed to avoid back pressure which would reduce engine power and speed and cause engine overheating. The most common cause of back pressure is deposits of oil and carbon which clog muffler passages.

50. Distribution Impeller

a. On engines equipped with a large number of cylinders, the uniform distribution of the fuel mixture becomes a greater problem, especially at high engine speeds when full advantage should be taken of larger air capacity. The fuel, as atomized into the air stream which flows in the induction system, consists of small globules or droplets. Partial vaporization takes place at this time, and the air temperature falls, due to the absorption of the heat of vaporization. The final vaporization takes place when the mixture enters the cylinders, where higher temperatures prevail. The air entering the carburetor drops in temperature because of the cooling effect of the partial vaporization of the fuel at the carbureto

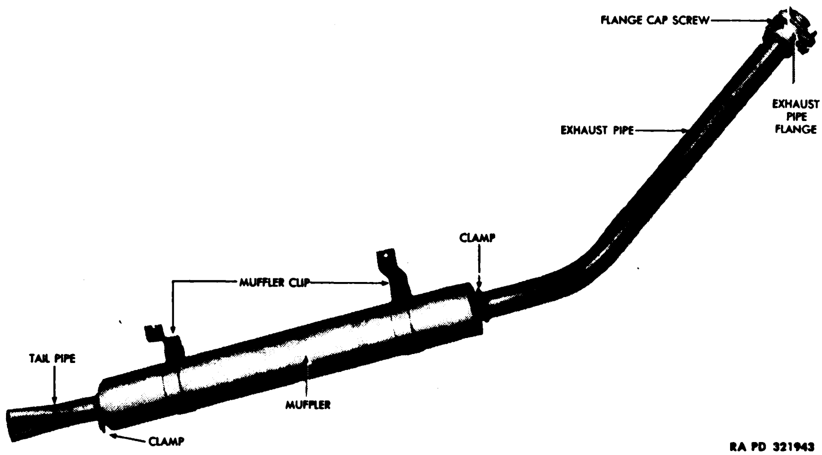

Figure 52. Muffler and Exhaust Pipe.

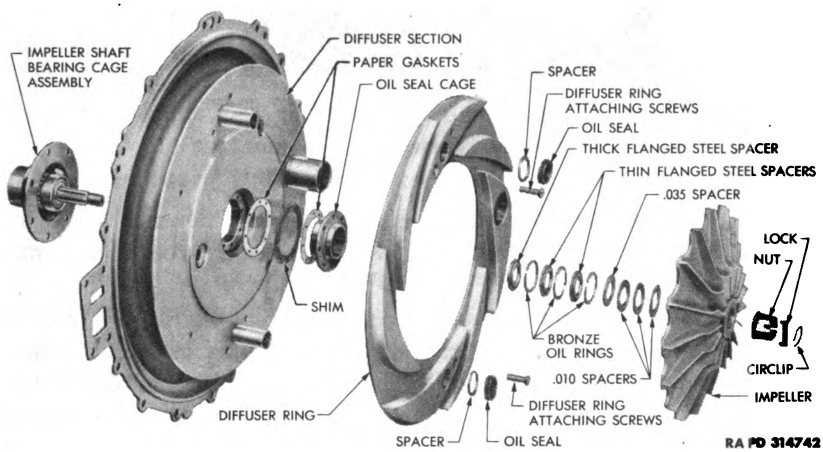

Figure 53. Impeller, Diffuser Ring and Oil Cage.

discharge nozzle. The problem becomes one of uniformly breaking up and distributing the fuel remaining in globular form to the various cylinders, regardless of variation of piping arrangement and cylinder pressures.

b. The impeller unit (fig. 53) is located between the carburetor and the intake pipes and is built as an integral part of the engine. It is turned at high speed (usually 10 to 1, relative to the crankshaft speed) by a gear train driven by the crankshaft gear. The fuel mixture enters the impeller at the center and is thrown outward at high velocity by centrifugal force into the diffuser chamber, a narrow, annular (ring-shaped) passage surrounding the impeller and formed by the space between the accessory section and the diffuser section of the crankcase

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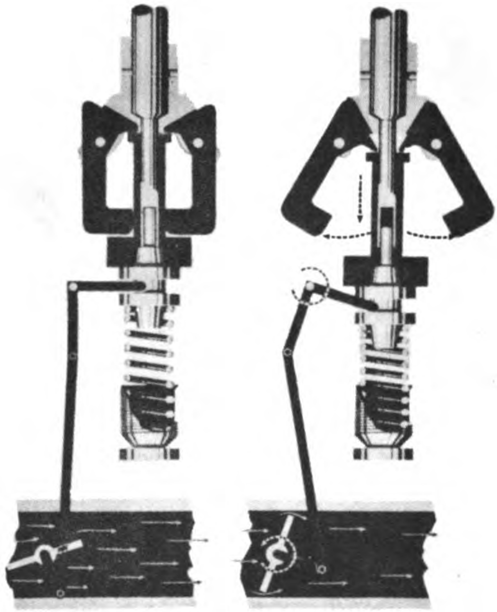

Figure 54. Centrifugal Governor.

assembly. From the diffuser chamber, the mixture flows into the distribution chamber or manifold ring, which extends around the entire diffuser assembly.

c. The impeller is profiled out of a solid duralumin forging, and the vanes are curved in such a manner as to strike the mixture at an angle in order to reduce shock load. It usually is fitted with a steel hub containing splines which fit on the splined impeller shaft. Due to the temperature drop accompanying vaporization, the remaining fuel is in a globular form when it strikes the impeller blades. The centrifugal force of the impeller will break it up considerably, permitting the fuel to come in contact with air more easily; the heat rise due to partial compression of the mixture in the diffuser chamber also aids vaporization. The impeller therefore puts the mixture in a gaseous form and increases its distribution to the cylinders.

d. The distribution impeller is commonly referred to as a supercharger, although the principal purpose of a supercharger is to put enough pressure on the air-fuel mixture so that the engine will be supplied with a greater weight of fuel mixture than would be induced normally at the prevailing pressure. This, of course, increases the volumetric efficiency and power output of the engine. The distribution impeller does put a slight pressure on the air-fuel mixture, but only at high speeds. Its main job is to aid vaporization and to distribute the fuel mixture equally to all cylinders.

51. Governor

Governors are used on automotive vehicles to regulate maximum engine speed to prevent excessive wear. Experiments have proved that the rate of wear increases by the square of the engine speed. In higher speed ranges, a change of a few hundred revolutions results in a greatly disproportionate amount of wear. That is why it is advisable to control maximum speeds. Two common types of governors are centrifugal and velocity, or vacuum, governors.

a. CENTRIFUGAL. In its basic form, a centrifugal governor is made up of two weighted arms pivoted on a spindle which is connected by suitable linkage to a throttle valve. This is shown schematically in figure 54. A flexible drive shaft, driven from the camshaft or an accessory drive of the engine, causes the rotation of the spindle. The throat in which the valve operates is bolted to the carburetor throat so that any action of the weighted arms on the throttle valve will affect the passage of fuel mixture from the carburetor to the cylinders. As the engine operates and the spindle rotates, the weights tend to fly out by centrifugal force but are prevented from doing so by the action of the spring against them. A screw at the end of the spring controls the tension with which the spring holds the weights against the spindle. As the centrifugal force of the spindle rotation overcomes the spring tension, the weights will be forced outward and will actuate the throttle valve through the linkage, closing it.

b. VELOCITY OR VACUUM. The velocity or vacuum type of governor (fig. 55) is operated by the velocity of the air-fuel mixture and by intake-manifold vacuum. On its way to the cylinders, the mixture must pass the throttle valve plate, which is attached to a shaft mounted in an off-center position in the throat. The throttle valve plate is set at a

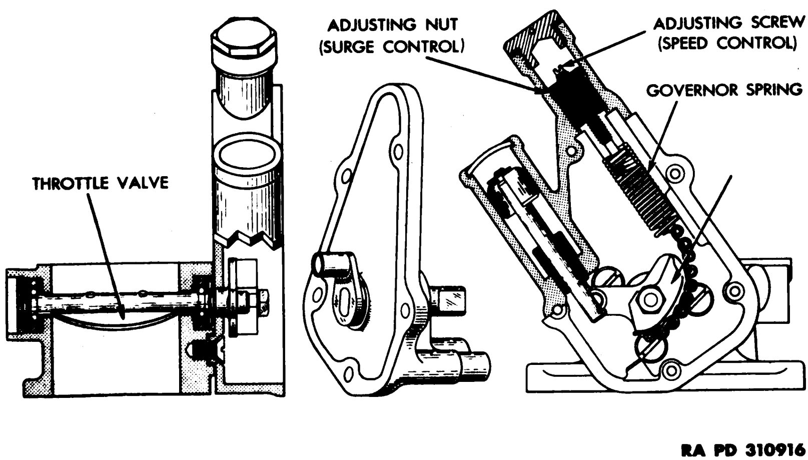

Figure 55. Velocity or Vacuum Governor.

slight angle so that the flowing fuel mixture tends to close it. The plate is held open by spring tension. The vacuum of the intake manifold, working on a piston connected to the throttle, stabilizes the throttle plate against the pressure of the fuel mixture and prevents the plate from fluttering. When the force of the fuel mixture against the plate overcomes the spring tension, the plate will close and reduce the amount of mixture entering the cylinders. It is against Army regulations to adjust a governor without proper authority. Settings are made at the factory and should not be changed without instruction from the manufacturer, and then only by authorized personnel.

Section III. CARBURETOR

52. Operating Principles

a. FUNCTION. The basic function of a carburetor is to meter the air and fuel in varying percentages, according to the engine requirements. The fuel must be mixed with air and atomized so that as complete a burning as possible will occur in the combustion chamber throughout the operating range from a no-load idle through acceleration, normal driving speeds, and full power. As the engine loads vary, the ratio of air to fuel needs to be changed even though there is no speed change.

b. VENTURI EFFECT. (1) Fuel is delivered from the carburetor to the engine because a greater pressure exists in the carburetor bowl than in the engine manifold. The atmospheric pressure in the bowl actually pushes the fuel through the metering jet into the low-pressure air stream in the throat of the carburetor. The low pressure in the throat is produced by a Venturi (hourglass-shaped restriction) which serves to increase the velocity of the air passing thru the throat. The increase in velocity is accompanied by a reduction in pressure, which makes it possible for atmospheric pressure to force the fuel into the air in the throat.

(2) A common example of this operation is the conventional insecticide gun, illustrated in figure 56. The spray-gun bowl contains a liquid and is comparable to a carburetor fuel bowl. The bowl is covered to prevent spilling and is equipped with a vent, as is the carburetor bowl. A small tube open at both ends is inserted below the fuel level and extends well above the liquid. By means of a hand pump, a stream of air is directed across the exposed end of the tube. The velocity of this stream of air over the tip of the tube reduces the pressure at this point. Atmospheric pressure, admitted to the bowl through the vent, pushes the liquid up the tube to the low-pressure point, where it is picked up by the air stream.

(3) Air flows through the throat of the carburetor when the piston of the engine is moving downward on the intake stroke, but the velocity of the air is not great enough to cause the flow of fuel. In order to build

up the speed of air passing the fuel discharge nozzle, the carburetor is equipped with one or more Venturi tubes in the throat. The Venturi is carefully designed so as to offer as little resistance to air flow as possible. If the air is passed through a tube in which a sharp restriction is located, the flow of air will be like that shown in figure 57. The pressure of the air after it passes through the restriction is less than when it entered the tube. This is shown by the difference in the liquid columns of the attached manometers.[1] However, such a restriction would probably result in air turbulence. If the dead space (shown as eddy lines) were filled in with some material, it would then be a Venturi and the flow of air would be much smoother. Figure 58 shows a Venturi with manometers attached to the three critical locations. Note that the column of water is highest on manometer No. 2 (the point of greatest restriction), and that there is a slight depression at manometer No. 3. Manometer No. 3 must show more depression than manometer No. 1 in order to have a flow of air through the tube. Thus it can be seen that the lowest pressure (highest vacuum) is at the point of greatest restriction.

c. Air-fuel Ratio. The most desirable carburetion ratio for internal combustion engines is 15 parts of air to 1 part of fuel by weight. A 15 to 1 ratio is referred to as a "medium" or "normal" mixture. A mixture containing more air (higher than 15 to 1) is called a "lean" mixture, and one containing less air is known as a "rich" mixture. Maximum horsepower is obtained at a ratio of between 12 and 13 to 1; maximum economy, however, is obtained with a 15 to 1 ratio. The carburetor must automatically vary the proportion of air and fuel to meet the ever-changing conditions under which the engine operates.

d. Air Bleed. Air is admitted into the carburetor fuel passages through an air bleed to aid fuel flow when the pressure differential is low and to limit fuel flow when the pressure differential is high. The air bleed may also be used to prevent siphoning which would cause fuel to flow needlessly when the carburetor is not in operation. The action of the air bleed is comparable to the action of water being sucked through a straw when the straw has a hole or crack in it above the level of the water. In figure 59a there is no hole in the straw, and a solid stream of water rises in the straw. In figure 59b the hole in the straw above the water level allows air to enter. This air mixes with the water to form tiny bubbles. If an air tube is placed below the surface of the water, as in figure 59c, the bubbles of air in the water will be smaller and more

[1] A manometer is an instrument used to measure vacuum. A simple manometer consists of a container of water and a glass tube, the upper end of which is connected to a point at which the pressure is to be measured. Reading is obtained by measuring the distance from the top of the column in the tube to the surface of the liquid in the container. The higher the liquid rises in the tube, the greater the vacuum or the lower the pressure.

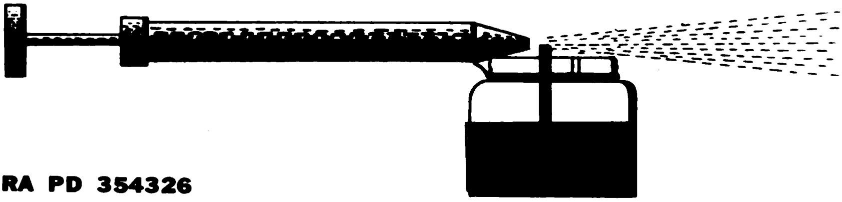

Figure 56. Insecticide Gun.

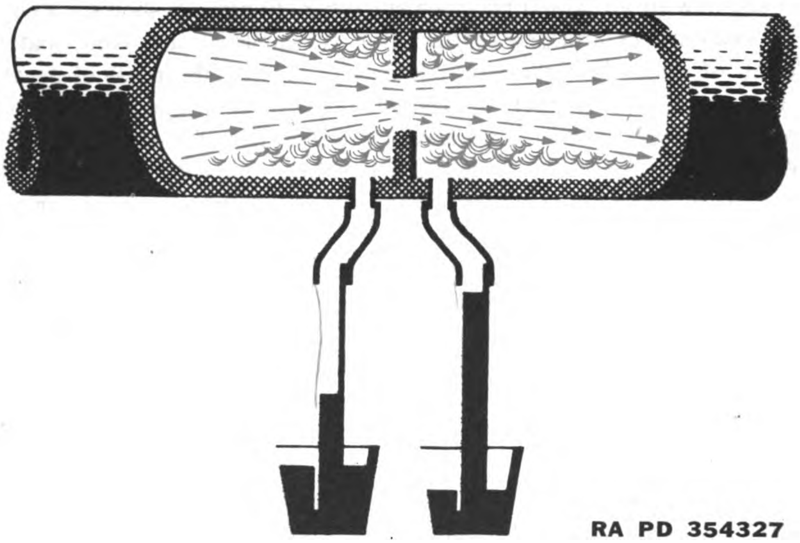

Figure 57. Flow Past Sharp Edged Restriction.

thoroughly mixed than if the hole or tube is above the surface. Applying this principle of air bleed to carburetion, it is possible to compensate for overrichness when the throttle valve is opened, since the air mixing with the gasoline will reduce the quantity of gasoline flowing from the bowl up into the Venturi.

53. Carburetor Circuits

There are five circuits by which gasoline may flow through the ordinary carburetor: the float circuit, low-speed circuit, high-speed circuit, accelerating-pump circuit, and choke circuit. Other circuits in a carburetor will be either variations or combinations of these. Because the high-speed circuit is not capable of handling satisfactorily all the varied conditions that a carburetor must meet, the other four circuits are necessary. The function of the five circuits will be described briefly, and then their operation will be explained in detail.

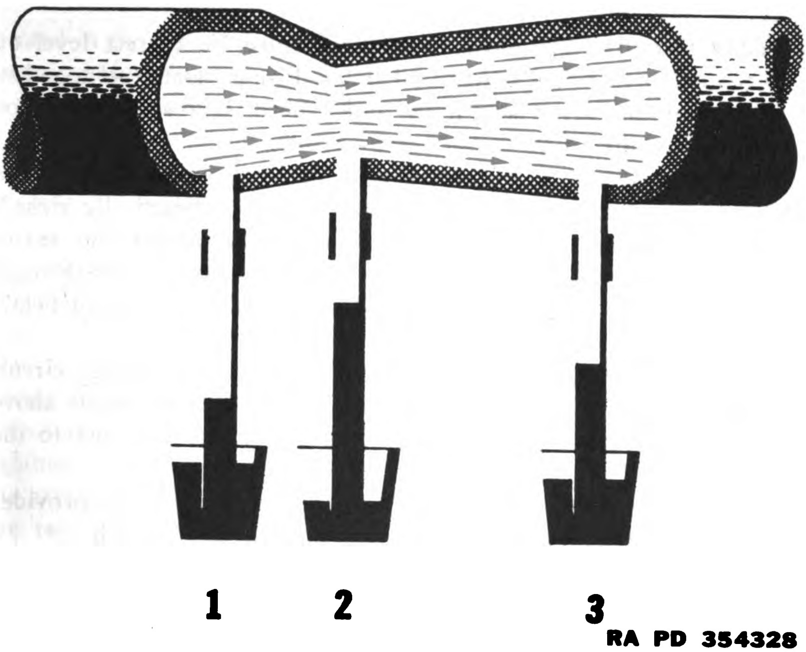

Figure 58. Venturi With Manometers.

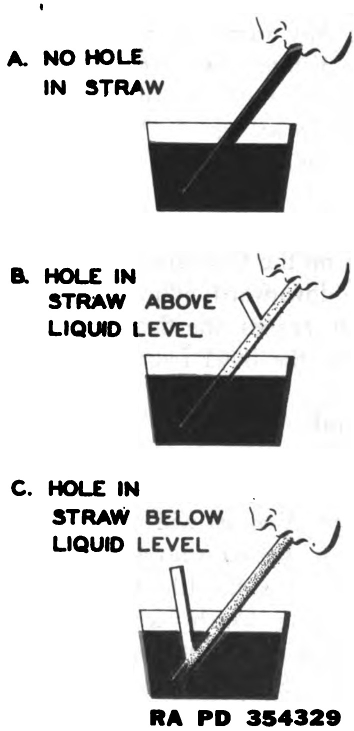

Figure 59. Air Bleed.

a. Float Circuit. The float circuit maintains the correct level of fuel in the carburetor fuel bowl at all times. Proper float level together with proper venting of the bowl to the atmosphere assures availability of the correct amount of fuel to the other circuits.

b. Low-speed Circuit. The low-speed, or idle, circuit delivers the proper mixture of air and fuel when the throttle is practically closed. In some carburetors, it continues to function throughout the entire speed range; in others, it merely overlaps the high-speed circuit through a short range. The circuit delivers fuel from the bowl to a point below the throttle valve.

c. High-speed Circuit. The high-speed, or main metering, circuit meters and delivers the proper air and fuel mixture in the range above the low-speed circuit. This circuit delivers fuel from the bowl to the Venturi.

d. Accelerating-pump Circuit. The pump circuit quickly provides a measured supply of fuel necessary for sudden acceleration.

e. Choke Circuit. The choke circuit provides a method of enriching the fuel mixture when starting and warming up a cold engine.

54. Float Circuit

Any variation in the height of the gasoline in the fuel bowl will have an appreciable effect on the pressure, which must be high enough to lift fuel into the Venturi. Any variation in the level of the gasoline in the bowl will change the distance between the height of gasoline in the high-speed discharge passage and the end of the passage. If the distance is too small, a rich mixture will result. The reverse is true if the distance is too great. It is the function of the float mechanism in the bowl to maintain a constant fuel level at all times. The float mechanism consists of a float, a needle-valve assembly, a float bowl, and a vent (fig. 60). The needle valve rests on the float arm. As the fuel level falls, the float and needle valve move downward, allowing more fuel to enter the bowl; and as the fuel level increases, the float and needle valve rise to close the passage leading into the bowl from the fuel pump.

55. Low-speed Circuit

a. When the throttle valve is almost closed, there will be very little air passing through the Venturi. Therefore, the difference in pressure between the bowl and the Venturi will not be great enough to cause fuel to enter the throat from the main nozzle. For this reason, a low-speed circuit is necessary. As the throttle valve closes, the air must pass through the slight opening which exists between the throat and the valve. This produces the same effect as a Venturi, increasing air velocity and decreasing pressure. Sufficient pressure differential is present between the bowl and outlet point (fig. 61) to push the gasoline from the bowl. The low-speed circuit consists of one or more discharge ports located in the side of the throat body, a low-speed jet to meter the gasoline, a passage leading upward from the float bowl and then downward to the discharge port, and an air bleed at the top of the passage.

b. Gasoline from the bowl is pushed through the calibrated hole in the low-speed jet and flows into the low-speed jet passage. At the top of the passage, air from the carburetor throat is admitted to aid in atomization and to prevent siphoning of fuel from the bowl to the throat when the circuit is not operating. The fuel and air then flow down the passage terminating at the discharge port.

c. Because of variations in the performance of identical engines, it is necessary to vary the amount of gasoline furnished by the low-speed circuit if similar idle characteristics are to be obtained. One method of adjustment is to vary the amount of air bled into the low-speed passage; another method is to vary the amount of air and gasoline admitted to the carburetor throat. The first method is illustrated in figure 62. There are two air-bleed ports: one permanent and one variable. When the needle in the variable port is all the way in, all air must enter through the permanent hole and the maximum amount of gasoline enters the carburetor throat. As the needle is moved out, additional air enters the circuit, making the mixture leaner. The second method of adjustment is shown in figure 63. A mixture of air and gasoline enters the carburetor throat through two ports: the low-speed circuit discharge port and the low-speed adjustment-screw hole. In operation, most of the gasoline and air mixture is discharged through the low-speed port. An additional amount, according to the engine's needs, is discharged through the screw hole. Turning the screw toward its seat decreases the volume of mixture discharged, making the mixture leaner. The reverse is true if the screw is moved away from its seat.

d. The high-speed circuit overlaps the low-speed circuit. This overlap is known as the transfer range. When the throttle valve is almost closed, the pressure below the valve is low and the air velocity in the Venturi is low. Under these conditions, the low-speed circuit operates. As the throttle valve opens, the pressure below the valve increases and the velocity of the air through the Venturi increases, which causes the low-speed circuit to drop off and brings the high-speed circuit into operation.

56. High-speed Circuit

a. The high-speed circuit controls the fuel mixture at part-throttle cruising speed and, together with the power jet, controls the mixture at wide-open throttle.

(1) In this circuit, air is forced through the throat by the difference between the pressure of the atmosphere and the pressure in the cylinder during the intake stroke. As air approaches the Venturi, it increases in velocity, decreases in pressure, and causes fuel to flow from the carburetor bowl into the air stream. In figure 64 the pressure above the

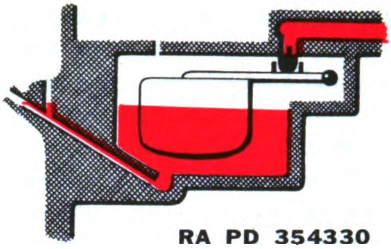

Figure 60. Float Circuit.

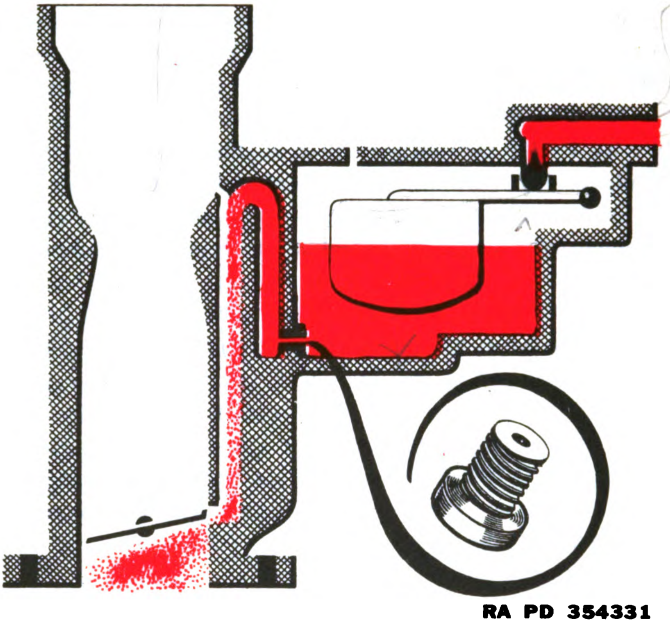

Figure 61. Low-speed Circuit.

Figure 62. Air Adjustment of Low-speed Circuit.

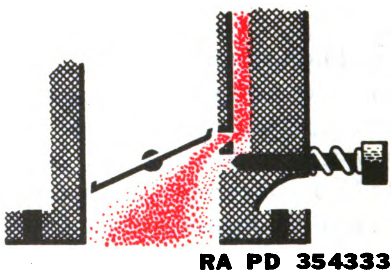

Figure 63. Fuel Adjustment of Low-speed Circuit.

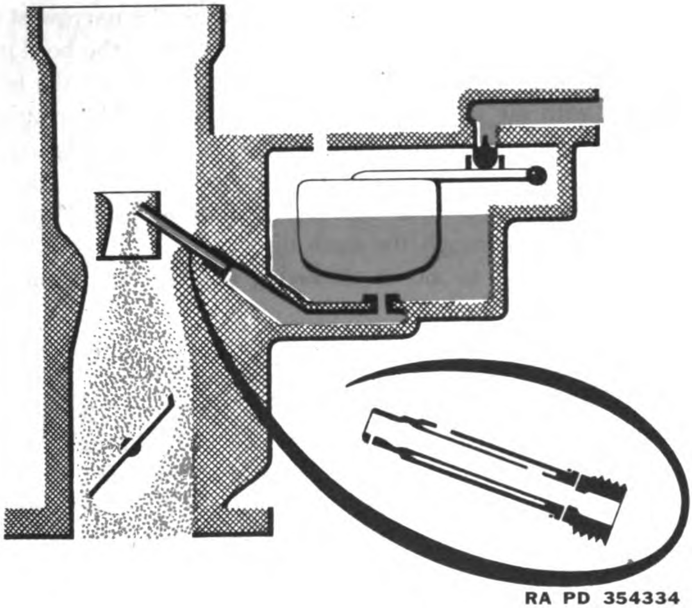

Figure 64. High-speed Circuit.

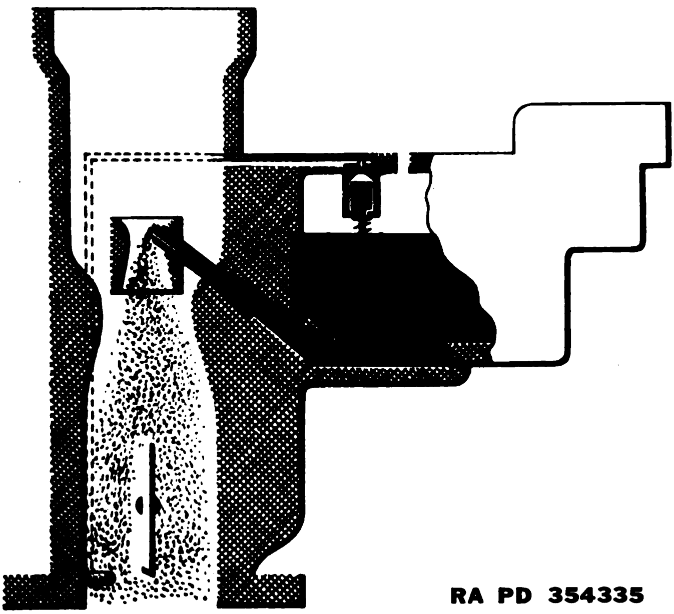

Figure 65. Power Jet.

Venturi is the same as the pressure in the bowl, both pressures being atmospheric. As already explained, the pressure in the narrowest part of the Venturi is less than atmospheric. If the pressure in the bowl is greater than the pressure in the Venturi, fuel will flow out of the bowl and will be mixed with air passing through the Venturi. The restriction at the bowl end of the passage is a machined hole called a high-speed jet. This jet allows a definite amount of fuel to pass up into the air stream for a given pressure differential between the bowl and the Venturi. Fuel enters the air stream through the main discharge nozzle, which has one or more air-bleed holes to aid in atomizing the fuel and maintaining a constant air-fuel ratio.

(2) The amount of air which passes through the Venturi is regulated by the throttle valve, which is located below the Venturi. This valve is connected by linkage to the foot and hand throttles operated by the driver. If the throttle valve is opened, more air goes through the Venturi and more gasoline is added to the air. Because of the difference in physical properties of air and gasoline, the mixture will grow richer as the air velocity increases unless an air bleed of the correct size is utilized.

b. As already indicated, the best air-fuel ratio for the development of power is between 12 and 13 to 1. The high-speed jet and air bleed permit enough fuel to enter the carburetor throat to provide a 15 to 1 ratio. Therefore, it is necessary to incorporate a device which will add more fuel to the mixture when maximum power is required. There are two devices for enriching the air-fuel mixture: the power jet and the metering rod. All carburetors include an application of either one or the other. Both devices are controlled either directly or indirectly by the amount of throttle opening.

(1) *Power jet.* The power jet provides the additional fuel necessary for maximum power at wide-open throttle. In some carburetors, a power-jet valve, controlled by a vacuum-actuated piston assembly, operates in accordance with the throttle opening (fig. 65). With the throttle closed, a high manifold vacuum is present, and the vacuum-controlled piston assembly is moved to the top of its cylinder against the tension of a spring, thus closing the valve. When the throttle is opened to a point where additional fuel is required, the manifold vacuum has decreased sufficiently so that the spring on the piston assembly moves the piston down, thereby opening the power jet to feed additional fuel into the high-speed circuit.

(2) *Metering rod.* Instead of using a power jet, some carburetors accomplish the same result by employing a metering rod which varies the size of the high-speed jet opening (fig. 66). Fuel from the float bowl is metered to this circuit through the calibrated orifice provided by the high-speed jet and the metering rod within it. From this point, the fuel is conducted to the nozzle extending into the Venturi. As the throttle valve is opened, its linkage raises the metering rod in the jet.

The rod has several steps or tapers machined on the lower end, and as it is raised in the jet, it makes the effective size of the fuel orifice greater, thus permitting more fuel to flow through the circuit to meet the load demand imposed upon the engine. At the wide-open throttle position, the smallest step of the metering rod is in the circular opening of the jet, thus permitting the maximum amount of fuel to flow through the circuit to meet the requirements of maximum power. The metering rod position must be synchronized with every throttle valve position so that the proper ratio of air and gasoline is delivered to the engine for all speeds and driving conditions.

57. Accelerating-pump Circuit

The accelerating-pump circuit controls a small amount of fuel that is momentarily discharged into the air stream when the throttle is opened quickly. This extra amount of fuel is necessary to insure instantaneous response from the engine on acceleration. When the throttle is suddenly opened, air rushes through both the carburetor and the intake manifold. The air is lighter than the liquid fuel and gets into motion quicker, so it reaches the manifold before the fuel charge supplied by the high-speed system. This results in a momentarily lean mixture. To counteract this condition, additional fuel must be supplied; this is accomplished by the accelerating-pump circuit.

a. The accelerating-pump circuit consists of a pump cylinder; a plunger mechanically actuated by a lever mounted on the throttle shaft, or vacuum-operated by intake-manifold vacuum; an intake check valve located in the bottom of the pump cylinder to control the passage of fuel from the bowl into the pump cylinder; a discharge check valve; and an accelerating jet to meter the amount of fuel used. A typical arrangement with a mechanically-actuated plunger is shown in figure 67.

b. When the throttle is opened, the pump plunger moves downward in its cylinder. If the plunger is mechanically operated, the downward movement will be brought about by direct linkage with the throttle. If it is vacuum-actuated, a sudden throttle opening will cause the manifold vacuum to drop, allowing the accelerating pump spring to force the pump plunger down in the cylinder. In either case, the subsequent action of the accelerating-pump circuit is the same. The downward travel of the plunger forces fuel past the pump discharge check valve to the accelerating jet which meters the rate at which it is discharged into the air stream. Fuel is supplied to the pump cylinder through the intake check valve at the bottom. The level of fuel in the pump cylinder when the plunger is held up to the top of its stroke is approximately equal to the level in the fuel bowl. The intake check valve in the bottom of the cylinder permits a supply of fuel to reach the cylinder but closes on the down stroke of the plunger, preventing the fuel in the cylinder from being pushed back into the bowl. The accelerating-pump discharge is

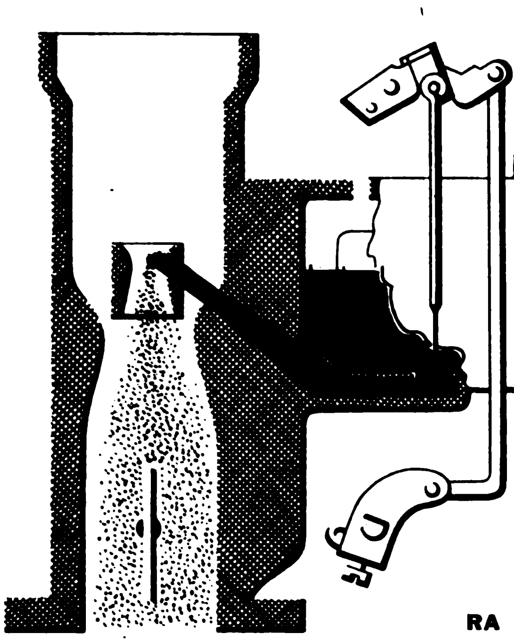

Figure 66. Metering Rod.

only needed momentarily when the throttle is opened suddenly. To prevent the accelerating jet from flowing at constant throttle openings, some models have an air-vent check valve (fig. 68) placed between the accelerating jet and pump cylinder above the fuel level. At steady part-throttle positions, when the pump plunger is inoperative, no pressure exists on the fuel in the pump cylinder. Under this condition, the air-vent check valve will be open; the air will enter the passage connecting the pump cylinder and accelerating jet and will prevent fuel from flowing through the jet. The pressure on the fuel, created by the down stroke of the pump plunger, causes the air-vent check valve to close against its seat to prevent the fuel from being discharged back into the bowl through the air-vent passage. On some carburetors the area above the plunger is connected to the intake manifold so that the accelerating pump does not work while the engine is not running. Under these conditions the pressure in the intake manifold is near atmospheric and holds the pump plunger down.

c. Successful operation of the accelerating pump depends on a delayed action which provides a continual stream of fuel from the pump jet after the throttle has ceased moving. This is to take care of the fuel demands of the engine in the interval that exists between the time the throttle is opened and the time the high-speed nozzle begins to discharge fuel.

(1) Some carburetors achieve this action by the "dry pump" method (fig. 67). A pocket of air is maintained in the plunger cup between the plunger leather and the fuel. When the plunger is pushed down, it compresses this air. The compressed air, in turn, forces the fuel from

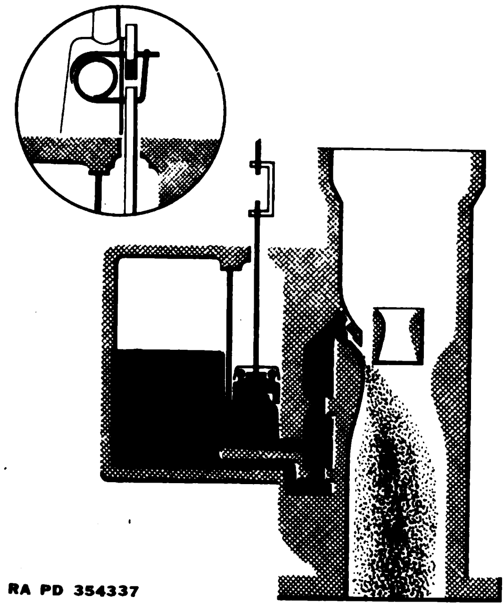

Figure 67. Accelerating-pump Circuit With Air Pocket and Link-spring Connection.

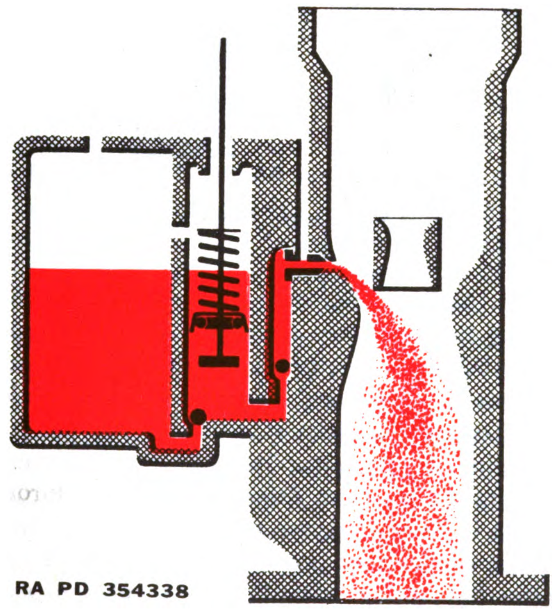

Figure 68. Accelerating Pump Circuit With Air Vent Check Valve and Wet Pocket.

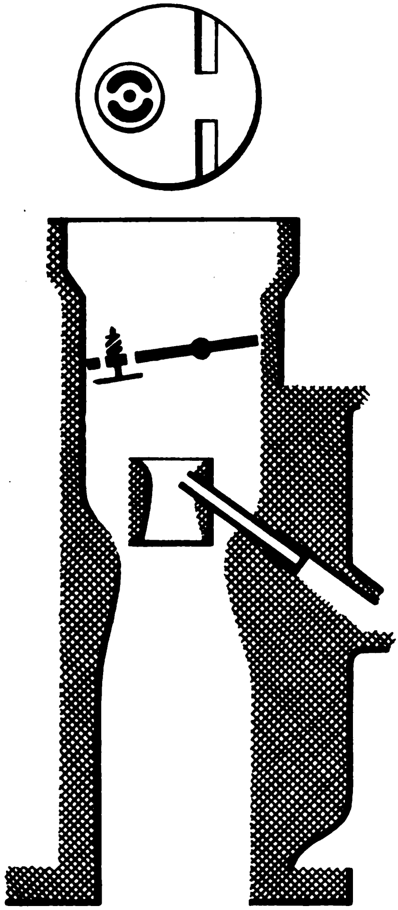

Figure 69. Spring-loaded Poppet Choke Valve.

the pump cylinder. At the end of the plunger stroke, the compressed air expands, providing the necessary force to continue the fuel discharge. If some of the air below the plunger is absorbed by the gasoline, a small amount of air escapes downward past the plunger, replenishing the supply of air necessary for delayed action in the pump cylinder. A carburetor employing a "dry pump" does not require an air vent to prevent the accelerating jet from flowing at constant throttle openings. The air remaining in the cylinder is under pressure below atmospheric and does not exert enough force to cause fuel to flow. Some models use a pump connector link spring instead of the regulation pump connector link (fig. 67). The spring has a double purpose, one of which is to assist in the delayed action of the pump discharge. When the throttle is opened suddenly, the plunger is driven down in the cylinder but the spring is also slightly compressed. As the spring expands to its normal position,

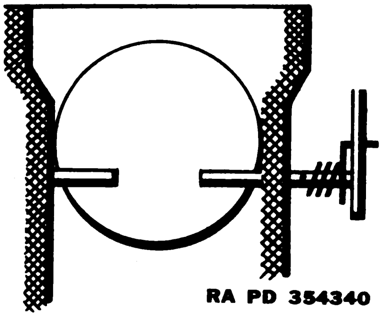

Figure 70. Off-center Choke Valve.

it aids in pushing the plunger against the air pocket and thus assists in the delayed delivery of fuel through the pump jet. The spring also will absorb any strain on the linkage if the pump jet becomes obstructed.

(2) Another type of accelerating pump is called a "wet pump" and functions without any cushion of air underneath the pump plunger (fig. 68). For its delayed action, this type of pump circuit depends upon the pump spring. Its expansion continues the discharge of fuel for a brief period after the sudden opening of the throttle. This operation is effected by a different linkage arrangement. As the throttle is closed, the pump operating link raises the plunger in the pump cylinder, compressing the pump spring. When the throttle is opened the linkage permits the spring to drive the plunger downward.

58. Choke Circuit

a. When the engine is cold the gasoline vapors tend to condense into large drops on their way to the cylinders. Because all the gasoline supplied to the cylinders will not vaporize, it becomes necessary to supply an extra amount in order to have enough vapor to assure combustion. This is accomplished by the choke circuit, which is simply a butterfly valve placed in the carburetor throat above the Venturi.

b. When a driver operates the choke, the valve reduces the amount of air entering the throat, giving a very rich mixture. Only the volatile parts of the gasoline will vaporize at cold temperatures. For this reason, a rich mixture is necessary. It provides enough ignitable vapor to start the engine. However, if the butterfly valve is in the full-choke position, it is completely closed, shutting off the supply of air. Consequently, there is not enough air entering the throat to ignite the gasoline. The necessary air is admitted in manual chokes by either one of two semiautomatic features.

(1) In one design (fig. 69), the butterfly choke valve incorporates a spring-loaded poppet valve. The poppet is held in the closed position by a weak spring. As soon as the engine turns over, there is sufficient pressure differential to open the valve, allowing air to flow.

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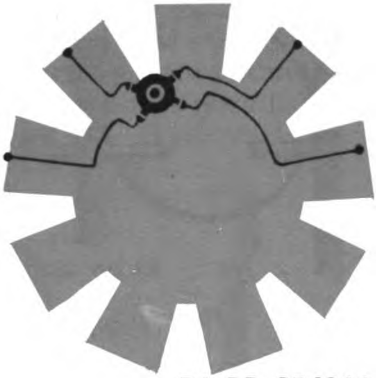
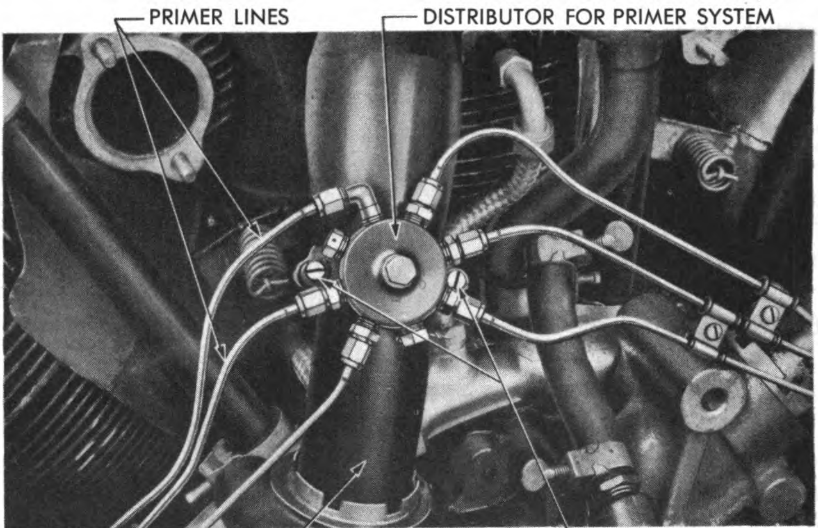


RA PD 354341

Figure 71a. Radial Engine Primer Lines.



RA PD 314658

Figure 71b. Radial Engine Primer Lines and Distributor.

(2) In the other design, the butterfly valve is off-center and operates through a coiled spring on the end of the choke shaft (fig. 70). In the full-choke position, the spring holds the valve in the closed position. As soon as the engine turns over, an increased pressure differential overcomes the spring tension and opens the valve part way, admitting air to avoid overchoking or flooding the engine. As the engine warms up, the choke valve is gradually advanced to the wide-open position by the operator to supply the leaner mixture required for a hot engine.

59. Primer System

The primer system consists of a hand pump, a pressure line leading to a small distribution chamber, and lines leading to the intake pipes of four upper cylinders (all upper cylinders except No. 1) if the unit is on a nine-cylinder radial engine (fig. 71). Fuel is obtained from a small line leading from the main tanks. When the pump plunger is pulled out by a handle located on the instrument board, fuel is forced through the inlet valve and into the pump barrel (fig. 72). The inward stroke of the plunger stem forces the fuel past the outlet and diaphragm valves, through the pressure line, distribution chamber, and distributor lines, and sprays it into the intake pipes of the upper cylinders. The diaphragm valve is so constructed that comparatively small pressure by the pump will open the valve, allowing fuel to pass for priming. However, if the engine backfires, the extreme pressure required to open the valve from the outlet side prevents the pressure from backing up into the pump, protects the springs of the ball valves, and prevents the balls from being driven down into their seats. The diaphragm valve also prevents fuel from siphoning from the tanks into the engine.

60. Automatic Choke

a. The automatic choke replaces the conventional manual choke. It not only controls the air-fuel ratio for quick starting at any temperature but also provides for the proper amount of choking to enrich the fuel mixture for all conditions of engine operation during the warm-up period. The automatic choke is an integral part of the carburetor. It consists of a thermostatic (bimetal) spring and a vacuum piston which opposes the action of the spring. The spring is connected to the choke butterfly valve in such a manner as to close the valve when the spring

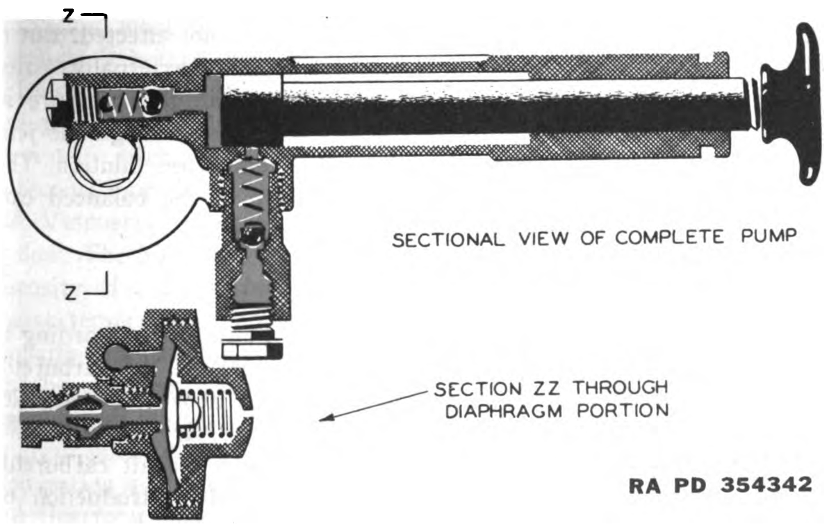


Figure 72. Primer Pump.

is cold. The vacuum piston tends to open the choke valve when the engine manifold vacuum is high. The choke butterfly valve is mounted off-center on the choke shaft so that any increase in air velocity through the air horn will tend to open the valve.

b. Thus it can be seen that the operation of the automatic choke is dependent on three factors: heat, intake-manifold vacuum, and the velocity of air passing through the air horn. When the engine is cold, the thermostatic spring holds the choke valve closed. When the engine is started, the low pressure (high vacuum) below the throttle valve permits atmospheric pressure to move the piston down and partially open the valve against the tension of the thermostatic spring. Therefore, under varying load conditions during warm-up, the position of the choke valve will be changed by the operation of the vacuum piston working against the thermostatic spring, and the air velocity in the air horn. Hot air from the exhaust manifold is directed to the thermostatic spring so that the spring loses its tension as the engine is heated. This permits the choke to open gradually, and after it reaches full-open position it is held open by the action of the intake manifold on the piston. When the engine is stopped, the thermostatic spring cools and closes the choke valve. The choke valve is fully closed at a temperature of aproximately 70° F.

61. Carburetor Vents

Carburetors may be internally and/or externally vented. In the internally-vented carburetor, air for venting the bowl and air for the Venturi all come through the same intake. As has been explained, the difference in pressure between the Venturi throat and the bowl forces fuel to flow through the jets. Dirt in the air cleaner will restrict the flow of air, which results in a lower pressure in the Venturi. If the bowl is internally vented, pressure in the bowl is also lower. There is no pressure difference, and the flow of fuel through the jets is not affected. But if the bowl is opened directly to the atmosphere, as is the externally-vented carburetor, bowl pressure would remain high when the pressure in the Venturi throat drops. More fuel would be forced through the jets, causing a rich mixture which would result in crankcase dilution. The internally-vented carburetor often is referred to as the balanced carburetor, whereas the externally-vented is unbalanced.

62. Updraft and Downdraft

Carburetors also are classified as updraft or downdraft, according to their position with respect to the intake manifold. If the carburetor is below the manifold, it is an updraft; if placed above the manifold, it is a downdraft. In early fuel systems it was necessary that fuel flow down by gravity to the float chamber, making the updraft carburetor essential because of its low position. However, the introduction of mechanical fuel pumps has eliminated this problem.

CHAPTER 6

DIESEL FUEL SYSTEMS

Section I. CHARACTERISTICS OF DIESEL COMBUSTION

63. Diesel Fuels

The fuels used in modern high-speed Diesel engines are a product of the petroleum refining process. They are heavier than gasoline because they are obtained from the left-overs, or residue, of the crude oil after the more volatile fuels, such as gasoline and kerosene, have been removed. The large, slow-running Diesel engines will burn almost any grade of heavy fuel oil, but the Diesel engines used in automotive installations require a fuel oil as light as kerosene. Diesel fuel is different from gasoline, but its specification requirements are just as exacting as those of gasoline. Of the various properties to be considered in selecting a fuel for Diesel engines, the most important are cleanliness, viscosity, and ignition quality.

a. CLEANLINESSS. Probably the most necessary property of a Diesel fuel is cleanliness. The fuel should not contain more than a trace of foreign substance; otherwise, fuel-pump and injector difficulties will occur. Diesel fuel, because it is heavier and more viscous than gasoline, will hold dirt in suspension for longer periods of time. Therefore, every precaution must be taken to keep dirt out of the fuel system or to eliminate it before it reaches the pumps. Water is more objectionable in Diesel fuels than it is in gasoline because it will cause ragged operation and corrode the fuel system. The least amount of corrosion of the accurately machined surfaces in the injection equipment will cause it to become inoperative.

b. VISCOSITY. The viscosity of an oil is an indication of its resistance to flow. The higher the viscosity, the greater the resistance to flow. The viscosity of a Diesel fuel must be sufficiently low to flow freely at the lowest temperatures encountered, but it must also be high enough to properly lubricate the closely fitted pump and injector plungers. It must also be sufficiently viscous so that leakage at the pump plungers and dribbling at the injectors will not occur. The viscosity of a fuel also determines the size of the fuel-spray droplets which, in turn, govern the atomization and penetration qualities of the spray.

c. IGNITION QUALITY. The ignition quality of a Diesel fuel is its ability

Figure 73. Diesel Engine Open Combustion Chamber.

to ignite spontaneously under the conditions existing in the engine cylinder. The spontaneous-ignition point of a fuel is a function of temperature, pressure, and time. Since it would be difficult to reproduce artificially these factors that exist in an engine cylinder, the best apparatus for measuring the ignition quality of a fuel is an actual Diesel cylinder running under controlled operating conditions. The yardstick used for measuring the ignition quality of Diesel fuels is the cetane-number scale. The cetane number of a fuel is obtained by comparing the operation of the unknown fuel in a special test engine with the operation of a known reference fuel in the same engine. The reference fuel is a mixture of alpha-methyl-napthalene, which will hardly ignite when used alone, and cetane, which will readily ignite at temperatures and pressures obtained in a Diesel cylinder. The cetane number indicates the percent of cetane in a reference fuel which will just match the ignition properties of the fuel being tested.

d. Knocking. It has been observed that Diesel engines "knock," particularly at light loads. This knock is believed to be due to the rapid burning of the charge of fuel accumulated during the delay period between the time of injection and ignition. When the fuel is injected it must first vaporize, then superheat until it finally reaches the spontaneous-ignition temperature under the proper conditions to start combustion. Time is required for sufficient fuel molecules to go through this

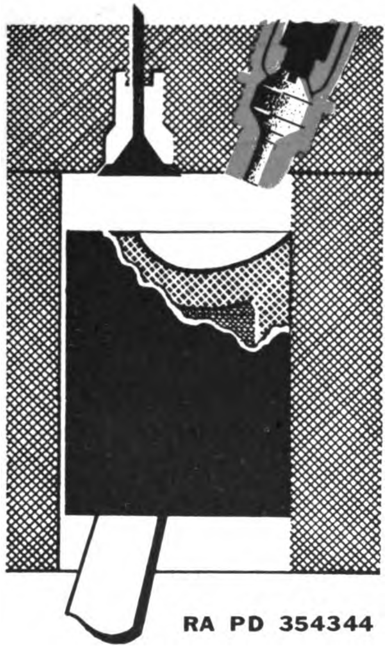


Figure 74. Diesel Engine Precombustion Chamber.

cycle to permit ignition. This time is called ignition lag or ignition delay. During this same time, other portions of the fuel are being injected and are going through the same phases but behind the igniting portion; therefore, as the flame spreads from the point of ignition, appreciable portions of the charge reach their spontaneous-ignition temperatures at practically the same instant. This rapid burning causes a very rapid increase in pressure, which is accompanied by a distinct and audible knock. Increasing the compression ratio in the Diesel engine will decrease the ignition lag and thereby decrease the tendency to knock. Increasing the compression ratio in a gasoline engine leads to preignition and, in addition, tends to make detonation worse. Knocking in the Diesel engine is affected by a large number of factors besides compression ratio, however. The type of combustion chamber, air flow within the chamber, the type of nozzle, the injection-pressure conditions, the fuel temperature, and the air temperature are all factors as well as the characteristics of the fuel itself. For these reasons more can be done in the design of a Diesel engine to make it operate smoothly without detonation than is possible with the gasoline engine.

64. Combustion Chamber Design

The fuel injected into the combustion space of a Diesel engine must be thoroughly mixed with the compressed air and distributed as evenly as possible throughout the chamber if the engine is to function under the principles discussed in paragraph 9. None of the liquid fuel should strike the chamber walls. Therefore, it is essential that the shape of the combustion chamber and the characteristics of the injected fuel spray be closely related. There are many types of combustion chambers in use today, but they are all designed to produce one effect—bring sufficient air into contact with the injected fuel to provide complete combustion at a constant rate. All modern combustion-chamber designs may be classified under one of the following headings: open, precombustion, turbulence, or divided chambers. Designs which fall under two or more headings will be covered under the heading which is the most applicable.

a. Open Chamber. The open chamber is the simplest form of chamber, but its use is limited to slow-speed engines and a few high-speed two-stroke cycle engines (fig. 73). The fuel is injected directly into the combustion space at the top of the cylinder. The combustion space, formed by the top of the piston and the cylinder head, is shaped to provide a swirling action of the air as the piston comes up on the compression stroke. There are no special cells, pockets, or passages to aid the mixing of fuel and air. This type of chamber requires higher injection pressures and a greater degree of fuel atomization than the other types require to obtain the same degree of mixing.

b. Precombustion Chamber. The precombustion chamber is an auxiliary chamber at the top of the cylinder (fig. 74). It is connected to the clearance volume above the piston through a restricted throat or passage. The precombustion chamber conditions the fuel for final combustion in the cylinder and distributes the fuel throughout the air in the cylinder in such a way that complete, clean burning of all the fuel is assured. On the compression stroke of the engine, air is forced into the precombustion chamber, and since the air is compressed it becomes hot. Thus at the beginning of injection this small chamber contains a definite volume of air. Consequently, combustion of the fuel actually starts in the precombustion chamber, since the fuel is injected into the chamber. Only a small part of the fuel is burned in this chamber because there is only a limited amount of oxygen present with which it can unite. The small predetermined amount which burns creates heat which, in turn, creates high pressure within the precombustion chamber; as injection continues, this high pressure forces the fuel at great velocity into the cylinder. There is ample oxygen present in the cylinder to burn all the fuel completely, regardless of the speed or load under which the engine is operating. Fuel injection pressures need not be as high with this type of chamber as in the open type. A coarser spray is satisfactory because the function of the chamber is to vaporize the fuel further before it enters the cylinder.

c. Turbulence Chamber. The turbulence chamber is similar in

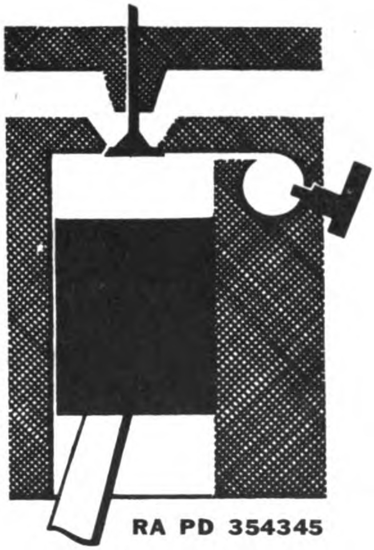


Figure 75. Diesel Engine Turbulence Chamber.

appearance to the precombustion chamber, but its function is different (fig. 75). There is very little clearance between the top of the piston and the head, so that a high percentage of the air between the piston and the cylinder head is forced into the turbulence chamber during the compression stroke. The chamber is usually spherical, and the opening through which the air must pass becomes smaller as the piston reaches the top of the stroke, thereby increasing the velocity of the air in the chamber. This turbulence speed is approximately 50 times crankshaft speed. The fuel injection is timed to occur when the turbulence in the chamber is the greatest. This insures a thorough mixing of the fuel and the air, with the result that the greater part of combustion takes place in the turbulence chamber itself. The pressure created by the expansion of the burning gases is the force that drives the piston downward on the power stroke.

d. Divided Chamber. (1) The divided chamber, or combination precombustion chamber and turbulence chamber, is probably better known by the trade name "Lanova Combustion Chamber." In the Lanova system, which is the most recently prefected of all Diesel combustion systems, the highest degree of success so far attained has been achieved. Like the open-chamber combustion system, the main volume of air remains and the principal combustion takes place in the main combustion chamber; but unlike the open-chamber combustion system, the combustion is controlled. Like the turbulence-chamber type, the Lanova system depends on a high degree of turbulence to promote thorough mixing and distribution of the fuel and air; but unlike it, this entails no increase in pumping losses. Ninety percent of the combustion chamber

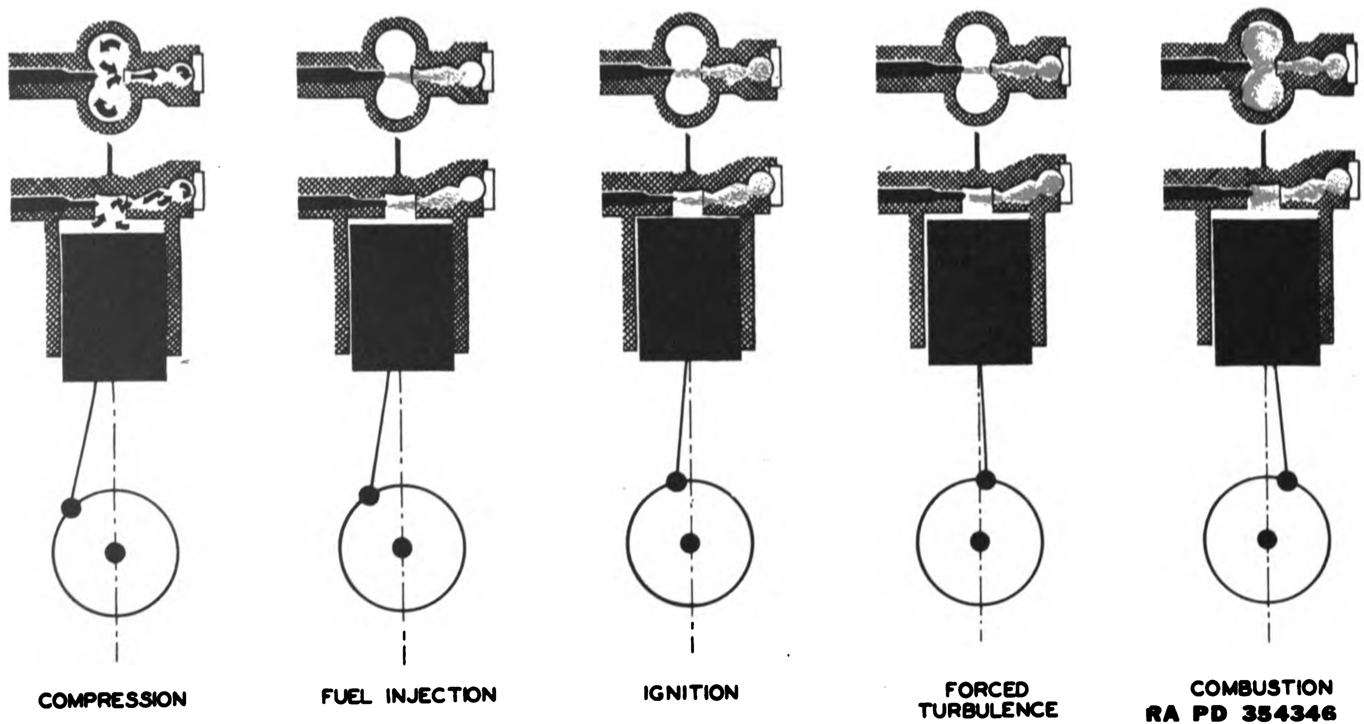
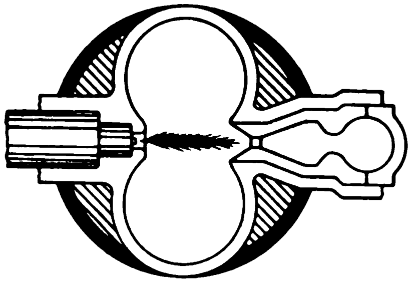
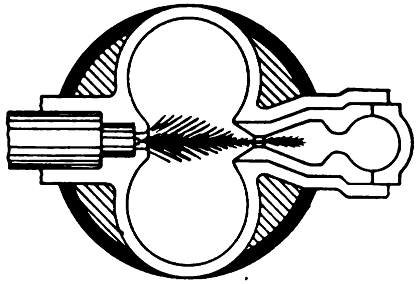


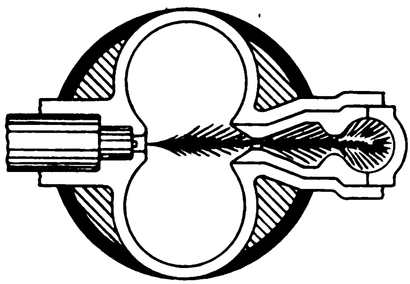
Figure 76a. "Lanova" Divided Chamber.



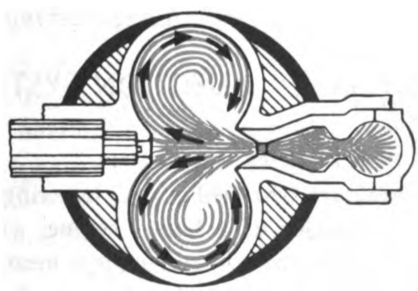
FUEL INJECTION



FUEL IGNITION



COMBUSTION IN ENERGY CELL



COMBUSTION IN MAIN CHAMBER

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Figure 76b. "Lanova" Divided Chamber.

is directly in the path of the in-and-out movement of the valves. The turbulence in the Lanova system is dependent upon thermal expansion and not on engine speed as are the other systems.

(2) Primarily, the Lanova system (fig. 76) involves the combination of the figure-8-shaped combustion chamber situated centrally over the piston, and a small air chamber known as the energy cell. In its latest development, this energy cell is comprised of two separate chambers, an inner and an outer. The inner chamber, which is the smaller of the two, opens into the narrow throat between the two lobes of the main combustion chamber through a funnel-shaped Venturi passage. The larger outer chamber communicates with the inner one through a second Venturi. Directly opposite the energy cell is the injection nozzle.

(3) During the compression stroke, about 10 percent of the total compressed volume passes into the energy cell, the remainder staying in the figure-8-shaped combustion chamber. The fuel is injected in the form of a pencil stream which passes directly across the narrow throat of the combustion chamber, most of it penetrating into the energy cell. A small portion of the boundary layer follows the curvature of the combustion-chamber lobes and swirls in two vortexes within them, thus initiating a weak combustion. The fuel entering the energy cell is trapped for the most part in the small inner cell, but a small part passes into the larger outer cell, where it meets a sufficient quantity of superheated air to explode violently. This explosion produces an extremely rapid rise to high pressure within the steel energy cell, which blows the main body of the fuel lying in the inner cell back into the main combustion chamber, where it meets the main body of air. Here, owing to the shape of the chamber, it swirls around at an exceedingly high rate of turbulence, thus burning continuously as it issues from the energy cell. Owing to the restriction of the two Venturis connecting the energy cells, the blowback of fuel into the combustion chamber is controlled so that this operation consumes an appreciable period of time, thus producing a prolonged and smooth combustion in which the rate of pressure rise on the piston is gradual.

Section II. INJECTION SYSTEMS

65. Fuel Injection Principles

a. METHODS. There are two methods of injecting the fuel against the air pressure in the cylinder of a Diesel engine: air injection, where a blast of air from an external source forces a measured amount of fuel into the cylinder; and solid injection, where the fuel is forced into the cylinder by a direct pressure on the fuel itself. The discussion which follows will be limited to those systems utilizing solid injection, because the air injection system has been proved impractical for automotive installations.

b. Fuel Atomization and Penetration. It was seen in paragraph 64 that the fuel spray entering the combustion chamber must conform to the shape of the chamber so that the fuel particles will be well distributed and thoroughly mixed with the air. The shape of the spray is determined by the degree of atomization and penetration produced by the orifice through which the fuel enters the chamber. Atomization is the term used to denote the size of the drops into which the fuel is broken, whereas penetration is the distance from the orifice which an oil drop attains at a given phase in the injection period. Roughly speaking, the penetration of a spray depends on the length of the nozzle orifice, the diameter of the orifice outlet, the viscosity of the fuel, and the pressure on the fuel. Penetration increases with the increasing ratio of the length of the orifice to its diameter; atomization, however, is increased by decreasing the ratio of the length of an orifice to its diameter. Since penetration and atomization are mutually opposed to each other, a compromise is necessary if uniform fuel distribution is to be obtained. The amount of pressure required for efficient injection is dependent on the pressure of the air in the combustion chamber, the size of the orifice, the shape of the combustion chamber, and the amount of turbulence produced in the combustion space.

c. Function of Injection System. It is impossible to cover the operation and construction of the many types of modern injection systems in this text. However, the operation of a few of the more common systems will be discussed in the succeeding paragraphs. Emphasis will be placed on functional operation rather than mechanical details. The function of each system is to meter the fuel accurately, deliver equal amounts of fuel to all cylinders at a pressure high enough to insure atomization, and control the start, rate, and duration of injection. If this three-fold function is kept in mind, the operation of the various systems will be more easily understood.

66. Multiple-unit Injection-pump System

a. General Operation. In this system each cylinder has an individual injection pump which meters the fuel and delivers it under high pressure to the spray nozzles which lead into the combustion chambers. The pumps are mounted in a common housing, are operated by a common camshaft, and utilize the same control mechanism to insure an equal amount of fuel in each cylinder at the proper time. The flow of fuel in a typical multiple-unit injection-pump system is shown in figure 77. Diesel fuel oil flows from the supply tank through a fuel filter to the fuel supply pump. The fuel supply pump forces the fuel through an additional filter to the injection pumps. The fuel injection pumps force

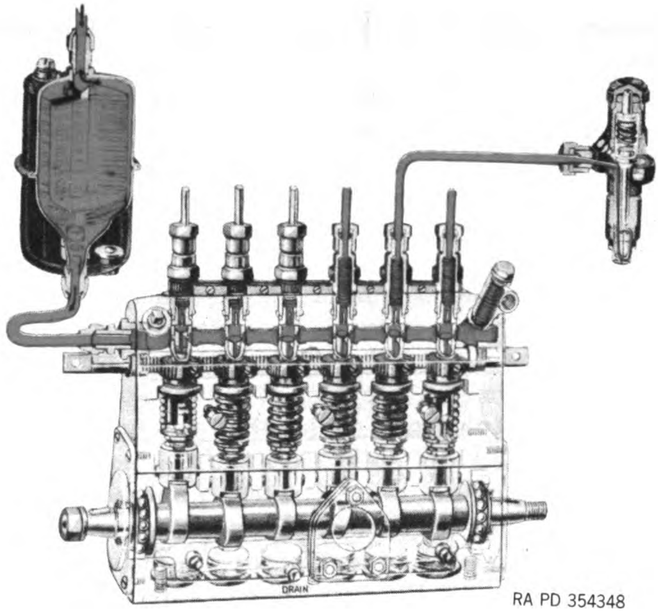

Figure 77a. Fuel Flow in Multiple-unit Diesel Engine Fuel Injection Pump.

a measured amount of fuel through high-pressure lines to the spray nozzles in the combustion chambers. Surplus fuel flows from the injection pumps through a check valve on the common housing and is returned to the fuel supply tank.

b. FUEL INJECTION PUMPS. (1) A phantom cross-section view of a typical multiple-unit injection pump is shown in figure 77. The unit is mounted on the engine in such a manner to permit its being driven by the engine. The pump camshaft, near the bottom of the housing, is carried on ball bearings. The cam lobes cause the upward movement of the plungers, and springs produce the downward motion. The cams are arranged to actuate the individual pumps in the same sequence as the firing order of the engine to eliminate the necessity for crossing lines leading from the pumps to the spray nozzles. On the four-stroke cycle engine, the injection pump is driven at one-half engine speed; on the two-stroke cycle engine it is driven at engine speed.

(2) The individual pumps are of the lapped-plunger constant-stroke metering bypass type. The quantity of fuel delivered to the spray nozzle is regulated by the time the plunger covers the bypass port. The plunger stroke remains constant at all loads. The injection must be timed to occur as demanded by the requirements of the engine. Volumetric control is effected by rotating the plunger. In figure 78 it is seen that two ports lead to the plunger barrel; the port on the left is the inlet port, and the one on the right is the bypass port. The plunger has a groove around its circumference, which has a circular lower edge and helical upper

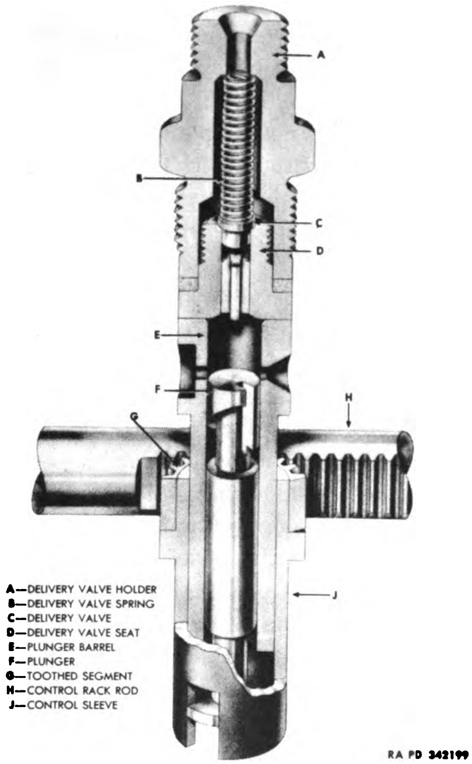

Figure 77b. Fuel Injection Pump Element and Control Rack.

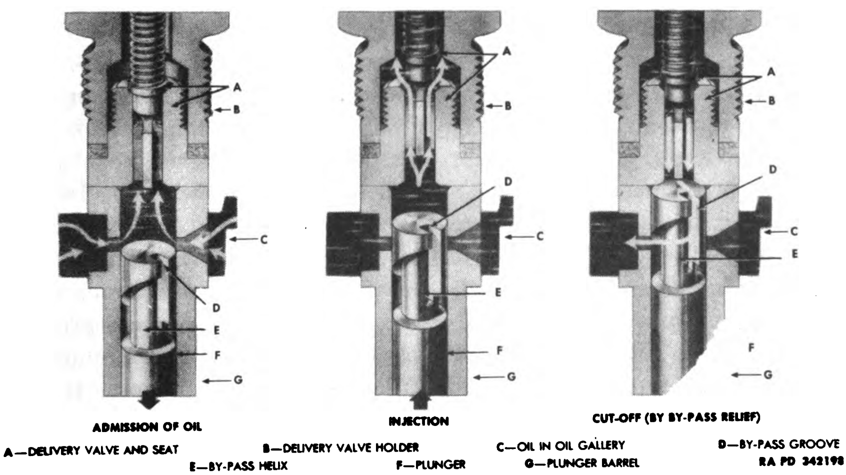

Figure 78. Fuel Injection Pump Plunger With Inlet and Bypass Ports.

edge. The space thus formed communicates with the top face of the plunger through a vertical slot. Hence any fuel above the plunger will flow down the vertical slot and fill the helical space. At the lower end of the plunger are two lugs which fit in corresponding slots in the bottom of an outer sleeve fitted around the pump barrel. The upper portion of the sleeve is fastened to a gear segment which meshes with a horizontal toothed rack. Any movement of the rack rotates the outer sleeve and plunger relative to the bypass port in the stationary pump barrel.

(3) Fuel from the sump rushes into the barrel as soon as the upper edge of the plunger opens the two opposite ports in the barrel. This action begins during the downward stroke of the plunger, and the ports remain open until the plunger starts moving upward. After the plunger covers the ports on its upward stroke, the pressure exerted on the fuel causes the spring-loaded delivery valve to lift off its seat, thereby permitting the fuel to discharge into the tubing which leads to the spray nozzle. The delivery of fuel ceases as soon as the helix on the plunger uncovers the bypass port in the barrel. At this instant the pressure chamber communicates with the sump by way of the vertical groove and the helix on the plunger, thus relieving the pressure in the barrel. The delivery valve is quickly returned to its seat by the combined action of its spring and the great difference in pressure which exists between the barrel and the high-pressure line. In returning to its seat, the delivery valve performs a double function—first, it prevents excessive draining of the fuel from the high-pressure line; second, it relieves the pressure in the high-pressure line. This pressure relief is accomplished by means of an accurately lapped displacement piston on the delivery valve. Before the delivery valve actually reseats, it reduces the pressure in the high-pressure line by increasing the volume therein by a quantity equal to the volume of the displacement piston.

(4) The positions of the plunger from no fuel to maximum fuel delivery are shown in figure 79. For maximum delivery, the plunger is positioned in the barrel so that it will nearly complete its stroke before the helix indexes with the bypass port. For zero delivery, the plunger is turned in its barrel until the vertical slot registers with the bypass port. In this position, the pressure chamber is connected with the sump during the entire stroke of the plunger. Any position between no fuel to maximum fuel delivery can be obtained by moving the control rack in or out, as the movement of the rack causes the plunger to rotate a proportionate amount. The same rack controls the position of all the plungers simultaneously, thereby insuring the injection of equal amounts of fuel in each cylinder of the engine.

c. SPRAY NOZZLES AND NOZZLE HOLDERS. (1) *General.* For proper engine performance, the fuel oil must be injected into the combustion space in a definite spray form. This is accomplished by the spray nozzle, which is held in the correct position in the cylinder head by the nozzle

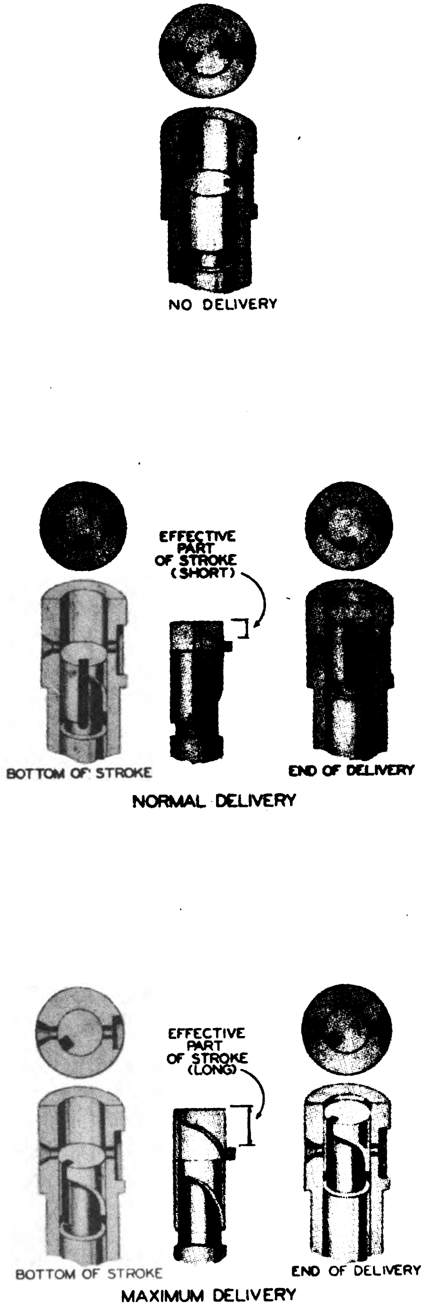

Figure 79. Injection Pump Plunger Positions for Varying Amounts of Fuel Delivery.

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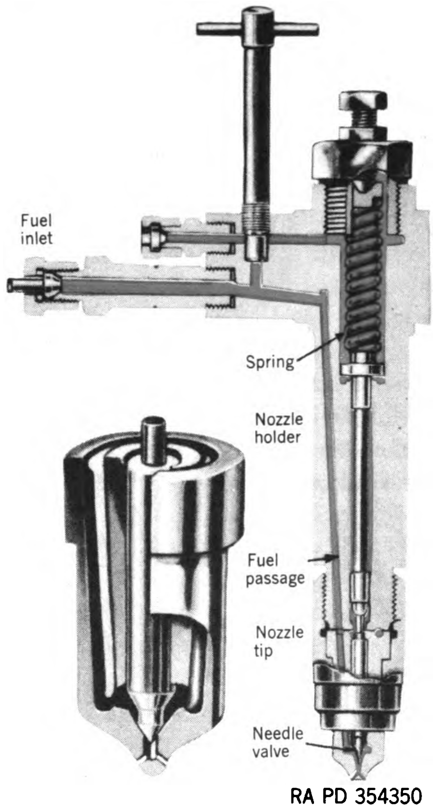

Figure 80. Spray Nozzle for Multiple-unit Fuel Injection Pump.

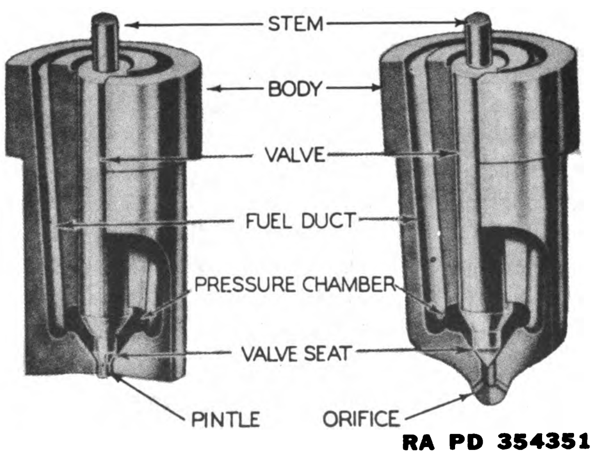

Figure 81. Pintle and Hole Type Fuel Nozzle Tips.

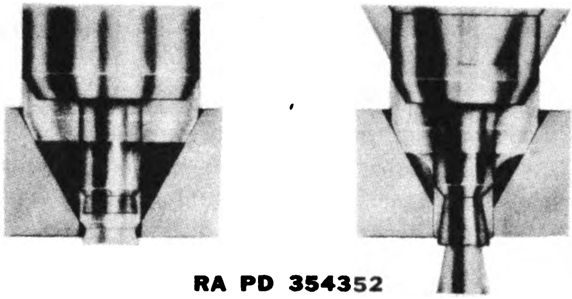

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Figure 82. Action of Pintle (Left) and Throttling Pintle Fuel Nozzles.

holder. The type of unit most commonly used with the multiple-unit injection pump is shown in cross section in figure 80.

(2) *Operation.* The fuel delivered by the injection pump flows through the high-pressure line and enters the nozzle-holder inlet stud. Then it passes through the edge filter, flows through the ducts in the holder and nozzle body, and flows down into the pressure chamber of the spray nozzle above the valve seat. There, the pressure of the fuel oil acts on the differential area of the nozzle valve. At the moment when the pressure of the fuel exceeds the pressure exerted by the adjusting spring, the nozzle valve is lifted off its seat and the fuel is forced through the orifices and sprayed into the combustion chamber of the engine. The nozzle valve returns to its seat after the injection pump has ceased to deliver fuel. The hydraulic opening pressure of the spray nozzle may vary from 1,000 to 4,000 lb per sq in., depending upon engine combustion-chamber requirements. A certain amount of seepage of fuel between the lapped surfaces of the nozzle valve and its body is necessary for lubrication. This leakage oil accumulates around the spindle and in the spring compartment, from which it drains through the leak-off connection provided for that purpose.

(3) *Spray nozzles.* Because of the widely differing requirements in the shapes of the fuel spray for various combustion-chamber designs and because of the wide range in engine power demands, there are a large variety of nozzles used with multiple-unit injection-pump systems. Essentially there are two basic groups, namely, pintle nozzles and hole nozzles (fig. 81). Pintle nozzles are generally used in engines having precombustion, turbulence, or divided chambers, whereas the hole-type nozzles are generally used with open combustion-chamber designs.

(*a*) In pintle nozzles, as shown in figure 82, the nozzle valve carries an extension at its lower end in the form of a pin (pintle) which protrudes through the hole in the nozzle bottom. This requires the injected fuel to pass through an annular orifice, thus producing a hollow, cone-shaped spray, the nominal included angle of which may be from 0° to 60°, depending on the combustion-system requirement. The projection of

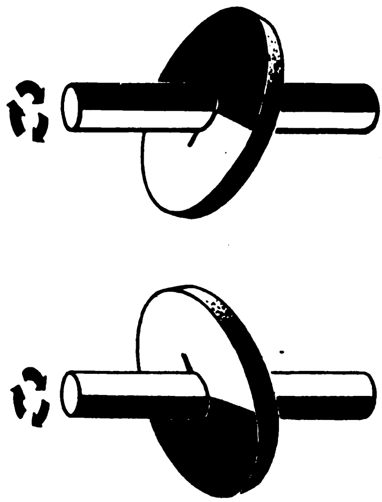

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Figure 83. Wobble-plate Fuel Pump Principle.

the pintle through the nozzle orifice induces a self-cleaning effect, discouraging the accumulation of carbon at this point.

(*b*) A specific type of pintle nozzle extensively used in small-bore high-speed Diesel engines is the throttling nozzle. It differs from the standard pintle nozzle in that the pintle projects from the nozzle body for a much greater distance, and the orifice in the bottom of the nozzle body is much longer. These differences are readily apparent from the cross-sectional illustrations in figure 82. The outstanding feature of the throttling nozzle is its control of the rate at which fuel is injected into the combustion chamber. The pintle extends through the nozzle orifice when no fuel is being injected, and hydraulic pressure from the injection pump causes the pintle to rise for fuel delivery. At the beginning of the injection period, only a small quantity of fuel is injected into the chamber because the straight section of the pintle is in the nozzle orifice. The volume of the fuel spray is then progressively increased as the pintle is lifted higher because the straight section leaves the orifice, and the tapered tip of the pintle in the orifice provides a larger opening for the flow of fuel. Another type of throttling nozzle has its pintle flush with the nozzle-body tip for no fuel delivery and extended through the body for maximum fuel delivery. In this type, fuel under high pressure from the injection pump acts on the seat area of the pintle, forcing it outward against a preloaded spring. This spring, through its action on a spring hanger, also returns the pintle to its seat, sealing the nozzle against further injections or dribble when the line pressure is relieved at the pump. When the pintle moves outward, due to fuel pressure, an increasingly larger orifice area is opened around the flow angle of the pintle.

(*c*) The hole-type nozzles have no pintle but are basically similar in construction to the pintle type. They have one or more spray orifices which are straight, round passages through the tip of the nozzle body beneath the valve seat (fig. 81). The spray from each orifice is relatively dense and compact, and the general spray pattern is determined by the number and arrangement of the holes. As many as 18 spray holes are provided in the larger nozzles, and the diameter of these drilled orifices may be as small as 0.006″. The spray pattern may or may not be symmetrical, depending on the engine combustion-chamber design and fuel distribution requirements. The size of the hole determines the degree of atomization attained. The smaller the hole the greater the atomization, but if the hole is too small it will be impossible to get enough fuel into the chamber during the short time allowed for injection. If the hole is too large, there will be an overrich mixture near the nozzle tip and a lean mixture at a distance from it. Multiple-hole nozzles overcome this difficulty because the holes can be drilled small enough to provide proper atomization, and a sufficient number can be provided to allow the proper amount of fuel to enter during the injection period.

(4) *Nozzle holders.* The nozzle holder holds the spray nozzle in its correct position in the engine cylinder, provides a means of conducting fuel oil to the nozzle, and conducts heat away from the nozzle. The holder also contains the necessary spring and a means of pressure adjustment to provide proper action of the nozzle valve. The component parts of a typical nozzle holder are shown in figure 80. The body has drilled

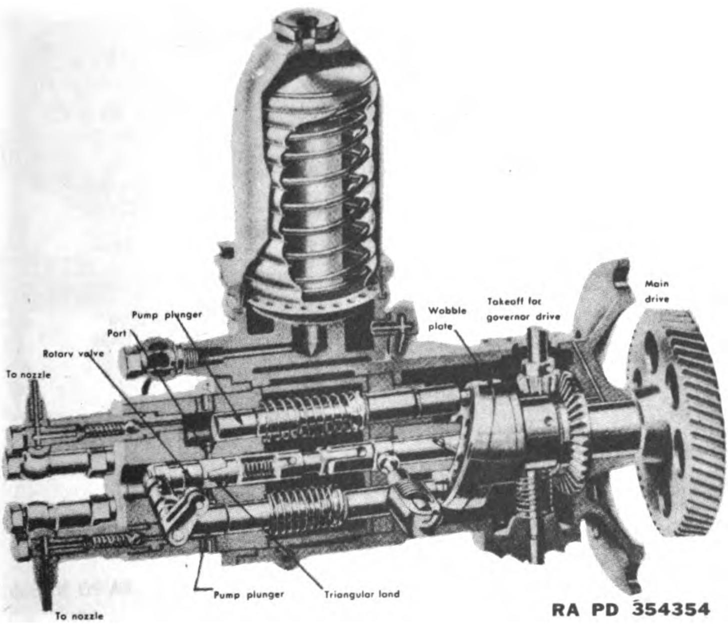

Figure 84. Wobble-plate Fuel Pump Unit.

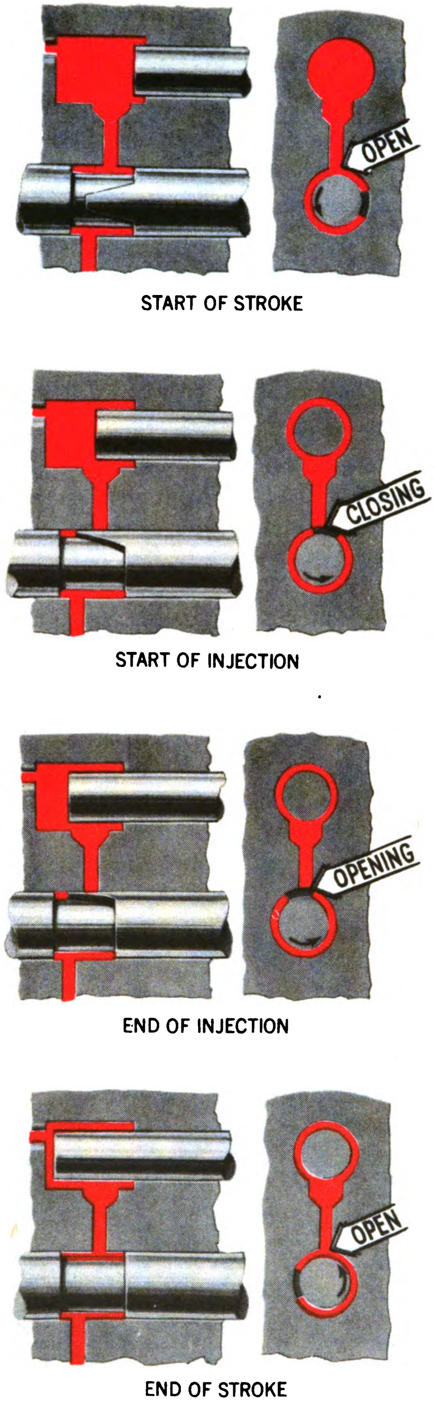

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Figure 85. Four Strokes in Action of Rotary Valve and Single Pump Plunger.

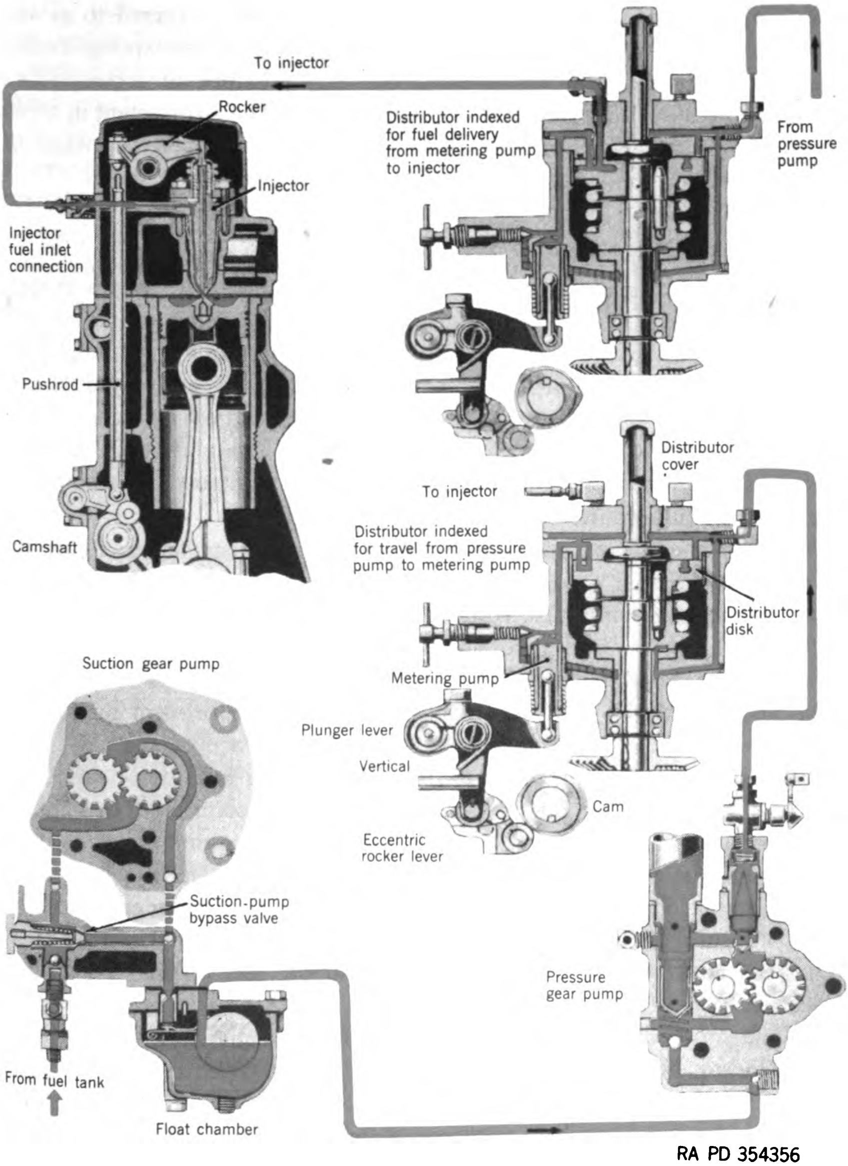

Figure 86. Fuel Flow in Distributor Type System.

passages for conducting the fuel from the inlet connection to the nozzle, and its lower end is provided with an accurately ground and lapped surface which makes a leakproof and pressure-tight seal with the corresponding lapped surface at the upper end of the nozzle. The nozzle is secured by means of the cap nut, as shown. At its upper end, the nozzle valve has an extension of reduced diameter (referred to as the "stem") which makes contact with the lower end of the spring-loaded spindle. Adjustment of nozzle-valve opening pressure is accomplished by means of the spring pressure-adjusting screw. The adjustment in other types of holders which are not illustrated is accomplished by means of spacers between the top of the spring and the upper spring seat.

67. Wobble-plate Pump System

a. The only major difference between the wobble-plate pump system and the injection system just described lies in the injection-pump unit itself. In the wobble-plate pump all the pump plungers are actuated by a wobble plate instead of the customary camshaft having an individual cam for each pump plunger. Also, the metering of the fuel is accomplished by a single axially located rotary valve in the wobble-plate unit, whereas the rotary movement of the individual plungers controls the amount of fuel in the multiple-unit injection-pump system.

b. The principles of a wobble-plate pump are illustrated in figure 83. A plate is mounted on a shaft and set at an angle to it so that as the shaft rotates, the plate also rotates and any particular spot on the plate will not only rotate but move laterally. The pump derives its name from the fact that the plate appears to wobble back and forth as it rotates. A push rod, or tappet, which is placed in a guide to prevent any movement except to the right or left, rides on the surface of the plate as it rotates. The rotation of the plate, then, sets up a horizontal motion to the left and right of the tappet. The tappet is connected to a pump plunger so that the movement to the left actuates the pump on its delivery stroke and a spring returns it on the suction stroke. The injection-pump unit contains one pumping plunger for each engine cylinder (fig. 84). Half the number of plungers are always moving to the right on their filling stroke, the other half are moving to the left on the delivery or injection stroke.

c. The rotary metering valve is driven by the same shaft which drives the wobble plate. The rotary valve consists of a lapped cylindrical shaft closely fitted in a barrel to prevent fuel from escaping at its ends. Fuel is admitted to the barrel at the center of the valve, which contains a spool-like reduction in diameter. This reduction in diameter acts as a fuel reservoir. The recessed portion of the valve is in the shape of a band broken by a triangular land of the same diameter as the ends of the valve, as shown in figure 85. A separate port leads from the recess to the end of each plunger bore. Through this port the plunger cavity is supplied with fuel. The angular relation of the valve and the wobble plate is such that the valve land will cover each port at the time the respective plunger is at approximately its maximum speed in the direction of discharge. Prior to port closing and after port opening (caused by the movement of the triangular land across the port), fuel displaced by the plunger in its pressure stroke flows back through the port into the recess. The fuel trapped in the plunger cavity when the port is closed is forced through a check valve into the high-pressure lines and on to the spray nozzle.

d. To obtain zero delivery, the valve is moved endwise to a position where the ports are never closed by the land. The movement of the plungers then merely causes fuel to move in and out through the ports without building up a pressure sufficient to open the delivery valves and cause injection. To cause the pump to deliver fuel, the valve is moved endwise so that, during rotation, the triangular-shaped land closes the port when the plunger is moving in the discharge direction. Further endwise movement of the valve causes a wider portion of the land to pass across the ports, thus increasing the duration of injection and the quantity of fuel injected. Each port is closed for exactly the same duration of plunger travel and, therefore, exactly the same quantity of fuel is delivered to each of the engine cylinders.

68. Distributor-type System

The distributor injection system used in automotive Diesel engines is classed as a low-pressure system in that pumping, metering, and distributing operations take place at low pressure. The high pressure required for injection is built up in the injector at each cylinder. A schematic diagram of the flow of fuel is shown in figure 86. A suction gear pump lifts fuel from the tank and delivers it to the float chamber, from which a second gear pump delivers it, at low pressure, to the distributor. Fuel passes through the distributor to the metering pump, then through the distributor again, and on to the injector where it is injected into the cylinder.

a. Distributor. The distributor consists of a rotating disk and a stationary cover to which are connected fuel lines running to individual injectors. The disk and cover have a series of holes which, when properly indexed, form passages from the fuel supply pump to the metering pump. This occurs when the metering plunger moves down on its suction stroke and thus permits the barrel to fill with oil. The disk continues to rotate and lines up with the correct discharge hole in the cover just as the metering plunger rises by action of the main fuel-pump cam. This forces the fuel into the proper injector line.

b. Metering Units. The metering pump is a closely fitted reciprocating pump, obtaining its motion through a link from the plunger lever. Operating the plunger lever is a vertical lever which is controlled by

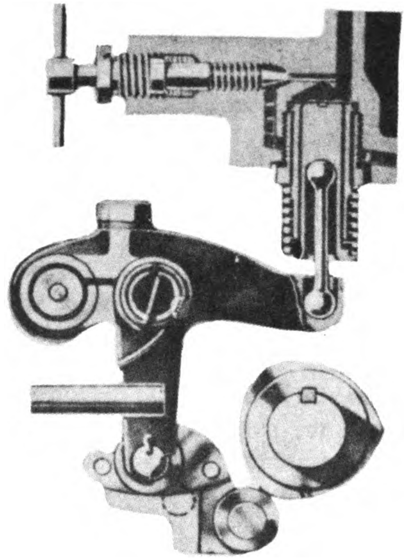

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Figure 87. Variable Stroke Plunger for Metering Fuel.

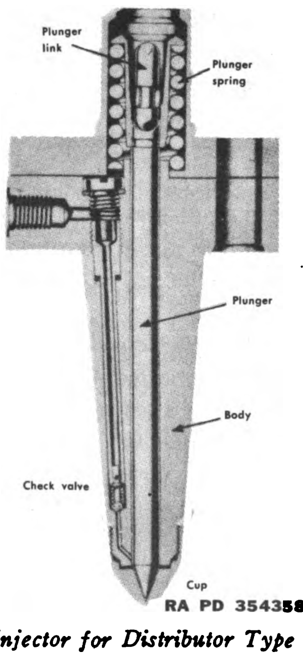

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Figure 88. Injector for Distributor Type Fuel System.

an eccentric rocker lever running directly off a cam on the fuel pump mainshaft. The position of the vertical lever in the eccentric of the rocker lever determines the travel of the plunger lever and, consequently, the travel of the metering plunger (fig. 87). As the metering plunger starts upward on its controlled stroke, it pushes fuel to the injector through passages formed by the rotating distributor disk. The stroke of the metering plunger, which determines the amount of fuel going to each injector, is varied by changing the position of the vertical lever between the stop pins in the cam rocker lever. When the roller is against the inside stop pin on the quadrant, there is no travel on the vertical lever or on the metering plunger, consequently no fuel is going to the engine. If the vertical lever is moved over to the outside pin, the stroke of the metering plunger is sufficient to deliver enough fuel to the engine for full speed and load.

c. Injector. The injector consists of a forged body with a properly fitted plunger (fig. 88). This plunger is forced down against spring action by a rocker arm actuated by push rods from the engine camshaft. Mounted on the end of the body is the injector cup which contains the nozzle tip. On the intake stroke of the engine, the fuel metering pump forces a charge of fuel of the exact amount or the load and speed of the engine into this cup. The operation of the metering pump requires that the fuel line and passage leading to the cup be filled with fuel. It naturally follows that any fuel added at the fuel metering-pump end will push the same amount of fuel into the injector cup. The fuel lies in the cup during the compression stroke of the engine, and the compressed air is forced through the small spray holes in the cup (fig. 89). The fuel oil in the tip of the cup is exposed to the intense heat and blasting of the compression and thus is preheated and broken up. A few degrees before top center, the plunger is forced down and the preheated fuel charge is driven out into the cylinder. A small check valve is located in the

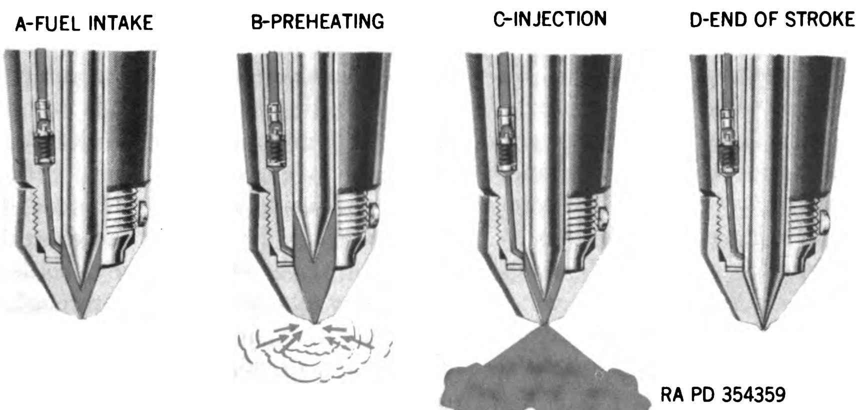

Figure 89. Four Stages in Fuel Injection Cycle.

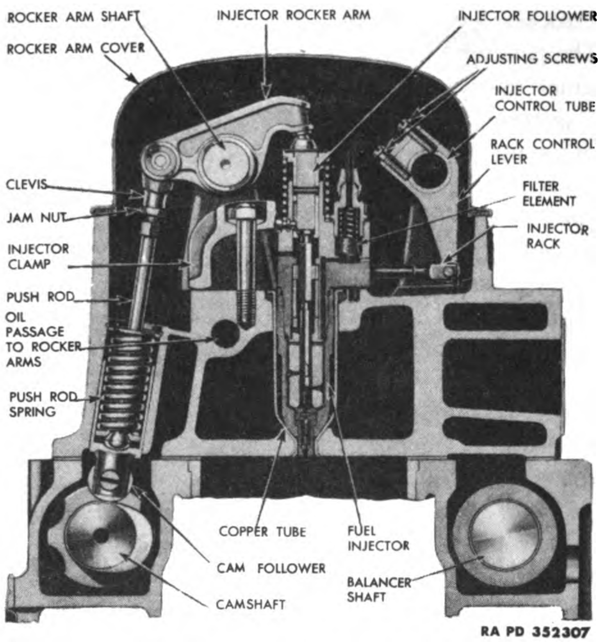

Figure 90. Single-unit Fuel Injector Mounted in Cylinder Head.

lower end of the fuel passage in the injector body. This check valve prevents the compression pressures from blowing the fuel back and filling the lines with air.

69. Unit Injection System

Included in this fuel system are the injectors, fuel supply pump, fuel-oil filters, and the fuel-oil manifolds. Fuel is drawn from the supply tank through the primary filter by the fuel supply pump. From the pump, fuel is forced through the secondary filter and to the fuel intake manifold which supplies the injectors. Surplus fuel, flowing through the injectors, is returned through the fuel outlet manifold to the supply tank.

a. Injector Mounting. Unit injectors combine the injection pump, the fuel valves, and the nozzle in a single housing to eliminate the high-pressure lines. These units provide a complete and independent injection system for each cylinder and are mounted in the cylinder head, with their spray tips slightly below the top of the inside surface of the combustion chambers (fig. 90). A clamp, bolted to the cylinder head and fitting into a machined recess in each side of the injector body, holds the injector in place in a water-cooled copper tube which passes through the cylinder head. The tapered lower end of the injector seats in the copper tube, forming a tight seal to withstand the high pressures inside the cylinder.

b. Injector Operation. (1) The cross section of a typical unit injector (fig. 91) shows the various parts. Fuel oil is supplied to the injector at a pressure of about 20 lb per sq in. and enters the body at the top through the filter cap. After passing through the fine grained filter element in the inlet passage, the fuel oil fills the annular (ring-shaped) supply chamber between the bushing and the spill deflector. The plunger operates up and down in this bushing, the bore of which is connected to the fuel supply in the annular chamber by two funnel-shaped ports, one on each side at different heights.

(2) The injector rocker arms are actuated through push rods from the engine camshaft. The motion of the injector rocker arm is transmitted to the plunger by the follower, which bears against the return spring. In addition to this reciprocating motion the plunger can be rotated in operation around its axis by the gear, which is in mesh with the control rack. Each injector control rack is connected by an easily detachable joint to a lever on a common control tube which in turn, is linked to the governor and throttle. For metering purposes, a recess with an upper helix and a lower helix or a straight cut-off is machined into the lower end of the plunger. The relation of this upper helix and lower cut-off to the two ports changes with the rotation of the plunger. As the plunger moves downward, the fuel oil in the high-pressure cylinder or bushing is first displaced through the ports back into the supply chamber until the lower edge of the plunger closes the lower port. The remaining oil is then forced upward through the center passage in the plunger into the recess between the upper helix, and the lower cut-off, from which it can flow back into the supply chamber until the helix closes the upper port. The rotation of the plunger, by changing the position of the helix retards or advances the closing of the ports and the beginning and ending of the injection period, at the same time increasing or decreasing the desired amount of fuel which remains under the plunger for injection into the cylinder.

(3) Figure 92 shows the various plunger positions from "no injection" to "full injection." With the control rack pulled out completely (no injection), the upper port is not closed by the helix until after the lower port is uncovered. Consequently, with the control rack in this position, all of the fuel charge is forced back into the supply chamber, and no injection of fuel takes place. With the control rack pushed in completely (full injection), the upper port is closed shortly after the lower port has been covered, thus producing a full effective stroke and maximum injection. From this no-injection position to full-injection position (full rack movement), the contour of the helix advances the closing of the ports and the beginning of injection.

(4) Figure 93 shows various positions for downward travel of the plunger with the rack in a fixed position. On the downward travel of the plunger, the metered amount of fuel is forced through the center passage of the valve assembly, through the check valve and against the

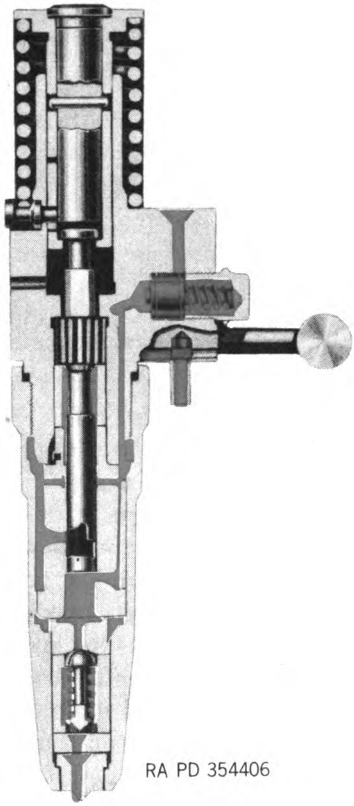

Figure 91. Cross Section of Unit Injector.

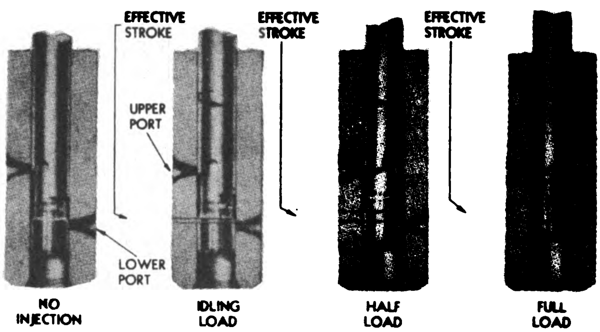

Figure 92. Plunger Positions from No-fuel to Full-fuel Injection.

spray-tip valve. When sufficient fuel pressure is built up, the spray-tip valve is forced off its seat and fuel is discharged through several small orifices in the spray-tip and atomized in the combustion chamber. The check valve prevents air leakage from the combustion chamber into the fuel system if the spray-tip valve is accidently held open by a small particle of dirt, thus allowing the injector to operate until the particle works through the valve.

(5) On the return upward movement of the plunger, the high-pressure cylinder is again filled with oil through the ports. The constant circulation of fresh cool fuel through the injectors, which renews the surplus fuel supply in the chamber, helps to maintain even operating temperature of the injectors, and also effectively removes all traces of air which might otherwise accumulate in the system. The amount of fuel circulated through the injector is in excess of maximum needs, thus insuring sufficient fuel for all conditions.

Section III. FUEL SUPPLY UNITS

70. Fuel Supply Pumps

a. Types. Fuel injection pumps must be supplied with fuel oil under pressure because they have insufficient suction ability. Therefore, all injection systems require a supply pump to transfer fuel from the supply tank to the injection pump. Pumps used for this purpose have a positive suction lift, and their performance is largely independent of any reasonable variations in viscosity, pressure, or temperature of the fuel. The pumps in use today are of the gear, plunger, or vane type. The gear type is similar in operation to the pump used in the lubrication system (par. 100), hence the discussion of supply pumps in this paragraph will be limited to the vane and plunger types.

b. Vane Type. (1) The fuel-oil pump shown in figure 94 is a vane type. An integral steel rotor and shaft, one end supported in the pump flange and the other end in the cover, revolves in the body, the bore of which is eccentric to the rotor. Two sliding vanes are placed 180° apart in slots in the rotor and are expanded against the body bore by coil springs in the slots. Two special seals on the pump shaft prevent leakage of fuel or lubricating oil. A drain hole between the two seals leads to the atmosphere.

(2) When the shaft is rotated the vanes pick up fuel at the inlet port and carry it around the body to the outlet side, where the fuel is discharged. Pressure is produced by the wedging action of the fuel as it is forced toward the outlet port by the vane. A spring-loaded horizontal relief valve is provided in the cover of the pump, connecting the inlet and outlet ports, and opens at a pressure of approximately 55 lb per sq in. This valve does not normally open, since its purpose is to relieve

excessive pump pressure if any of the fuel lines or filters become plugged and build up an extremely high pressure in the pump. When the valve opens, fuel passes from the discharge side (pressure side) to the suction side of the pump.

c. PLUNGER. (1) *Description.* The type of pump shown in figure 95 is usually mounted directly on the housing of the injection pump and is driven by the injection pump camshaft. It is a variable-stroke self-regulating plunger type of pump which will only build pressure up to a predetermined point.

(2) *Operation.* As the injection-pump cam allows the plunger to be forced by its spring toward the camshaft, the suction effect created opens the inlet valve and permits the fuel to enter the plunger-spring chamber. Then, as the cam lobe drives the plunger against its spring, the fuel is forced by the plunger through the outlet valve and around into the chamber created in back of the plunger by its forward movement. As injection-pump cam continues to rotate, it allows the plunger spring (which is now under compression) to press the plunger backward again, thus forcing the fuel oil behind the plunger out into the fuel line leading to the filters and injection pump. At the same time the plunger is again creating a suction effect which allows additional fuel to flow through the inlet valve into the spring chamber. This pumping action continues as long as the fuel is being used by the injection pump fast enough to keep the supply pressure from rising to the point where it equals the force exerted by the spring on the plunger. Then the pressure between the supply pump and the injection pump holds the plunger stationary against the spring and away from the cam. This prevents further pumping action until the pressure drops enough to permit the plunger to resume operation. This entire cycle is automatic and continues as long as the engine is running.

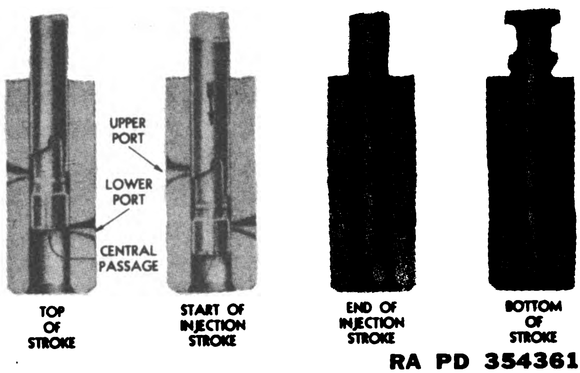

Figure 93. Four Positions of Injector during Downward Travel.

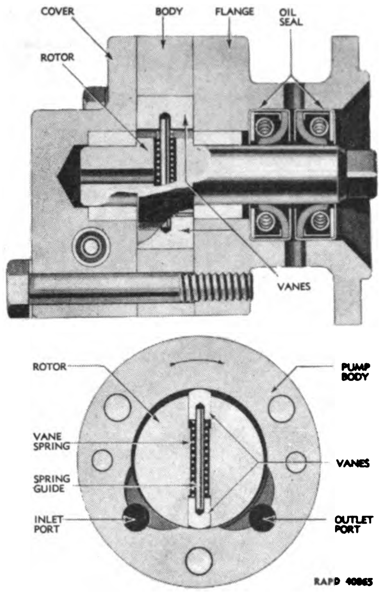

Figure 94a. Vane-type Fuel Supply Pump.

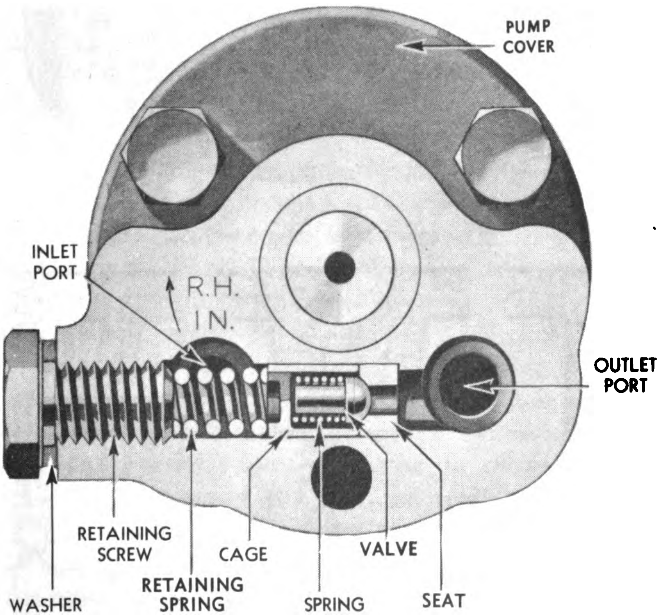

Figure 94b. Fuel Supply Pump Relief Valve.

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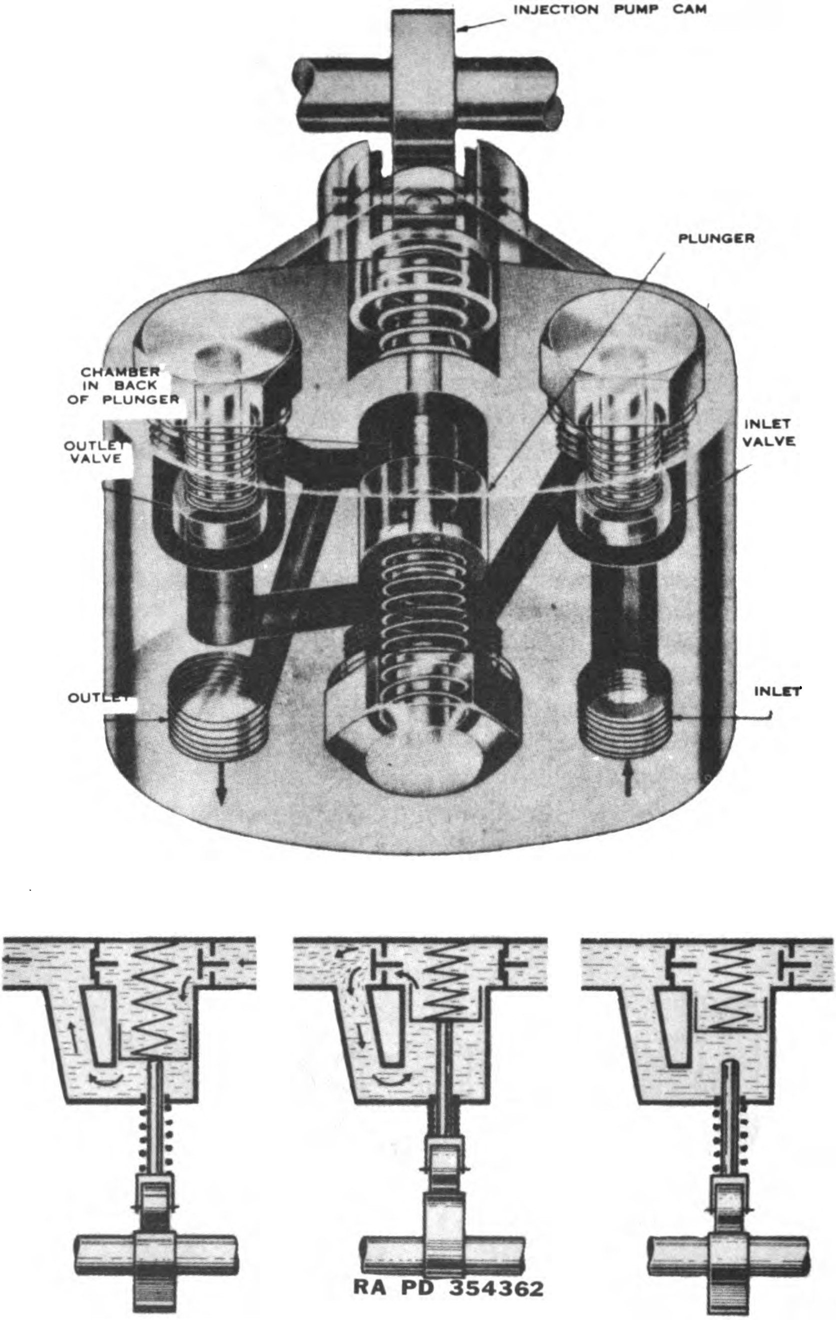

Figure 95. Plunger-type Fuel Supply Pump.

71. Governors

a. Types. All Diesel engines require a governor to prevent overspeeding of the engine under light loads. Automotive Diesel engines also demand control of the idling speed. Many of the installations provide a variable-speed control which, in addition to controlling minimum and maximum speed, will maintain any intermediate speed desired by the operator. Engine speed in a Diesel engine is controlled by the amount of fuel injected; consequently, the injection system is designed to supply the maximum amount of fuel which will enable the engine to operate at full load and reach a predetermined maximum rpm. However, if the maximum fuel charge were supplied to the cylinders with the engine operating under "partial load" or "no load," the engine speed would increase beyond the critical range and soon cause a failure. Thus it can be seen that the governor must control the amount of fuel injected in order to control the engine speed.

b. Actuation. Governors may be actuated through the movement of centrifugal flyweights or the air-pressure differential produced by a butterfly valve and Venturi assembly. The centrifugal-flyweight type may incorporate a mechanical linkage system to control the injection pump or it may include a hydraulic system to transmit the action of the weights to the pump. Where the rate of acceleration must be high, the governor-controlling weights must be small to obtain the required rapidity of response from the governor. These small weights may not exert sufficient force to control the injection equipment; hence the injection pump will be controlled by a servo piston utilizing pressure from a pump within the governor. The centrifugal weights actuate a valve which controls the amount of oil going to the servo piston.

c. Mechanical (Centrifugal). (1) The operation of the mechanical governor is based on the centrifugal force of rotating weights counterbalanced by springs. When the speed of the engine increases, the weights fly outward, pulling with them suitable linkage to change the setting of the injection-pump control rod. The governor linkage is connected to the injection pump in such a manner that the spring tends to move the control mechanism toward the full-fuel position, and the action of the flyweights tends to reduce the amount of fuel delivered.

(2) A typical variable-speed governor is shown schematically in figure 96. With this type of governor, the operator varies the governor spring tension to control the quantity of fuel and does not at any time move the injector control rack directly. The control rack of the injection pump is connected to the yoke of the governor in such a manner that any movement of the yoke will directly affect the quantity of fuel injected. The spring tension is controlled by the operating lever, the movement of which is determined by the position of the foot throttle. The travel of the operating lever is limited by the idle- and maximum-speed adjusting screws. With the weights fully collapsed (engine stopped), the

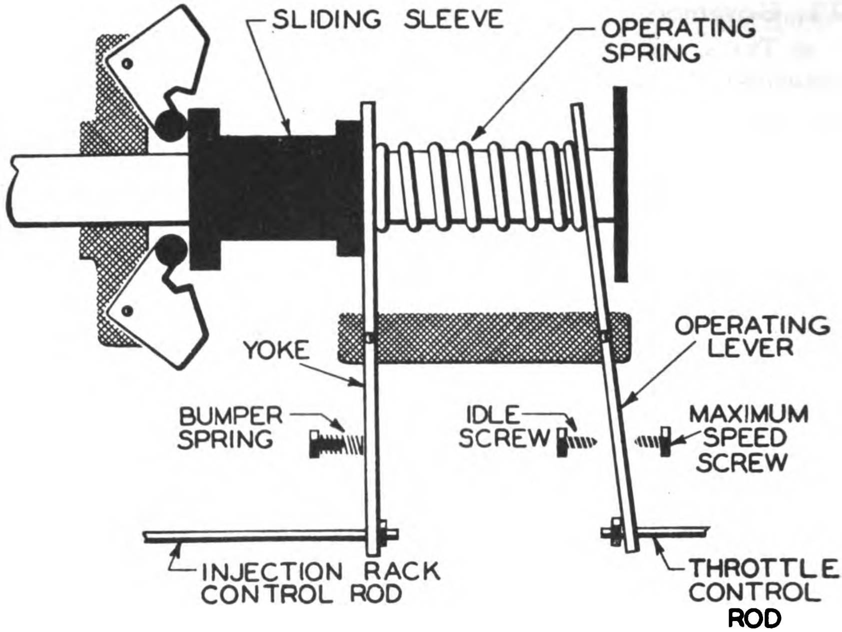

Figure 96a. Variable Speed Governor.

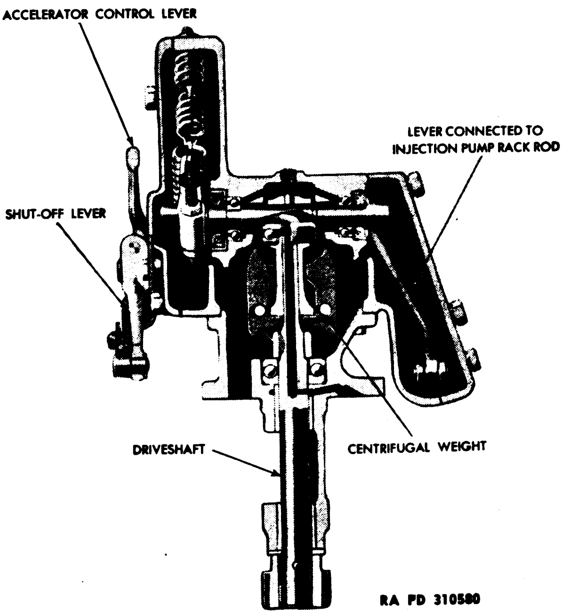

Figure 96b. Variable Speed Governor.

spring moves the sliding sleeve and yoke so the fuel injection pump is in the full-fuel position. When the weights are fully extended, the sliding sleeve and yoke move to the right and decrease the amount of fuel delivered.

(3) In the event that the load on the engine is decreased, the engine naturally tends to accelerate. However, when the engine accelerates, the governor flyweights move outward due to increased centrifugal force. Since the flyweights are in contact with the sliding-sleeve assembly, this movement causes a longitudinal movement of the sleeve to the right. This movement continues until an equilibrium is established between the governor spring force and the centrifugal force exerted by the flyweights. This occurs when the engine returns to the original speed, as determined by the position of the foot throttle and its effect on the governor spring.

(4) In the event the load on the engine increases, the engine tends to slow down, thereby causing an inward movement of the flyweights. As the weights move inward, resulting in reduced force on the sliding sleeve, the compressed governor spring shifts the sleeve to the left until the spring force and the centrifugal force exerted by the flyweights are again balanced. In this way, the yoke, following the movement of a sliding sleeve, moves the control rack of the fuel injection pump toward the more-fuel position and thereby returns the engine to the preset speed.

(5) If it is desired to accelerate the vehicle, the operator depresses the foot throttle which, in turn, increases the spring tension. This causes the yoke to pivot to the left, thereby increasing the supply of fuel. The flyweights move outward due to the increased engine speed and prevent the control rack from reaching the full-fuel position unless the foot throttle is fully depressed. Deceleration is accomplished in the reverse manner. Spring pressure is decreased, the engine slows down, the flyweights move inward, and a balanced condition between the flyweights and the spring is obtained at a lower engine speed.

(6) The adjustable bumper spring prevents rapid oscillations of the control rack at low no-load engine speeds. The spring contacts the yoke at idling speed and insures steady operation of the governor. The bumper spring also assists in preventing stalling of the engine on sudden deceleration to idle speed, as it prevents the control rack of the injection pump from moving into the full-stop position when this speed change occurs.

d. PNEUMATIC. (1) The actuating force for the pneumatic or vacuum-controlled governor is the pressure drop caused by the velocity of air passing through a Venturi located in the air intake manifold (par. 52*b*). The governor consists essentially of an atmospheric-suspended diaphragm connected by linkage to the control rack of the fuel injection pump (fig. 97). The chamber on one side of the diaphragm is open to

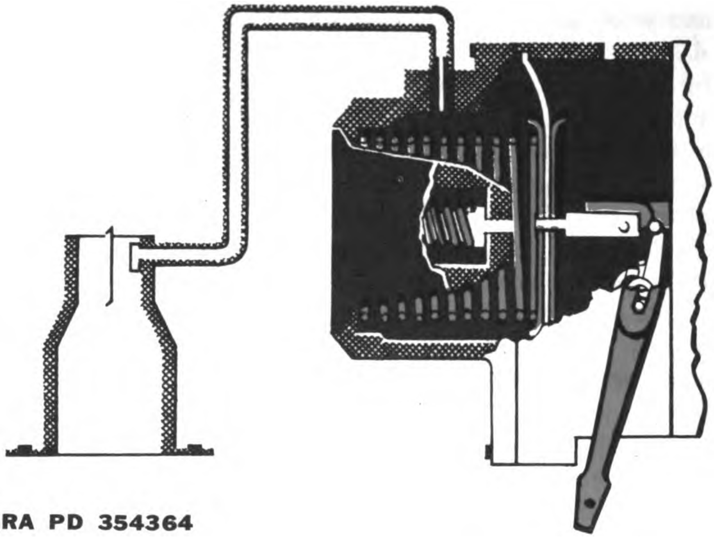

Figure 97. Pneumatic Governor.

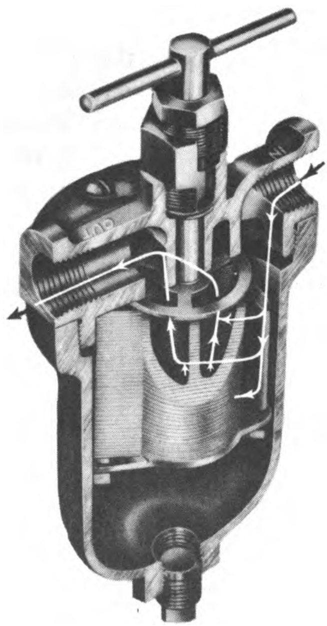

Figure 98. Metal Filter.

the atmosphere, and the chamber on the other side is sealed and connected to the Venturi in the manifold. In addition, there is a spring acting on the sealed side of the chamber, which moves the diaphragm and control rack to the full-fuel position when the engine is not operating and both sides of the diaphragm are at atmospheric pressure. When the engine is running, however, the pressure in the sealed chamber is reduced below the atmospheric pressure existing in the other chamber. The amount of pressure reduction depends on the position of the butterfly valve and the speed of the engine. It is this pressure differential that positions the diaphragm and, consequently, the control rack. The butterfly valve is controlled by a lever which is connected by suitable linkage to the foot throttle. There is no actual connection between the foot throttle and the governor or fuel injection pump.

(2) If the engine is operating under load and the rpm is below governed speed, the velocity of air passing through the Venturi is comparatively low and only a slight pressure differential is present. The spring tends to move the diaphragm and control rack toward the full-fuel position, and the engine speed tends to approach that of governed speed.

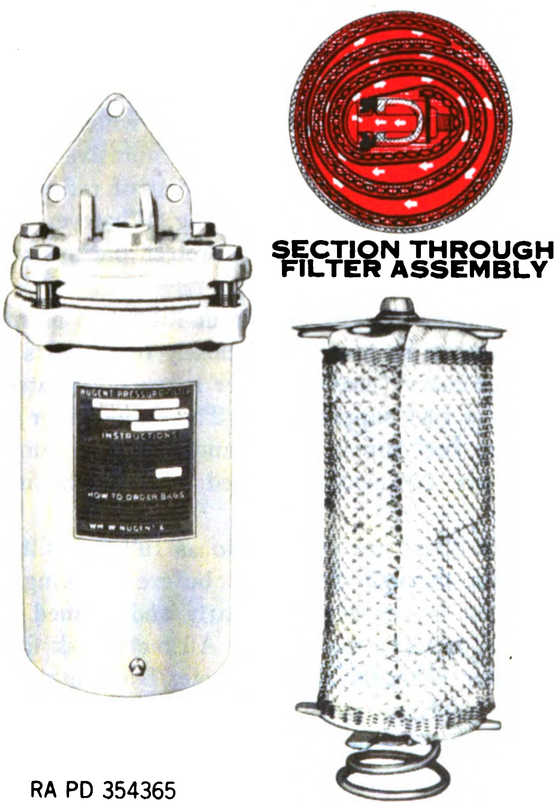

Figure 99. Cloth Filter (Bag Type).

The same principle prevents the engine from overspeeding at light loads. As the engine speeds up, the velocity of air through the Venturi increases, with the result that the pressure differential at the diaphragm is increased. This differential is sufficient to overcome the spring force and to cause the diaphragm and control rack to move toward the "stop" position. When the engine is operating at governed speed with the butterfly valve wide open, the pressure differential is just slightly below that of the spring force and the diaphragm remains in the full-delivery position.

(3) For any position of the butterfly valve between idling and full load of the engine, the diaphragm finds its relative position. Since any movement of the diaphragm is also transmitted to the control rack, the amount of fuel delivery is definitely controlled at all engine speeds. As the pressure drop between the chambers is increased, the diaphragm is moved in the direction of less fuel delivery. As the pressure drop is decreased, the spring can move the control rack in the direction of greater fuel delivery. Therefore, in order to increase the speed of the engine, the butterfly valve is opened; to decrease the engine speed, the valve is closed.

72. Fuel Filters

a. Thorough and careful filtration is especially necessary to keep Diesel engines efficient. Diesel fuels are more viscous than gasoline. They contain more gums and more abrasive particles, which may cause premature wear of the injection equipment. The abrasives may consist of material difficult to eliminate during the process of refining, or they may enter the fuel tank through careless refueling. Whatever the source, it is imperative that means be provided to protect the system from these abrasives.

b. Most Diesel-engine designs include at least two or more filters in the fuel supply systems to protect the closely fitted parts in the pumps and nozzles. The primary (coarser) filter is usually located between the supply tank and the fuel supply pump. The main (finer) filter will be found between the fuel supply pump and injection pump. Additional filtering elements are frequently installed between the injection pump and the nozzle.

c. Diesel fuel-oil filters are referred to as full-flow filters in that all the fuel must pass through the filters before reaching the injection pumps. Filters must be inspected regularly and cleaned or replaced if maximum efficiency is to be maintained. All metal-disk filters and some cloth-bag type filter elements are cleanable, but most cloth or fabric elements must be replaced when they become dirty. Diesel-oil filters usually incorporate an air vent to release any air which might accumulate in the filter during operation.

d. Metal filters are used as primary filters because the fine particles that may pass through them are not as injurious to the supply pump as they would be to the injection pump. The filter illustrated in figure 98 is similar to the one described in paragraph 43 except that a cleaning knife is added. Solids larger than 0.005" remain on the outside of the element, and the cleaning knife serves to scrape these deposits off the filtering disks. The solids fall to the bottom of the filter housing where they can be removed through the drain-plug hole. The ball relief valve in the filter cover enables the oil to bypass the filter element if the disks become clogged.

e. Fabric filters, because of their greater filtering qualities, are used principally as main filters for protecting the fuel injection pump. Many of the filters in use are similar to the lubricating-oil filter described in paragraph 103; however, the bag-type filter (fig. 99) is more desirable because the element can be cleaned. The filtering medium is a large-area bag of close, evenly woven, lintless, acid-resisting textile material. Maximum benefit is derived from the bag's large area by keeping the sides of the bag separated by a wire-screen mat. The screen is the same size as the bag, and the two are detachably fastened to a central feeding spool and wound around it. Layers of bag and screen are thus alternated through the winding, and the entire surface of the bag is available for filtering purposes. The fuel to be filtered flows from the filter inlet at the top, through the spool, and out the ports to the inside of the bag. The dirt, solids, abrasives, carbon, etc., are caught in the bag, and the clean fuel passes outward and to the filter outlet. The bag may be turned inside out to expel the dirt, washed, and reinstalled.

CHAPTER 7

IGNITION SYSTEMS

Section I. BATTERY IGNITION

73. Function

a. Ignition of the fuel mixture may be accomplished by heat of compression, as in the Diesel engine, or by electrical spark, as in the gasoline engine. Spark ignition may be subdivided into two classes: battery and magneto. Essentially these two are the same. In either instance the fundamental job is to step up low voltage to a much higher value—15,000 to 20,000 volts. This high voltage is capable of driving current through the high resistance set up by pressure in the combustion chamber and across from one sparkplug electrode to the other. The hot spark thus created ignites the fuel mixture.

b. This chapter will include only the mechanical details of the battery system. The electrical principles of the system are discussed in OS 9–31, Automotive Electricity for In-line Engines, and the operation of the magneto will be included in section II of this chapter.

74. Ignition Circuits

The ignition system is composed of two circuits—primary and secondary. The primary is the low-voltage circuit; the secondary is the high-voltage circuit.

a. Primary Circuit. The component parts of this circuit (fig. 100) are the battery, the ammeter, the ignition switch, the primary winding of the ignition coil, and the cam and breaker points.

(1) The battery is merely the source, until the engine fires and the generator takes over, of electromotive force which pushes current through the primary circuit when it is complete.

(2) The ammeter is not essential to the operation of the circuit but is customarily inserted in it; it may conveniently be used to check the general condition of the circuit.

(3) The ignition switch opens and closes the circuit.

(4) The primary winding of the ignition coil is made of several hundred turns of wire of approximately the same diameter as a common steel pin. When the circuit is closed the flow of current through the coil builds up a magnetic field about the coil. This field collapses rapidly when the circuit is interrupted.

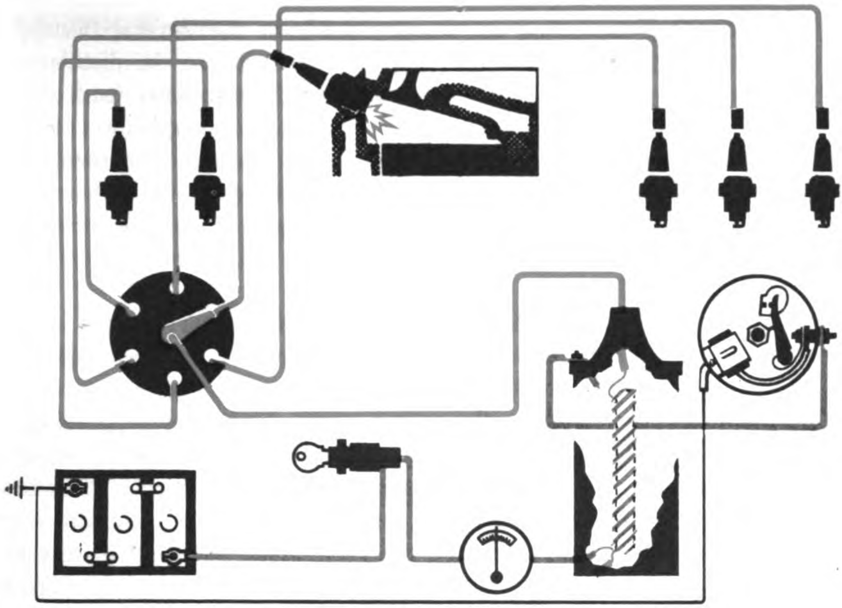

Figure 100. Ignition Circuits.

(5) The cam and breaker points serve to interrupt the primary circuit at certain very definite intervals. Spring tension holds the points together. The cam is located on the distributor shaft and is driven indirectly by the engine crankshaft. Ordinarily, the cam will have as many lobes as the engine has cylinders and is rotated one-half as fast as the crankshaft. As it rotates, the cam opens the breaker points and interrupts the primary circuit. Within the time necessary for one revolution of the cam, the four-stroke cycle has been completed within each cylinder and the primary circuit has been interrupted once for each cylinder. Thus the cam and breaker points, located in the distributor, are in reality a timing device, the need for which will shortly become clear.

b. Secondary Circuit. The secondary, or high-voltage, circuit (fig. 100) is composed of the secondary winding of the ignition coil, the distributor (insofar as it is a rotary switch), the spark-plug leads, and the spark plugs.

(1) The secondary winding of the ignition coil is made of several thousand turns of hair-like wire, wound either inside or outside the primary winding. One end of this winding is grounded, usually by a connection to the primary winding. The other end is connected by a heavily insulated lead to the distributor. It will be remembered that a magnetic field is built up around the coil when the primary circuit is complete and current flows through it, and that this magnetic field collapses rapidly when the circuit is opened. The rapid movement of collapsing lines of magnetic force induces a very high voltage (15,000

to 20,000 volts, depending on construction) in the several thousand turns of the secondary winding. This voltage is led to the distributor, where the rotary switch directs the impulse first to one spark plug, then to another, and so on. The voltage being great enough to overcome the resistance at the gap between the electrodes, the circuit is completed to ground and the hot spark ignites the fuel mixture. The high voltage induced in this manner is momentary; and a surge occurs each time the magnetic field, established by current flow through the primary circuit, is rapidly collapsed.

(2) The distributor, to the extent that it is a rotary switch in the secondary circuit, must make contact with a spark-plug lead each time a high-voltage surge is developed in the secondary. The high-tension lead from the coil is connected to the center terminal of the distributor cap. The circuit continues through the cap to the rotor, which is a revolving arm. As it rotates, the outside edge of the arm lines up with electrodes connected up through the cap to the terminals in which the spark-plug leads are inserted. These terminals are positioned near the outside edge of the cap. Since the rotor must line up with the lead to a spark plug each time the high-voltage surge is produced, and since this surge occurs each time the cam interrupts the primary circuit, the cam and rotor are driven by the distributor shaft to synchronize their operation. Timing is accomplished by adjusting the position of the distributor so that the breaker points open and the rotor is alined with a spark-plug lead at the proper moment for igniting the fuel mixture in the cylinder.

(3) The high-tension leads to the spark plugs are heavily insulated to withstand the high voltage to which they are subjected. At one end they are inserted into the terminals of the distributor cap. The other end is connected to the spark plug.

(4) The spark plug serves to provide the proper gap across which high voltage may create an arc within the combustion chamber. One electrode extends through the center of the plug and is insulated by porcelain. It is connected to the distributor block by means of high-tension electric cable. The other electrode is attached to the steel shell and thus is grounded to the frame through the engine block assembly. The arc created between the two electrodes is sufficiently hot to ignite the fuel mixture. Since the plug seals an opening in the cylinder, it must be strong enough to withstand the pressure developed in the combustion chamber.

75. Condenser

a. It is now possible to mention another component of the primary circuit. The collapse of the magnetic field which induces high voltage in the secondary circuit also induces a fairly high voltage in the primary circuit. This voltage would tend to drive across the small gap established as the breaker points open and interrupt the circuit.

b. A condenser is connected across the points to detour the surge away from the points, thus charging the condenser. The condenser then immediately discharges; the points now being wide open, the surge reverses through the primary coil. The operation of the condenser is two-fold—it prevents arcing at the ignition points and speeds up the collapse of the magnetic field by reversing the surge. The increased speed of collapse insures high voltage in the secondary.

Section II. MAGNETO IGNITION

76. General

a. Ignition of the air-fuel mixture in the cylinder combustion chamber may be performed by an electric spark, as in the gasoline engine, or by the heat of compression, as in the Diesel engine. The electric spark can be produced in two ways: by magneto ignition or by battery ignition. The magneto is a compact combination of generator, ignition coil, and distributor. It requires no battery. Voltage is induced within the magneto by relative movement between a coil and the poles of a permanent magnet. Most radial engines use magneto ignition.

b. The problem in magneto ignition is to generate a spark of sufficient voltage to ignite the air-fuel mixture instantly and to synchronize the spark with the engine cycle so that maximum power will be realized from the combustion. Six fundamental units are necessary:

(1) A means of developing electricity.

(2) A transforming device to increase the voltage of the electricity developed.

(3) An interrupting device to determine the proper timing of the electrical impulses.

(4) A distributor to direct the electrical impulses in the proper order to the different cylinders.

(5) A spark gap in each cylinder in the engine.

(6) The proper wiring and switches to bring these units together to form the ignition system.

c. The first four units are contained within the magneto. The spark plug supplies the fifth unit; wiring and switches make up the sixth unit. The same four fundamental units that make up the magneto also can be classified broadly as just two parts—a generator and a transformer. The generator provides a means of inducing low voltage in a primary circuit (par. 74*a*); the transformer changes the low voltage of the primary circuit to the high voltage in a secondary circuit so that an extremely hot spark can be produced across the spark-plug gap.

77. Comparison—Battery and Magneto Ignition

The magneto ignition system is generally reliable, requires little maintenance, and does not have a battery to run down or wear out. Its

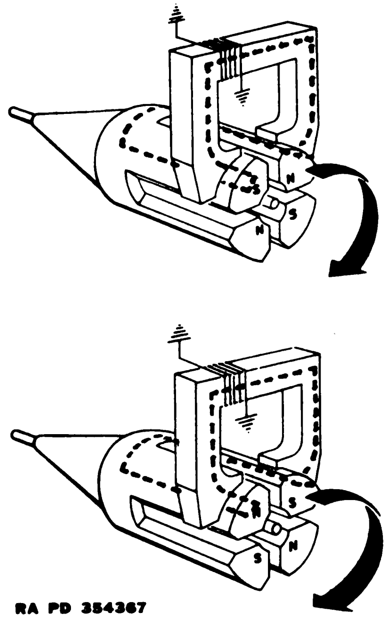

Figure 101. Two Views of Magneto Rotor With Magnetic Field Going Through the Winding First in One Direction and Then in The Opposite Direction.

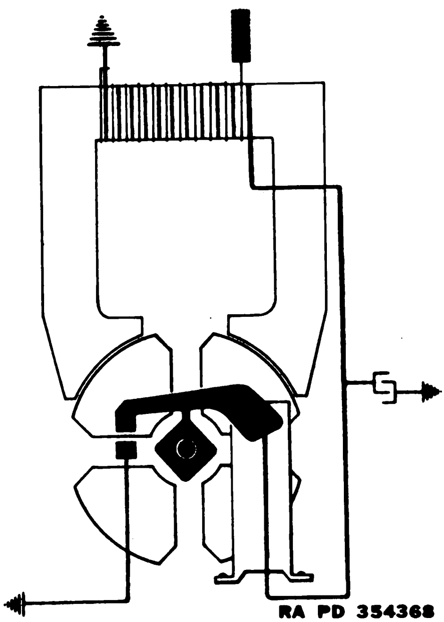

Figure 102. Magneto Rotor and Winding With Transforming and Interrupting Devices Added.

principal disadvantage is that it turns so slowly during the cranking of the engine that a hot spark is not produced. Therefore, a supplementary high-voltage source must be provided. This may be a booster magneto or a high tension coil to which primary current is supplied by a battery. In some magnetos an impulse starter is provided which produces high armature speeds at engine cranking speeds in order to provide a hot spark.

78. Source of Electrical Energy

In studying the magneto, it should be understood that three things are necessary to induce voltage: an electrical conductor, a magnetic field, and relative motion between the field and the conductor. In the magneto, a permanent magnet supplies the magnetic field, a wire coil is the conductor, and the engine provides mechanical energy for motion between the field and the conductor. There are two types of magnetos: armature-wound, in which the coil moves while the magnets are stationary, and the inductor type, in which the reverse is true—the magnets move and the coil is stationary. In the inductor type, for example, a rotor which is a permanent magnet is used to direct the magnetic field flow through the windings, first in one direction, then in the other (fig. 101). As the winding is stationary, it is easier to make connections from it. Either type of construction satisfies the first requirement of an electric ignition system, that is, a means of developing electrical energy.

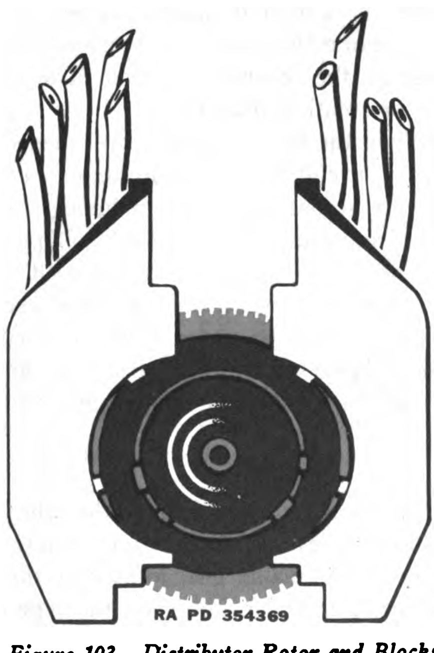

Figure 103. Distributor Rotor and Blocks.

79. Transforming Device

Most engines require about 15,000 volts at the spark gap in the cylinder. The problem when the magneto is used is to raise the low voltage induced in the conductor (primary winding) to the required high voltage. This is accomplished in the same way that it is in the battery ignition coil (par. 74*b*). When the current in the primary winding or conductor is at its maximum flow, the circuit is suddenly broken, collapsing the electromagnetic field set up around the primary circuit as the result of current flow. The lines of force in the field collapse at an extremely high rate of speed across the secondary winding, which is made up of many turns of line wire, whereas the primary winding is composed of relatively few turns of coarser wire. This rapid movement of the lines of force across the secondary winding induces a momentarily high voltage in the secondary winding, in proportion to the ratio of the number of turns on the primary winding to the number on the secondary winding. This makes about 15,000 volts available at the spark gap and satisfies the second requirement for an ignition system.

80. Interrupting Device

a. Breaker Points. The interrupting device which breaks the primary circuit when the high-voltage spark is desired is a set of breaker points (fig. 102). One end of the primary winding is connected to ground; the other end is connected to the insulated breaker point. When the points are closed, the circuit is completed through them to a ground. When they are open, the circuit is broken. Lobes on a cam actuate the breaker points, interrupting the primary circuit and timing the induction of maximum voltage in the secondary circuit. The cam is mounted on either the armature or rotating magnet.

b. Condenser. When the breaker points are opened, the current then flowing in the primary circuit has a certain amount of inertia due to its motion and tends to arc across the points, reducing the speed with which the circuit is broken and the magnetic field collapsed. This inertia is controlled by inserting a condenser in parallel with the breaker points. When the primary circuit is broken, the condenser receives the surge of current and then, on discharging, reverses the normal flow of current; it thus hastens the collapse of the magnetic field around the primary winding and increases the amount of voltage induced.

81. Distributor

a. The distributor rotor, which directs the electrical impulses in proper order to the cylinders, is fastened to a large distributor gear (fig. 103). It is driven by a smaller gear located on the drive shaft of the rotating magnet or armature (depending on the type of magneto). The ratio between these two gears is such that the distributor cylinder is always driven at one-half crankshaft speed. This ratio insures that each cylinder will be fired during the cycles of the engine.

b. One end of the secondary winding is grounded to the primary. The other end terminates at the high-tension insert, which is a piece of metal extending through the bakelite case covering the coil. The high-tension voltage developed in the secondary coil passes through the insert to a carbon brush and then internally through the distributor rotor to the electrodes on the surface (fig. 104). The rotor is timed so that these electrodes will line up with other electrodes on distributor blocks to which spark-plug leads are connected.

c. The spark-plug assembly provides a gap where a surge of high voltage may cause a spark to ignite the fuel mixture. One spark-plug electrode is connected to the high-tension cables from the distributor blocks; the other is fastened to a ground. Most radial engines have two spark plugs per cylinder and two separate magnetos for the ignition system. The second spark plug insures better combustion.

d. The high-tension wires which conduct the current from the distributor blocks to the spark plugs are commonly called the ignition "harness." As a magneto ignition system transmits a form of high-frequency current, radiations emanating from it during operation will interfere with radio reception if the ignition system is not shielded. This shielding is a metal covering of woven construction that surrounds the wires. Plain metallic shields cover the distributor blocks and booster coil. The shielding is grounded to the engine so that it can pick up the undesirable radiations from the magneto and carry them directly to a ground. The radiations are thus prevented from reaching the vehicle's radio aerial and interfering with reception.

82. Booster Coil

It was mentioned previously that magneto speed during cranking is not high enough to develop a hot spark. An external source of high-tension current for starting is provided either by a booster magneto or by a high-tension coil with the primary current being supplied by a battery. The coil method is the most common. Current from the booster coil, which operates just like the coil in the battery ignition system, is conducted to the booster electrode on the distributor rotor. This electrode follows directly behind the electrode through which current flows for normal operation, giving the slower or retarded spark required for starting. From the booster electrode the current follows on its way to the spark gap. It crosses the air gap to the distributor-block electrodes and then goes through the high-tension wires to the spark plugs.

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CHAPTER 8

COOLING SYSTEMS

Section I. COOLING ESSENTIALS

83. Need for Cooling

All internal combustion engines are equipped with some type of cooling system because of the great amount of heat they generate during operation. Heat is highly necessary, as it causes expansion of the gases which act on the head of the piston. Without heat, power could not be produced. However, it is not possible to use all of the heat of combustion without producing harmful results. There is no accurate method of measuring the temperature in the combustion chamber during the burning of fuel, but it has been determined to be about twice the temperature at which iron melts. Therefore, if nothing is done to cool the engine during operation, valves will burn and warp, lubricating oil will break down, pistons and bearings will overheat, and pistons will seize in the cylinders.

a. Only about one-third of the heat created by combustion must be dissipated by the cooling system. Other important but often overlooked mediums of cooling an internal combustion engine are the fuel and the lubricant. Cooling is not their primary purpose, but they nevertheless dissipate an appreciable amount of heat. Additional heat is lost through the exhaust. There must be careful control over the amount of heat dissipated because thermal efficiency is directly proportional to operating temperature. For liquid cooled engines, the ideal operating temperature is just below the boiling point of the coolant used if this temperature is not so high that it breaks down the lubricant.

b. Cooling systems usually are classified as liquid or air. Diesel- and gasoline-engine cooling systems are similar mechanically; however, the Diesel runs cooler and it is not necessary that the capacity of its cooling system be as large as that of a gasoline engine. Diesel engines usually have the same size radiators as gasoline engines, but the speed and size of the fans are reduced.

84. Coolants

Water is the most widely used coolant for liquid-cooled engines. It should be clear and soft. Water is usually available, it costs practically

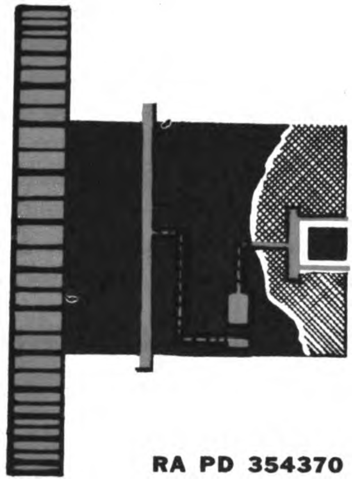


Figure 104. Side View of Distributor Rotor.

nothing, and its boiling point falls within the range of efficient operating temperatures. The main objection to the use of water is that it has a high freezing point and cannot be used alone at temperatures below 32° F. Ethylene glycol is used in some liquid-cooled aircraft engines where the cooling system is sealed. Its advantages are that it does not evaporate in use, has a higher boiling point than water, does not require renewal unless lost through leakage, and requires less radiator area to obtain the same degree of cooling that water gives.

85. Additives

a. ANTIFREEZE. When a vehicle is operated where the atmospheric temperatures fall below 32° F, an antifreeze solution must be added if water is used as the cooling liquid. The four solutions in common use are methyl alcohol, ethyl alcohol, glycerin, and ethylene glycol. The first two, prepared commercially as antifreezes, are the cheapest and provide adequate protection when used in sufficient quantities. The main objection to them is that they boil and evaporate if normal operating temperature is exceeded. Glycerin offers the same degree of protection as alcohol and does not evaporate in use because it has a high boiling point. Ethylene glycol (anti-freeze compound) has an extremely high boiling point (330° F), does not evaporate in use, is noncorrosive, has no odor, and furnishes complete protection when used in the proper amount. The maximum protection from freezing is obtained from a solution of 40 percent water and 60 percent anti-freeze compound. This mixture gives protection at temperatures as low as minus 65° F. A higher concentration of anti-freeze compound will only raise the freezing point of the solution. If 100-percent anti-freeze compound is used, the freezing point is not much below that of water.

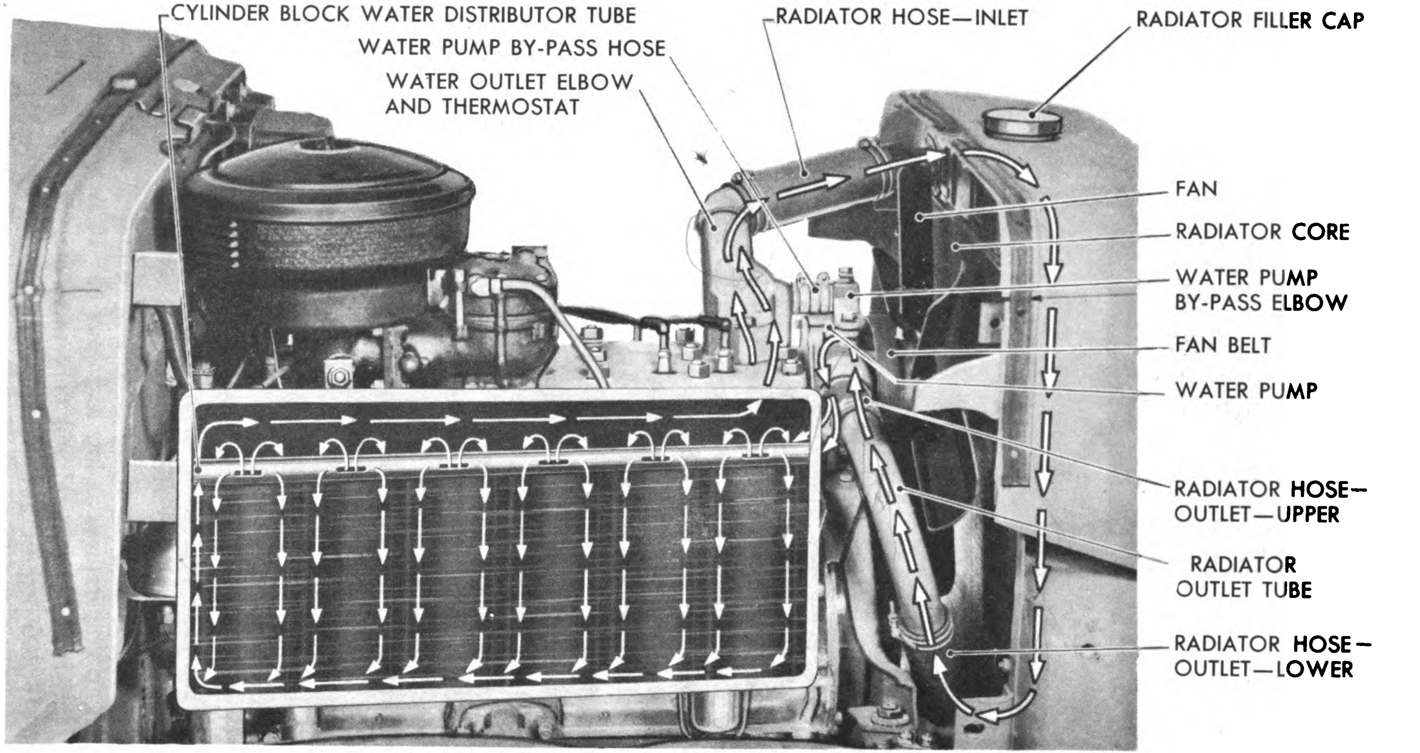


Figure 105. Cooling System Circulation Diagram.

b. INHIBITORS. The cooling system must be free of rust and scale in order to maintain its efficiency. The use of inhibitors or rust preventives will reduce or prevent corrosion and the formation of scale. Inhibitors are not cleaners and do not remove rust or scale already formed; they are merely added to the cooling liquid to arrest further rust or corrosion. Most commercial antifreezes contain an inhibitor. If water alone is used as the coolant, an inhibitor should be added.

86. Flow of the Coolant

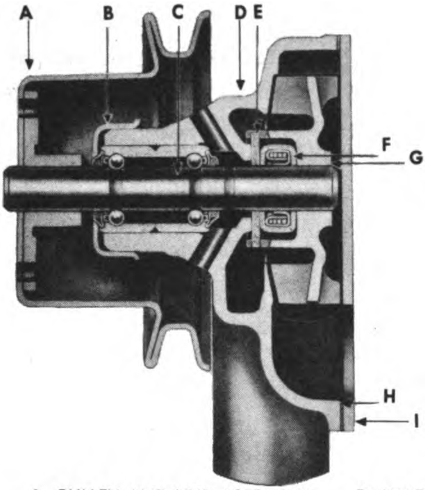
A simple liquid cooling system consists of a radiator, a coolant pump, piping, a fan, a thermostat, and a system of jackets and passageways throughout the engine within which the coolant circulates. Some engines are equipped with a water distribution tube inside the cooling passages that directs additional coolant to the points where temperatures are highest. Cooling of the engine parts is accomplished by keeping the coolant circulating and in contact with the metal surfaces to be cooled. The pump draws the coolant from the bottom of the radiator, forces it through the jackets and passages, and ejects it into a small tank on top of the radiator (fig. 105). The coolant passes through a set of tubes to the bottom of the radiator and again is circulated through the engine by the action of the pump. A fan draws air over the outside of the tubes in the radiator and cools the liquid as it flows downward. It should be noted that the liquid is pumped through the radiator from the top down. The reason for this direction of flow is that thermosiphon actions aids the pump to circulate the coolant. This simply means that as the coolant is heated in the jackets of the engine, it expands, becomes lighter, and flows upward to the top of the radiator. As cooling then takes place in the radiator tubes, the coolant contracts, becomes heavier, and sinks to the bottom. This desirable thermosiphon action cannot take place if the level of the coolant is permitted to become low.

Section II. LIQUID COOLING SYSTEM

87. Engine Water Jacket

a. The water passages in the cylinder block and cylinder head form the engine water jacket (fig. 105). In the cylinder block, the water jacket completely surrounds all cylinders along their full length. Within the jacket, narrow water passages are provided between cylinders for coolant circulation. In addition, water passages are provided around the valve seats and other hot parts of the cylinder block.

b. In the cylinder head, the water jacket covers the combustion chambers at the top of the cylinders and contains water passages around the valve seats when they are located in the head. The coolant flows from the cylinder block up into the cylinder head through passages called



A PULLEY AND HUB ASSEMBLY
B WATER PUMP BEARING RETAINER
C SHAFT AND BEARING ASSEMBLY
D WATER PUMP BODY
E WATER PUMP SEAL WASHER
F WATER PUMP SEAL ASSEMBLY
G WATER PUMP IMPELLER
H WATER PUMP PLATE GASKET
I WATER PUMP PLATE

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Figure 106. Water Pump.

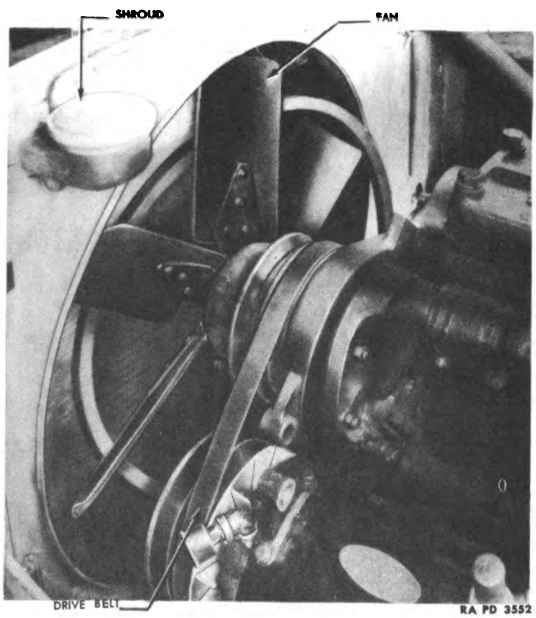

Figure 107. Cooling Fan, Drive Belt and Shroud.

water transfer ports. A tight seal at the ports between the cylinder head and block is very important. The water-tight seal at the ports, as well as the gastight seal at the combustion-chamber openings, is obtained with one large gasket called the cylinder-head gasket. It has two functions to perform: it must seal the extreme pressures of combustion within the cylinders and at the same time maintain a tight seal in the coolant joints at the water transfer ports.

88. Radiator

Radiators for automotive vehicles using liquid cooling systems consist of two tanks with a core between them to form the radiating element (fig. 105). The inlet tank contains an outside pipe called the radiator inlet and usually has a coolant baffle inside and above, or at, the inlet opening. The radiator filler neck is generally attached to the upper part of the top tank and has an outlet to the overflow pipe. The outlet tank also has a pipe opening (radiator outlet).

a. The inlet tank collects incoming coolant and distributes it across the top of the radiator core. The baffle in the tank assists in distributing the coolant to the water tubes and also prevents coolant from being thrown out of the radiator. The over-flow pipe provides an opening from the radiator for escape of coolant or steam that otherwise might case excessive pressure which would rupture the thin metal walls of the radiator. The bottom tank collects coolant flowing from the core and discharges it through the radiator outlet.

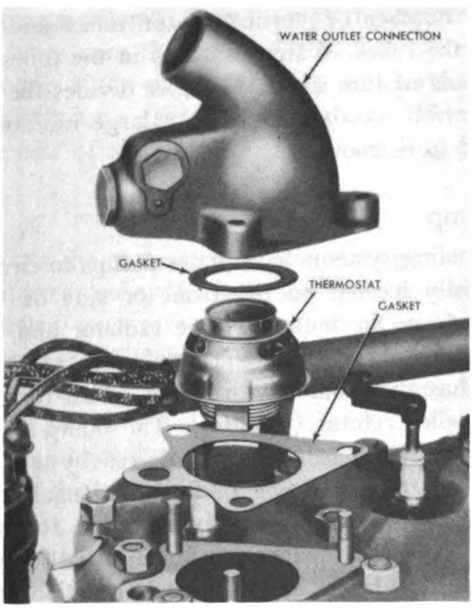

Figure 108. Thermostat.

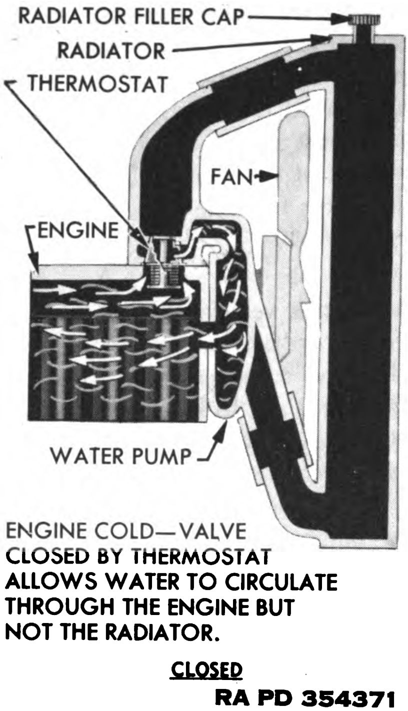

Figure 109. Thermostat Closed.

b. Some liquid cooling systems have tubular radiator cores which consist of a large number of vertical water tubes and many horizontal air fins around the tubes. Water passages in the tubes are narrow, and the tubes are made of thin metal. The core divides the coolant into very thin columns or ribbons, thus exposing a large radiating surface to the volume of liquid to be cooled.

89. Water Pump

All modern cooling systems have water pumps to circulate the coolant. The pump, usually located on the front or side of the engine block, receives coolant from the bottom of the radiator and forces it through the water jacket into the radiator inlet tank. The pump is a centrifugal-type pump and has an impeller with blades which force the coolant outward as the impeller rotates (fig. 106). The pump and fan usually are driven from a common V-belt which is driven by a pulley at the front end of the crankshaft. Advantages of the centrifugal pump are that it is inexpensive, circulates great quantities of liquid for its size, and it is not clogged easily by small particles of dirt. Another advantage is that it permits limited circulation by thermosiphon action even if the engine is not running.

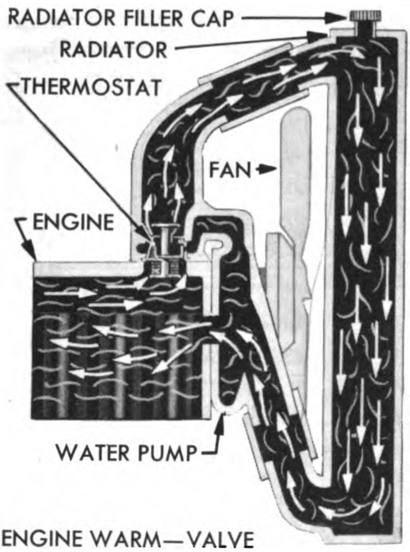

Figure 110. Thermostat Open.

90. Fan and Shroud

The fan pulls a large volume of air through the radiator core. In addition to removing heat from the radiator, this flow of air also provides some direct air cooling of the engine. Military vehicles are often equipped with a tunnel-like structure (shroud) around and behind the fan. The shroud directs the flow of air for most effective cooling (fig. 107).

91. Thermostat

As the pump starts the coolant circulating through the system as soon as the engine is started, no matter how low the temperature, a thermostat must be installed to assure quick warm-up and to prevent overcooling in cold weather. A thermostat regulates engine temperature by automatically controlling the amount of coolant flowing from the engine block to the radiator core.

a. When the engine is cold, the thermostat is closed and the coolant is recirculated through the water jacket without entering the radiator. As the engine warms up, the valve slowly opens and some of the coolant begins to flow through the radiaor, where it is cooled. The thermostat is merely a heat-operated unit which controls a valve between the water jacket and the radiator. A typical thermostat consists of a flexible-metal

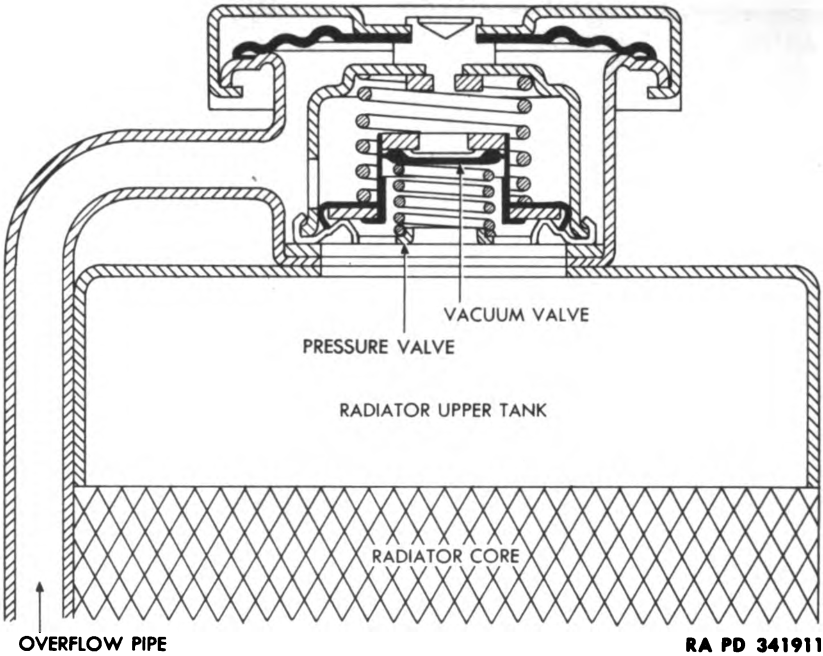

Figure 111a. Pressure Radiator Cap.

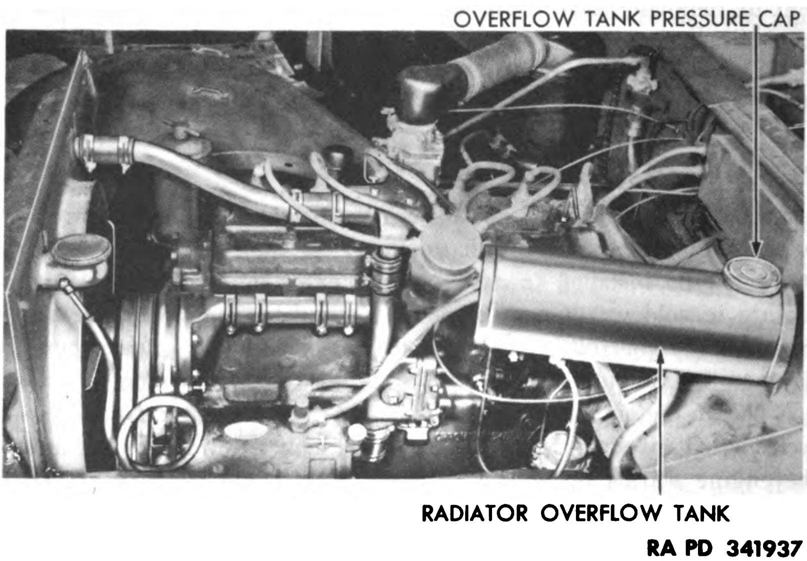

Figure 111b. Overflow Tank and Pressure Cap.

bellows attached to a valve (fig. 108). The sealed bellows, which is expandable, is filled with a highly volatile liquid such as ether. When the liquid is cold the bellows chamber is contracted and the valve is closed (fig. 109). When heated, the liquid is vaporized and expands the chamber. As the chamber expands, the valve opens (fig. 110). Other types include a sealed copper bellows containing only air; another is bimetallic and depends upon the difference in coefficients of expansion of the two metals for its operation.

b. The thermostat is located between the water jacket and the radiator, usually in the housing at the cylinder-head water outlet. It is constructed so that if it fails to function properly it will fail in the open position, allowing free circulation of water through the engine.

c. Some military vehicles are equipped with air inlet screens or shutters. They have no direct connection with the cooling system and are primarily for protection. However, they may be used to supplement or replace the action of a thermostat and are operated either by hand or by an automatic thermostatic device. The shutters restrict the flow of cool air through the radiator when the coolant is below a predetermined temperature. When the coolant reaches the proper temperature, the shutters start to open.

92. Pressure Radiator Cap

Some cooling systems are sealed and use a pressure-type radiator cap (fig. 111). By closing off the overflow-pipe opening, the pressure cap prevents overflow loss of coolant during normal operation. It also allows a certain amount of pressure to develop within the system, which raises the boiling point of the coolant and permits the engine to operate at higher temperatures without coolant overflow from boiling. The cap contains two spring-loaded normally closed valves which seal the system. The larger valve is the pressure valve, and the smaller one is the vacuum valve. The pressure valve acts as a safety valve to relieve extra pressure within the system; the vacuum valve opens only when the pressure within the cooling system drops below the outside air pressure as the engine cools off. Higher outside pressure then forces the vacuum valve to open, allowing air to enter the system by way of the overflow pipe.

93. Overflow Tank

When the cooling system is equipped with an overflow tank the pressure cap is placed on the tank instead of on the radiator, and a plain cap is used on the radiator. Overflow or surge tanks are special equipment for operation in hot or dry country. The coolant expands as it is heated and contracts as it cools, consequently, the level of coolant in the radiator is constantly changing as the engine operating temperature changes. This condition is further aggravated when the temperature

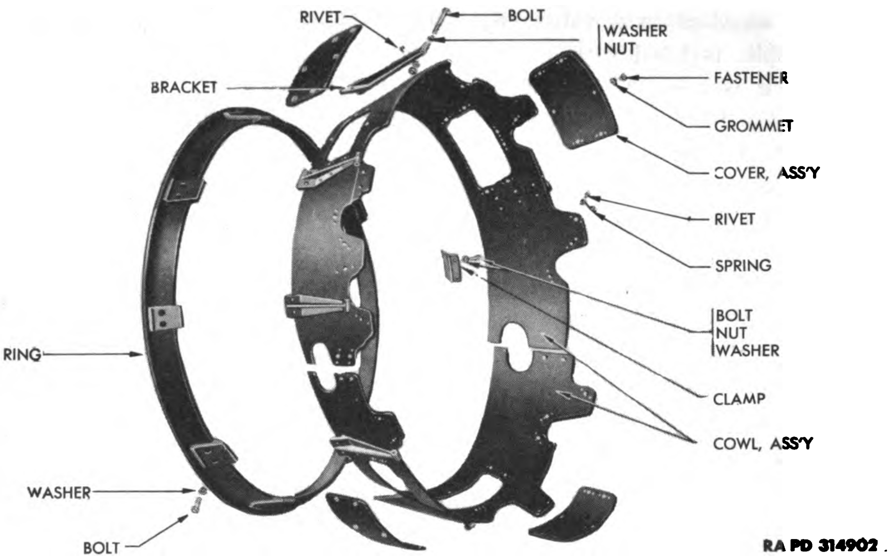

Figure 112. Radial Engine Cowling or Shroud.

becomes high enough to change the water to steam. The expansion is much greater and the pressure is also increased. The overflow tank makes it possible to keep the radiator full at all times. Overflow from the radiator, caused by the expansion or surging of steam vapor within the cooling system, passes through a tube to the overflow tank. The pressure cap on the overflow tank controls the pressure within the system in the same manner as described in the preceding paragraph. The plain cap on the radiator effectively seals the radiator opening so that the only vent to the atmosphere is through the cap on the overflow tank. When the coolant cools off it contracts and the pressure in the upper part of the radiator drops below atmospheric. The pressure in the overflow tank, which is maintained above atmospheric by the presure cap, forces the liquid to return to the radiator where it is available for circulation through the engine.

Section III. AIR COOLING SYSTEM

94. General

It is acknowledged that the thermal efficiency and power output of an engine are directly proportional to the heat of combustion. However, there are many disadvantages in permitting an engine to operate at top temperatures. Preignition, valve warpage, and spark-plug failures are only a few of the difficulties that may result. Some of the heat of combustion must be dissipated through a cooling medium. This is accomplished in the radial engine by air cooling, with substantial assistance from the fuel and lubrication systems. The radial engine is designed to consume a certain amount of oil as a cooling aid; it is also cooled by fuel contacting the metal parts prior to combustion.

95. Construction

There are several physical characteristics peculiar to the automotive air-cooled engine: the cylinder head and barrel are heavily finned for strength and adequate cooling; air deflectors or baffles direct the air flow to the cylinders and increase its velocity; a streamlined ring-type cowling or shroud surrounds the engine as another means of controlling the airflow; and a cooling fan is mounted on the flywheel to direct air to the cylinders, at the same time increasing the speed of the air.

96. Principles

Construction of the parts mentioned in the preceding paragraph embodied several fundamental principles of cooling: the rate of cooling is dependent upon the area exposed to the cooling medium, the heat conductivity of the metal used, the volume of metal or its size in cross section, the amount of air flowing over the heated surfaces, and the difference in temperature between the metal surfaces exposed and the cooling air.

97. Components

a. Cowling. The engine cowling surrounds the cylinders and helps keep the flow of air near them. It is made in three sections: the upper and lower sections and the outer ring (fig. 112). At the rear edge the cowling is connected to the cowl mounting bosses, to the head and inter-cylinder baffles, and also at the front of the rocker boxes. At the front edge the cowling is bolted to the outer ring, which provides a means of support and completes the cowling framework.

b. Cooling Fan. The cooling fan is mounted on the flywheel and operates within the front of the cowling (fig. 113). Its main job is to force air through the cooling passages formed between the cowling and baffles. In early engine design, the objective of the cooling system was to force a large volume of air across the engine, with a relatively small change in pressure; there was little obstruction to the free flow of air. However, it was noticed that the velocities over the rear heat-transfer surfaces of the cylinders were too low for good heat transfer. Some method had to be devised to increase the velocity of air and thereby increase the effectiveness of the fan.

c. Baffles. Baffles or deflectors (fig. 114) are used to obtain more effective use of the cooling air and to increase velocity of the air flow over the fins. They limit the volume of air and confine it to useful heat-transfer passages. The result is an appreciable difference in pressure

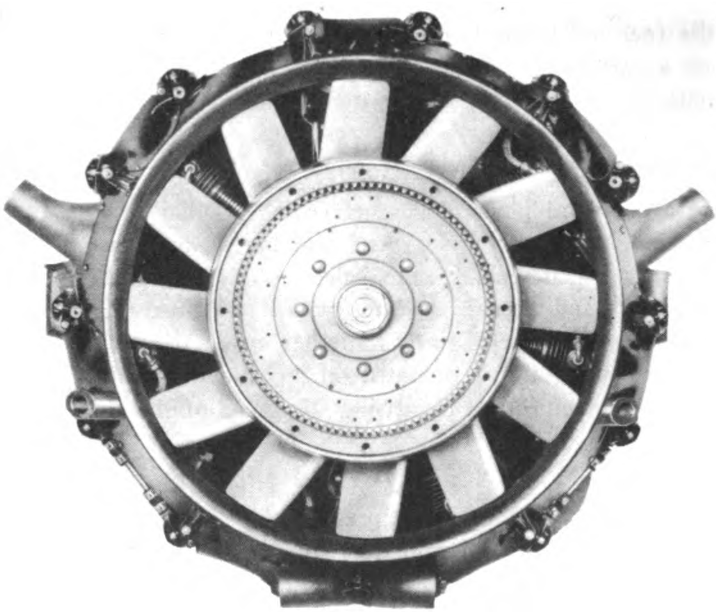

Figure 113. Radial Engine Cooling Fan.

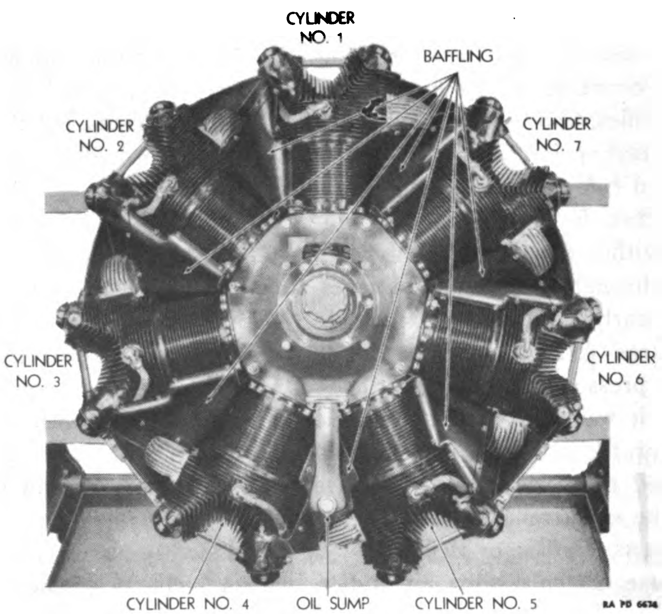

Figure 114. Radial Engine Baffles or Deflectors.

across the fin-baffle passages, which gives the desired increase in velocity for hastening heat transfer. (This is actually a simple application of the Venturi principle—a restriction is used to increase velocity and decrease pressure.) The conventional arrangement of baffles places them only on the rear of the cylinders, where they direct air from the cooling fan to the fins on the rear sides of the cylinders. The unbaffled front portion is cooled by turbulence attributed partly to air passing the front edge of the cowling and partly to rotation of the cooling fan.

d. FINS. The design of the fins also has some effect on the velocity of air flow. Use of high fins exposes more surface for heat transfer but increases the size of the air passages, reducing the velocity of air flow. On the other hand, if low fins are used the size of the air passages is reduced and velocity increases, but there is less surface available for heat transfer.

CHAPTER 9

LUBRICATING SYSTEMS

98. Purpose

a. Engine lubricating oils have four functions: to prevent metal-to-metal contact, assist in carying heat away from the engine, clean the engine parts as they lubricate, and form a seal between the piston rings and cylinder walls to prevent "blow by" of the combustion gases.

b. The primary function of engine lubrication is to reduce the friction between moving parts. Oils are used to reduce friction not only because friction uses up power that otherwise would be available to drive the vehicle but also because friction is destructive and creates heat that can cause moving parts to disintegrate. The greater the friction present betwen moving parts, the greater the energy required to ovecome that friction. This increase in energy merely adds to the heat generated. Moving parts that have become deprived of oil will melt, fuze, or seize after a very short period of engine operation. It is lubrication alone which makes possible the use of plain bearings or bushings in a modern engine. Cylinders and pistons must be effectively lubricated to prevent burning or seizure of the parts as they move against one another; friction is severe at certain points, particularly along the surfaces of the piston rings where they contact the cylinder walls. Although the crankshaft, connecting-rod, and piston-pin bearings, pistons, and rings are the most important engine lubrication points, there are many other parts which must have an adequate supply of oil. Valve stems must operate under stress and great ranges of temperature for long periods of time. Valve lifters and cams must be lubricated. All gears and accessory drives must be constantly bathed in oil, as must every other moving part in the engine that is subject to friction.

c. The oil is heated through contact with pistons and cylinder walls, after which it drops into the oil pan. The flow of air past the oil pan then cools the oil. In some instances where the oil pan is not exposed to a flow of air, it is necessary to add an oil-cooling unit (par. 105) which is a functional part of the water cooling system.

99. Engine Oils

a. Mineral oil is used in most internal combustion engines. Racing and other engines which operate under exceptional condition use castor oil

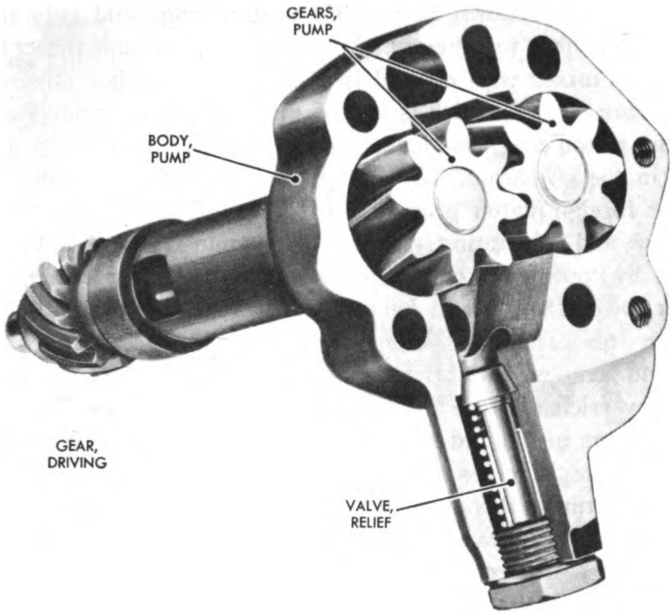

Figure 115a. Gear-type Oil Pump.

or other special oils. Lubricating oils are designated according to certain characteristics they possess and according to their reactions to certain tests. Oil ordinarily is classified according to its viscosity.

b. The viscosity of an oil refers to its resistance to flow. When oil is hot, it will flow more rapidly than when it is cold. In cold weather, therefore, oil should be thin (low viscosity) to permit easy flow. In hot weather, oil should be heavy (high viscosity) to retard the rate of flow. The atmospheric temperature in which a vehicle is to operate determines whether an engine oil of high or low viscosity should be used. If, for example, too thin an oil were used in hot weather, the oil would literally burn up; consumption would be excessively high, and the lubricating cushion between moving parts would be too thin to provide adequate protection for the parts. In cold weather heavy oil would not give adequate lubrication, because its flow would be sluggish; some parts of the engine might not receive any oil at all.

c. Oils are graded according to their viscosity by a series of SAE (Society of Automotive Engineers) numbers. The Army has standardized its engine oils on three grades: SAE 10, SAE 30, and SAE 50. The higher the SAE number, the more viscous or heavy is the oil. This method of designating oils has no connection with the quality of the oil.

d. Oil does not wear out, but it does become contaminated and diluted. When dust enters through the carburetor, some of it mixes with other foreign material to form deposits in the combustion chamber. Some of

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the dust also moves down beyond the piston rings and gets into the crankcase. This dirt, together with dirt entering through the crankcase breather pipe, mixes with oil and is deposited on the bearings, causing excessive wear. Water, which is one of the products of combustion, will seep by the piston rings as steam (especially in cold weather) and will condense in the crankcase. This water emulsifies with the oil and with any dirt or foreign matter present to form a thick sludge which clogs up the oil lines and lubricating passages. Contamination of engine oils is minimized by controlling engine temperature, by an air cleaner on the carburetor, by oil filters, and by controlled crankcase ventilation.

e. When lubricating oil becomes diluted with gasoline, it loses its viscosity and some of its lubricating qualities. Excessive use of the choke causes an overrich mixture to be forced into the cylinders. The excess gasoline remains in a liquid state and drains by the piston rings into the crankcase, where it mixes with the oil. When the engine operates at higher temperatures, this condition is corrected as the excess gasoline vaporizes in the crankcase and is carried off through the ventilation system. Presence of gasoline will not lower the oil level but will maintain or even raise it. However, the lubricating quality of the oil is definitely reduced.

100. Oil Pumps

Oil pumps are mounted either inside or outside the crankcase, depending on the design of the engine. They usually are mounted so that they can be driven by a worm or spiral gear directly from the camshaft. Oil pumps are of three general types—gear, vane, and plunger.

A gear oil pump is shown in figure 115. In this type a gear driven by the camshaft drives a companion gear. Oil is forced into the pump cavity, around each gear, and out the other side into the oil passages. The pressure is derived from the action of the meshed gear teeth, which prevents oil from passing between the gears and, instead, forces it around the outside of each gear. The two radial-engine pumps, the main pump and the front scavenger pump, are both of the gear type. The main pump is divided into two separate sections — a pressure pump and a scavenger pump. The pumps have two spur gears with large teeth for each section. The pressure section supplies oil for lubrication of the internal circuit; the scavenger section returns oil from the rear of the sump to the supply tank. The pump is driven through a bevel gear, which is driven by a similar gear on the left magneto drive shaft. The oil pump incorporates a pressure-relief valve which is a spring-loaded ball that rises when the desired pressure is reached and allows the excess oil to be delivered to the inlet side of the pump. Pressure regulation is accomplished by turning the adjusting screw, which increases or decreases the tension in the spring. The front scavenger pump is also a gear-type pump. It is built

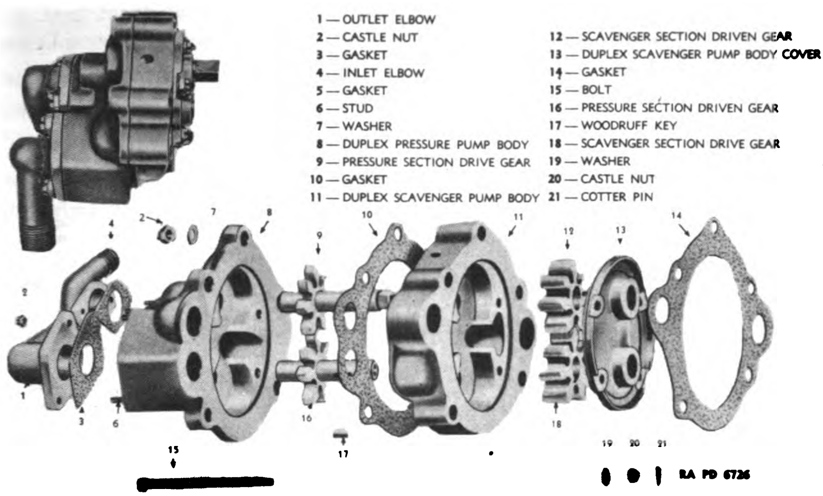

Figure 115b. Radial Engine Combination Pressure and Scavenger Gear-type Oil Pump.

into the crankcase front section and is driven directly off the crankshaft. Oil from the front part of the sump is forced through an external tube to the front scavenger pump, where it is returned to the supply tank. The scavenger section of the main pump picks up oil from the main part of the sump.

101. Oil Gages

There normally are two oil gages in an engine — one indicates the pressure of the oil in the lubricating system, the other indicates the oil level in the oil pan if the gage is in a wet-sump system. In the case of radial engines, oil is measured by oil-level gages located in storage tanks.

a. Pressure Gage. The pressure gage is mounted on the instrument panel. It is calibrated in pounds per square inch or in some other comparative system to indicate the pressure in the lubrication system. The gage on the instrument panel is connected to an oil line tapped into the main oil supply passage leading from the pump. The pressure of the oil in the system acts on a diaphragm within the gage, causing a needle to register on a dial. Vehicles are fitted with proper gages and instructions may be found in pertinent TM's as to the pressure which should be maintained. If some part of the engine lubricating system becomes clogged, the pressure indicated on the gage will rise abnormally. New or cold oil also will produce high pressure readings.

b. Oil-level Gage. The oil-level gage is usually of the bayonet type. It consists of a small rod which extends into the oil pan through a small hole in the side of the crankcase near the oil filler opening. It usually is

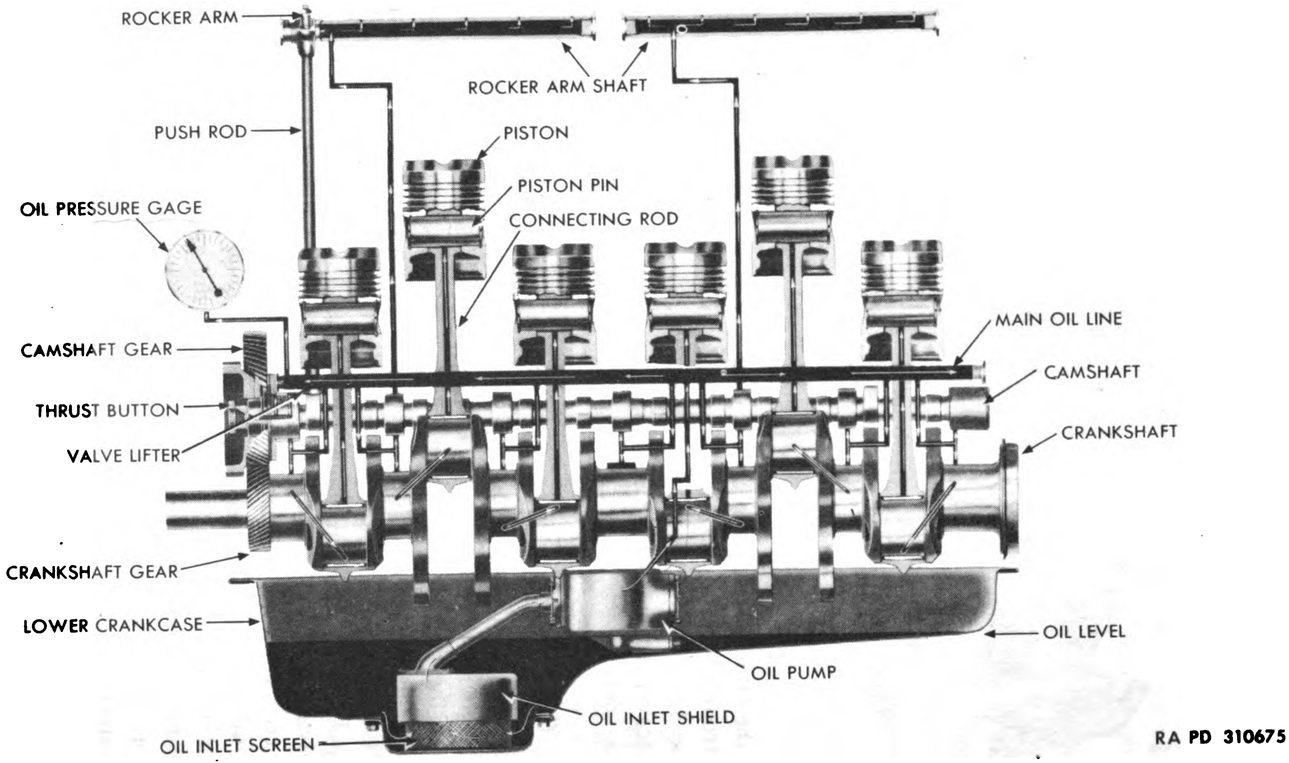

Figure 116a. Lubrication System of In-line and V-type Engines.

marked to show empty, low, and full oil levels. Readings are taken by pulling the gage out from its normal place in the crankcase, wiping clean, replacing and again removing and noting the height of the oil on the lower end.

c. Warning Lights. Electrically operated warning lights for indicating oil pressure are being used in combat vehicles. These lights register only abnormal pressure — too low or too high.

102. Oil Strainers

a. Most manufacturers of in-line and V-type engines place at least one oil strainer in the lubrication system (fig. 116). This is usually a fine-mesh bronze screen located so that all oil entering the pump from the oil pan must flow through it. The strainer will usually be hinged to the oil-pump inlet so that it floats on top of the oil. Thus, all oil taken into the pump comes from the surface. This prevents the pump from drawing oil from the bottom of the oil pan where dirt, water, and sludge are likely to collect.

b. The radial engine lubrication system has two finger-type screen strainers, one coarse and one fine. The coarse strainer is in the rear of the sump (fig. 117), and oil is forced through it on the way to the scavenger section of the main oil pump. The fine strainer is located in the oil pump to the right of the governor. Oil passes through this strainer on its way from the supply tank to the pressure section of the main pump. Most strainers are designed so that they will be collapsed by high oil pressure if they become clogged, thereby preventing the possibility of a complete stoppage of oil flow and consequent damage to the engine.

103. Oil Cleaner (Filter)

a. The oil cleaner is placed in the oil line above the pump (fig. 116). It filters the oil and removes most of the impurities (dirt, sand, and metal particles) that have been picked up by the oil as it has circulated through the engine and have not been caught by the strainer. The cleaner is mounted outside the engine and is connected so that part or all of the oil passes through it each time the oil is circulated through the engine. Some filters, called full-flow filters, are designed to handle the full output of the oil circulating pump, and all of the oil passes through them before being distributed to the engine parts. Other types divert only a small amount of the oil each time it is circulated and, after filtering it, return it directly to the oil pan.

b. A typical filter unit is shown in figure 118. The filtering element consists of an arrangement of screens and a filtering material capable of retaining impurities as the oil is forced through. Filters will eventually become blocked with impurities so that the oil cannot pass. For this reason, most filters are provided with relief or bypass valves which allow

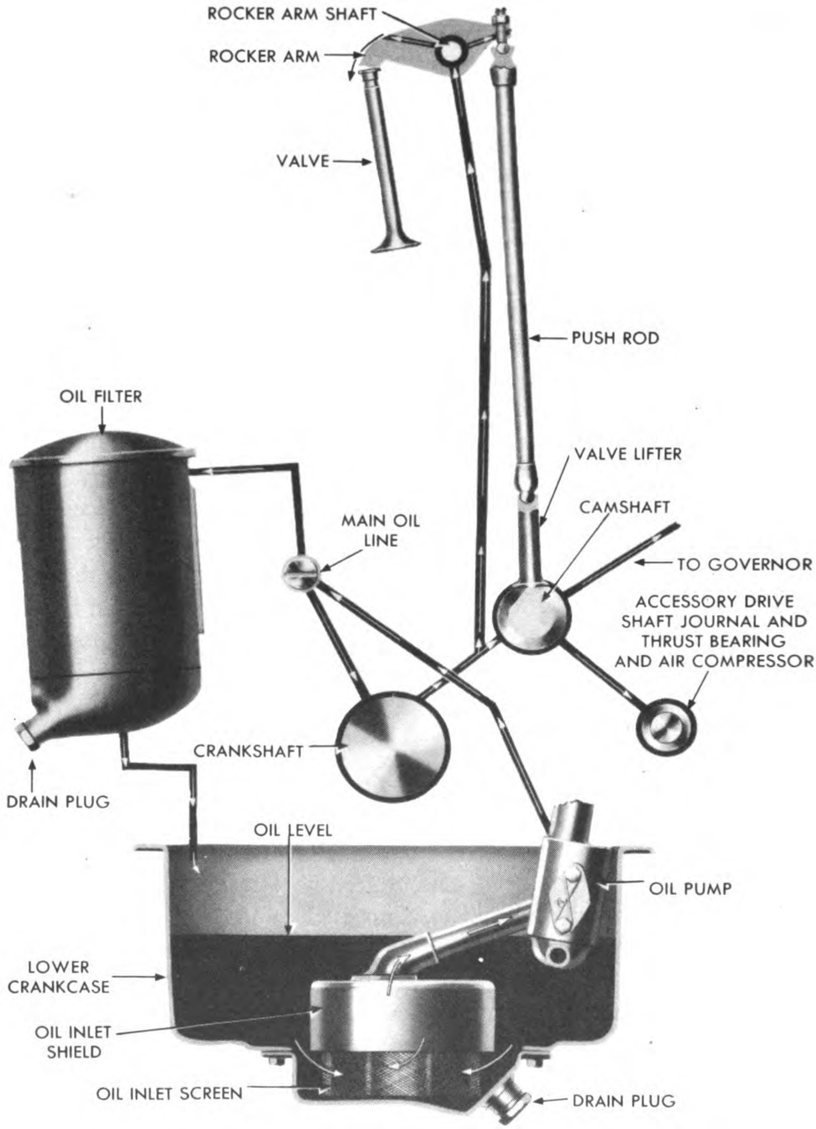

Figure 116b. Lubrication System of In-line and V-type Engines.

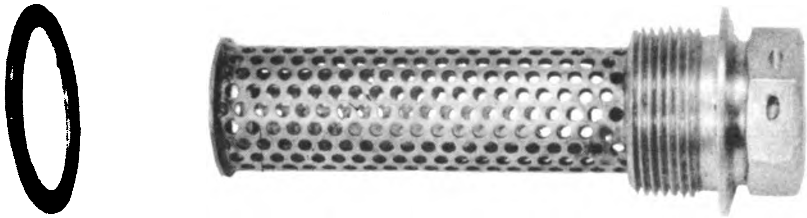

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Figure 117. Oil Strainer.

the oil to flow around the filter when the back pressure caused by clogging is greater than the tension of the relief-valve spring. Some filters must be replaced after they are clogged; in others, the filter element can be removed and cleaned.

c. The radial engine oil filter is usually of the disk type. It consists of a series of stationary disks or cleaning blades attached to the unit and a second set of filtering disks attached to a shaft. The oil passing into the engine system flows from the outside of the filtering disks to the inside through narrow slots between the disks, the dirt collecting on the outer surfaces. Cleaning is accomplished by turning the shaft; the stationary cleaning blades pass between the moving disks, and the dirt drops down into the chamber below the filter, where it stays until the filter unit is removed for cleaning. The movable filtering disks are turned by hand or by a hydraulic unit on top of the filter. Oil returning from the engine to the supply tank is used to operate the hydraulic unit.

104. Crankcase Ventilators

Gasoline vapor and steam are harmful if they are allowed to remain in the crankcase oil. Steam will condense and mix with oil to form sludge; gasoline vapor will condense and dilute the oil. There are two methods of removing these vapors from the crankcase. The first, or nonpositive, method consists of a breather tube which depends on the flow of air past its open end to remove the vapors. The second, or positive, method utilizes engine intake-manifold pressure to circulate air through the engine.

a. Breather Tube. One end of the breather tube opens into the crankcase above the oil level; the other end extends down under the vehicle, where there is sufficient air stream to create a low pressure at the open end of the tube (fig. 119). The pressure differential between the crankcase and the open end of the tube is sufficient to force any vapors out of the crankcase. Some breather tubes are placed so that air from the cooling fan will flow through the tube and increase the pressure differential.

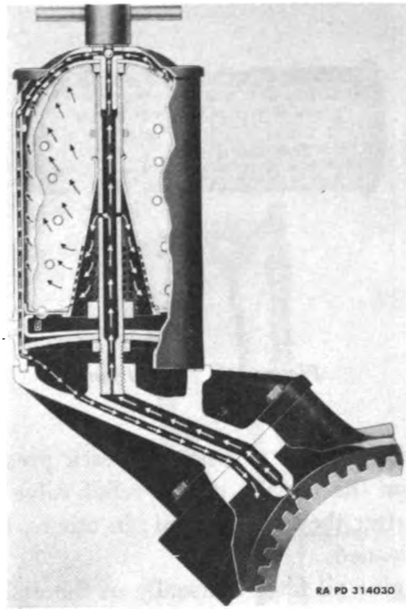

Figure 118. Oil Filter.

AIR

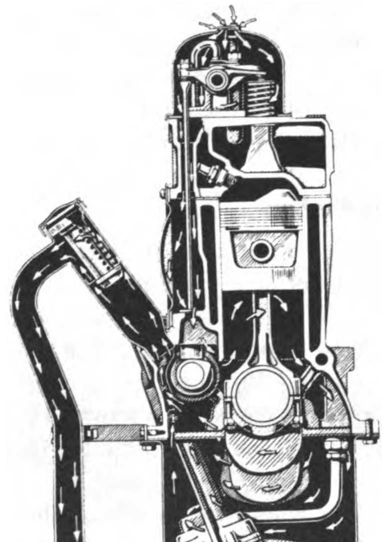

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Figure 119. Crankcase Breather Tube.

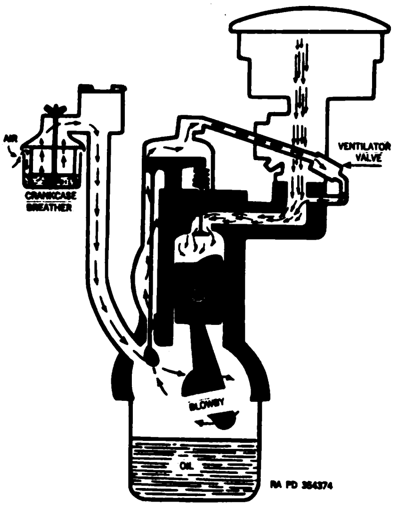

Figure 120. Positive Crankcase Ventilation.

There is an opening in the valve cover so that air can enter to replace that forced out the breather tube.

b. Positive Method. In this case air is drawn directly into the crankcase through a filter similar to a carburetor air cleaner (fig. 120). After circulating through the crankcase and picking up vapors, the air is forced upward and out of the engine through an opening in the valve cover. It then goes through a tube connected to the intake manifold. This tube has a restriction to regulate the amount of vapor being forced into the manifold, thereby minimizing the effect of the vapor on the air-fuel ratio delivered to the manifold by the carburetor. In connection with crankcase ventilators, it should be emphasized that, when possible, an engine should be operated at a coolant temperature of over 140° F. so that the volatile impurities in the crankcase will stay in a gaseous state and those already condensed will be vaporized and rise above the oil, where they can be removed.

c. Breather, Radial Engine. Most radial engines use a variation of the breather tube. Like in-line engine crankcases, the radial-engine crankcase has pressures generated within it by expansion of gases, by leakage of pressure past the piston rings, and by other similar actions. It is necessary to have some form of breather opening to relieve the pressures. Formerly, the radial engines on automotive vehicles used a system of internal breathing between the accessory and main crank sections; the only external vent was located in the front section and was connected with the external tank, where the oil supply is carried. This permitted oil vapor to condense and return to the system rather than be lost, as it would be if the engine were vented directly to the atmosphere. Now, however, the engine has external vents leading from the accessory and

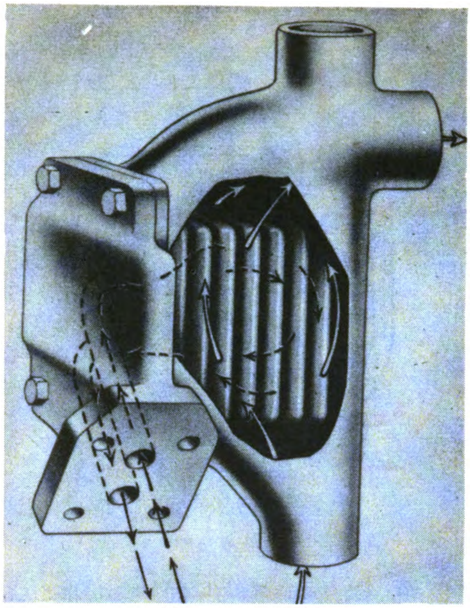

Figure 121. Oil Temperature Regulator (Cooler).

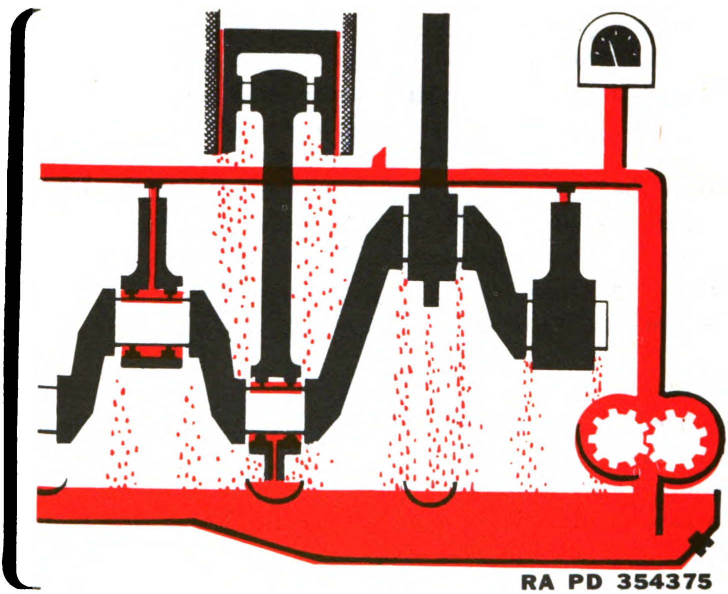

Figure 122. Combination Splash and Force-feed Lubrication System.

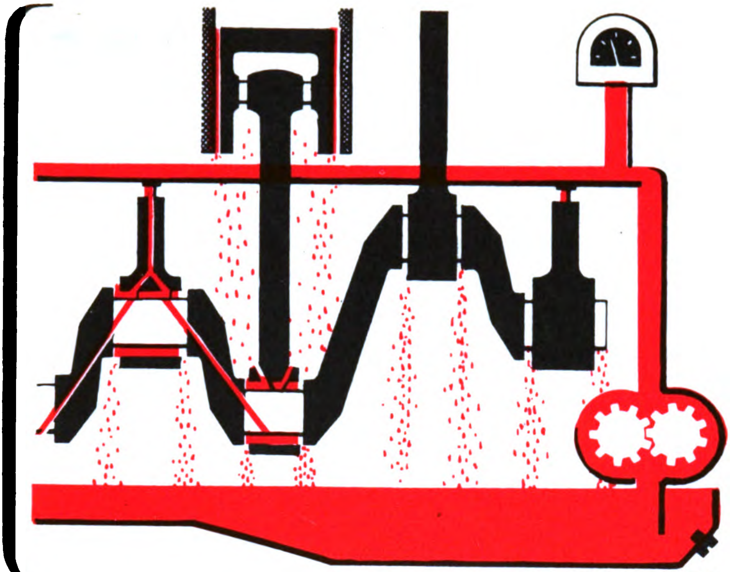

Figure 123. Force-feed Lubrication System.

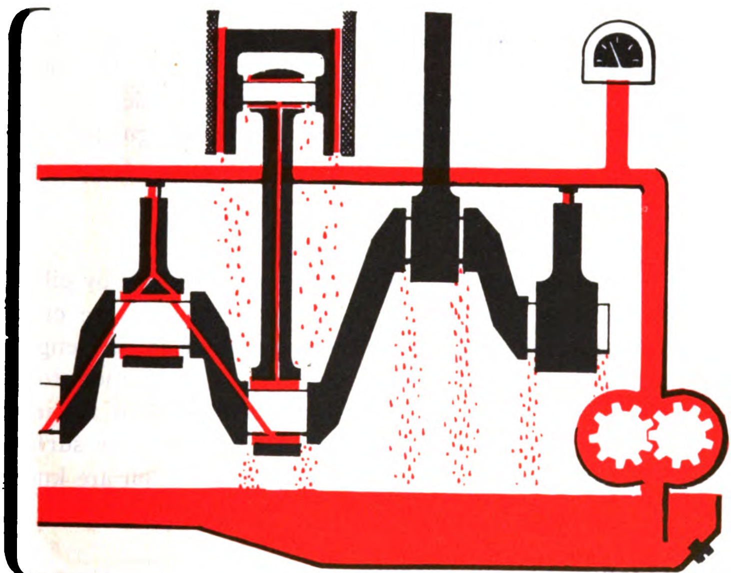

Figure 124. Full Force Feed Lubrication System.

tappet (rear part of main crank section) sections through an air filter to the atmosphere. Air goes through the filter in two directions. When the engine is cool and the pressure inside the crankcase is low, air is drawn in through the filter. As the engine warms up and pressure develops, the pressure is relieved by the gases escaping through the filter.

105. Oil-Temperature Regulator and Cooler

a. OIL-TEMPERATURE REGULATOR. The oil temperature regulator is used to prevent the oil temperature from rising too high in hot weather and to assist in raising the temperature during cold starts in winter weather. The regulator shown in figure 121 makes use of the liquid in the cooling system. It provides a more positive means of controlling oil temperature than does cooling by radiation of heat from the oil-pan walls. The regulator unit is made up of a core and a housing. The core, through which the oil circulates, is of cellular or bellows construction and is built to expose as much of the oil as possible to the coolant which circulates through the housing. The regulator is attached to the engine so that the oil will flow through the regulator after passing through the pump. The oil leaves the regulator either cooled or heated, depending upon the temperature of the liquid in the cooling system, and enters the oil passages to the engine parts.

b. OIL COOLER. Oil coolers of the type used with combat vehicles consist of a radiator, through which air is circulated by movement of the vehicle or the cooling fan. Oil from the engine is passed through this radiator and back to the engine and to the oil supply tank. This radiator acts only to cool the oil and does not function as a regulator in which the temperature may be increased during cold weather operations.

106. Lubricating Systems

All important working parts of an engine are lubricated by oil carried in the crankcase. The fact that oil is always present in the crankcase explains why the lubricating system used in most in-line engines is known as a wet-sump system. The dry sump is common to radial engines. The oil in the in-line engine wet-sump system is circulated under pressure (force-feed) or splash mechanically on the surfaces to be lubricated. The different methods of circulating the oil are known as splash, combination splash and force-feed, force-feed, and full force-feed.

a. COMBINATION LUBRICATING SYSTEM. Engines no longer use a straight splash system, but they do use splash in combination with force-feed. In the combination system, oil is pumped under pressure directly to the main bearings through oil passages (fig. 122). Positive pressure also is provided for lubrication of the camshaft bearings. Connecting-rod bearings are lubricated by dippers on the rod bearing caps, which dip into oil-filled troughs in the oil pan. The dippers entering the oil also splash oil up into the cylinders and over the pistons and cylinder walls. Lubrication of the valve mechanism in an overhead-valve engine is accomplished by oil pumped to the hollow rocker-arm shafts.

b. Force-feed Lubricating System. In the force-feed system of lubrication, oil is forced by the pump to the main bearings, the connecting-rod bearings, and the camshaft bearings (fig. 123). If the valves are overhead, the rocker arms are also force-fed as in the combination system. The cylinders and pistons are still lubricated by splash. The connecting-rod bearings receive oil from the main bearings through passages drilled in the crankshaft.

c. Full Force-feed Lubricating System. In the full force-feed system (fig. 124) all bearings mentioned in *b* above and the piston pin bearings in addition are lubricated under pressure. The pistons and piston pins are lubricated by oil forced through rifle-drilled passages which run the length of the connecting rods. Oil sprayed out of these passages lubricates the pistons and cylinder walls.

PART THREE

ELECTRICAL SYSTEMS AND RELATED UNITS

CHAPTER 10

ELECTRICAL SYSTEMS

Section I. BATTERY

107. General

a. Charging and Discharging. The storage battery provides electrical energy through a chemical reaction. When a generator in the electrical system of a motor vehicle produces more electrical energy than required for ignition and for operating electrical accessories, the surplus passes through the battery to reverse the chemical reaction. This is known as charging the battery. When the generator is not producing the necessary electrical energy the battery, through chemical reaction, can supply the energy required in the electrical system of the vehicle. The battery is then said to be discharging.

b. Comparison With Water Storage. In any system of storage, if more is taken out than is put back, the reservoir ultimately becomes empty. Comparing the electrical system of a motor vehicle to a water storage system (fig. 125) will explain why a storage battery runs down or becomes discharged. If more water is taken from the outlets than can be pumped into the tank, the tank eventually runs dry. Similarly, if the energy used by the starter, lights, horns, etc., exceeds the energy input from the generator, the battery eventually becomes discharged or loses its energy. If the engine is not in good order, more energy may be required for starting than the generator can put back in a limited time. Electrical accessories that continuously require more energy than the generator can provide are a drain on the battery and will discharge it.

108. Construction

The storage battery, as used for starting, lighting, and ignition purposes, consists of three or more cells, depending upon the voltage desired. A battery of three cells (2 volts each) connected in series is known as a

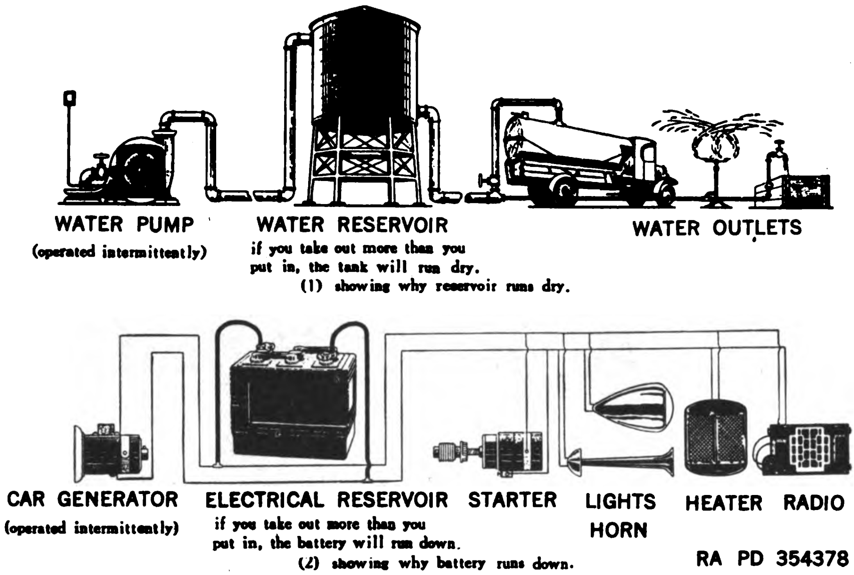

Figure 125. Comparison of Storage Battery and Water Reservoir.

6-volt battery and one of six cells connected in series is known as a 12-volt battery. Typical battery construction is shown in figure 126.

a. Plates. (1) Each cell consists of a hard rubber jar or compartment into which are placed two kinds of lead plates, known as positive and negative. These plates are insulated from each other by suitable separators and are submerged in a solution of sulphuric acid and water.

(2) The backbone of both the positive and negative plates is a grid made of stiff lead alloy casting. The grid, usually composed of vertical and horizontal cross members, is carefully designed to give the plates mechanical strength and at the same time to provide adequate conductivity for the electric current created by the chemical action. The active material, composed chiefly of lead oxides, is applied to the grids in paste form, allowed to dry and harden like cement. Part of a grid is shown in figure 127, with a cross section showing the active material in place. The plates are then put through an electrochemical process that converts the hardened active material of the positive plates into brown lead peroxide and that of the negative plates into gray, spongy, metallic lead. Plates that have been put through this process, known as forming the plates, are shown in figure 128 (1) and (2).

b. Groups. After the plates have been formed, they are built into positive and negative groups. The plates of each group are permanently joined by melting a portion of the lug on each plate to form a solid weld with a connecting post strap. The heat necessary for this process, termed "lead burning," is produced by a gas flame or an electric arc. The connecting post strap to which the plate lugs are burned contains a

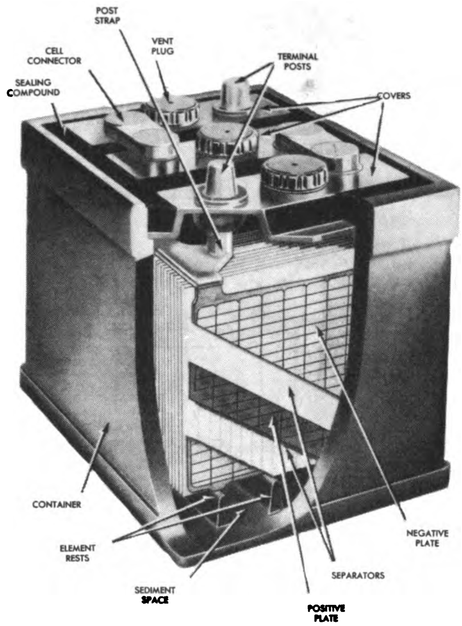

Figure 126. Storage Battery Cross Section.

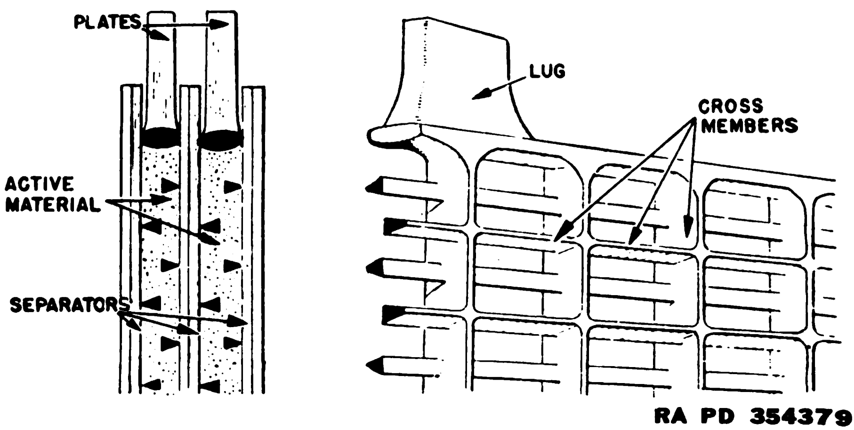

Figure 127. Section of Battery Plate Grid with Cross Section Showing Active Material in Place.

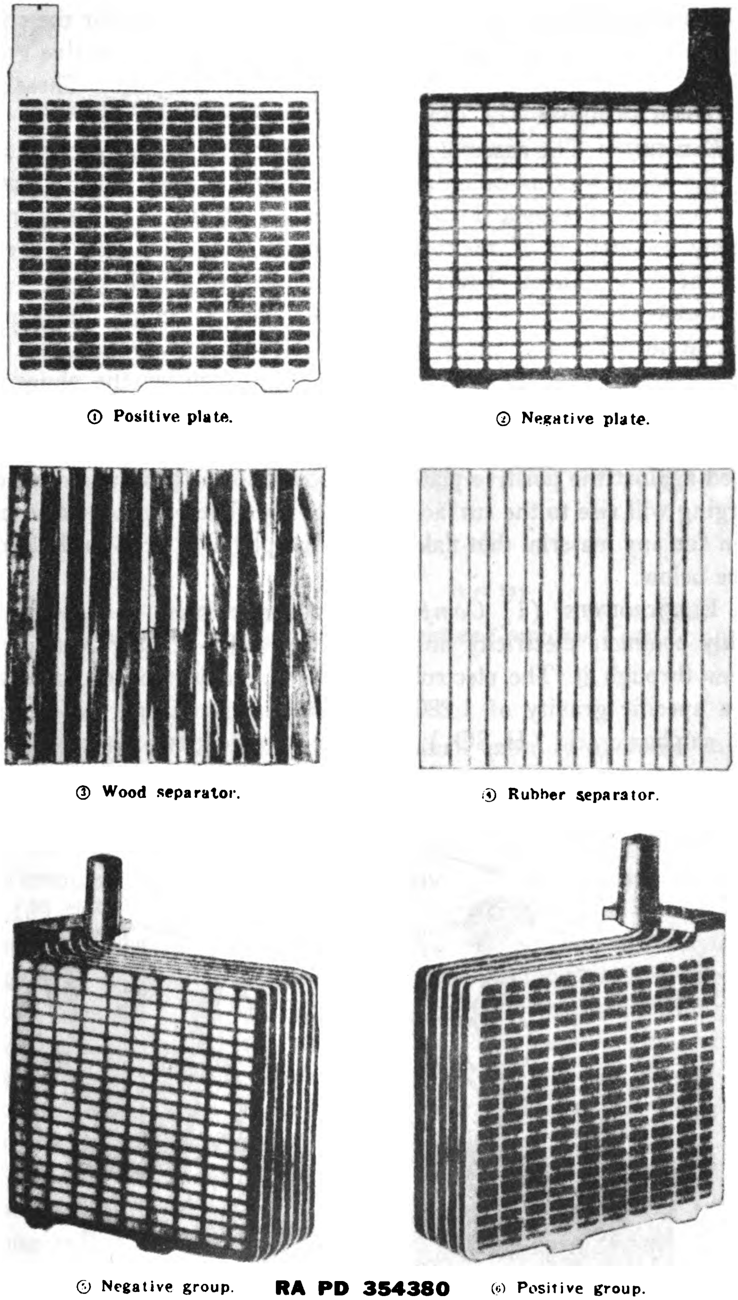

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Figure 128. Storage Battery Plates and Separators.

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cylindrical terminal which forms the outside connection for the cell. The negative group of plates has one more plate than the positive group to provide a negative plate on both sides of all positive plates. These groups are shown in figure 128 (5) and (6).

c. Elements. The assembly of a positive and negative group, together with the separators, is called an element. Since storage battery plates are more or less of standard size, the number of plates in an element is roughly a measure of the battery capacity. The distance between the plates of an assembled element is approximately ⅛ inch.

d. Separators. To prevent the plates from touching and causing a short circuit, sheets of insulating material (either wood, porous rubber, or spun glass) called separators are inserted between the plates. These separators (fig. 128 (3) and (4)) are thin and porous so the electrolyte will flow easily between the plates. One side of the separator (that placed against the positive plate) is grooved so the gas that forms during charging will rise to the surface more readily. These grooves also provide room for any material that flakes from the plates to drop to the sediment space below.

e. Electrolyte. (1) *Composition.* An electrolyte is a liquid which readily conducts electricity and is decomposed when an electric current passes through it. The electrolyte in the lead-acid storage battery, having a specific gravity of 1,280, is composed of one part of chemically pure sulphuric acid (H_2SO_4) and approximately two and three-fourths

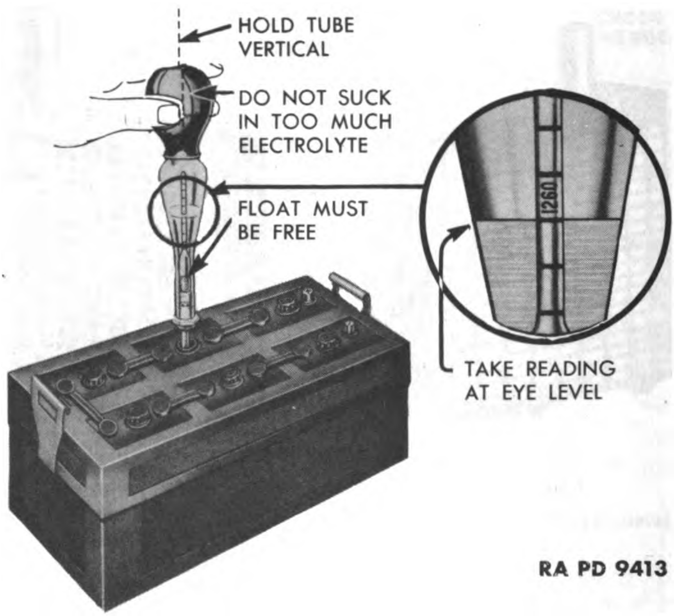

Figure 129a. Taking Specific Gravity Reading of a Battery with Hydrometer.

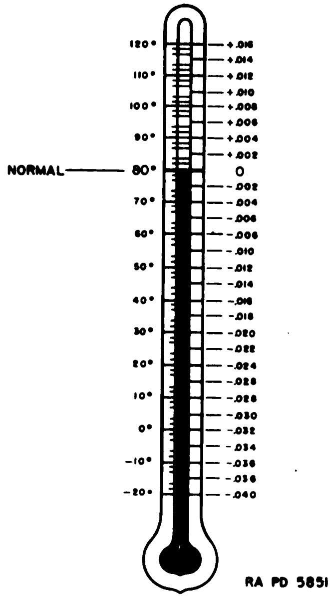

Figure 129b. Hydrometer Temperature Correction Chart.

parts by volume of distilled water. A small quantity of some impurity introduced into the acid solution by using impure water might interfere with the chemical action and cause battery trouble.

(2) *Specific gravity readings.* Specific gravity is the weight of a substance compared to weight of the same volume of chemically pure water at 4°C. (39.2°F.) The specific gravity of sulphuric acid is 1.835; that is, sulphuric acid is 1.835 times heavier than water. The electrolyte of a storage battery is a mixture of water and sulphuric acid in such proportions that when the battery is fully charged it has a specific gravity of 1.280 at 80°F. Since the amount of sulphuric acid in the electrolyte changes with the amount of electrical charge, the specific gravity of the electrolyte changes with the amount of charge. This provides a convenient way of measuring the degree of charge in a battery.

(3) *Hydrometer.* (*a*) Specific gravity of the electrolyte can be measured by a hydrometer syringe (fig. 129). A reading is taken by drawing sufficient electrolyte into the syringe to float the hydrometer element within the glass tube. For convenience, the reading is spoken of as being 1150, 1200, 1280 etc. instead of 1.15, 1.2, 1.28 etc., which is true specific gravity. The electrolyte is returned to the cell by compressing the bulb, and the reading of the next cell can then be taken.

(*b*) Specific gravity readings of from 1270 to 1285 indicate that the battery is fully charged. Readings between 1200 and 1215 indicate that the battery is more than half discharged, and starter and accessories

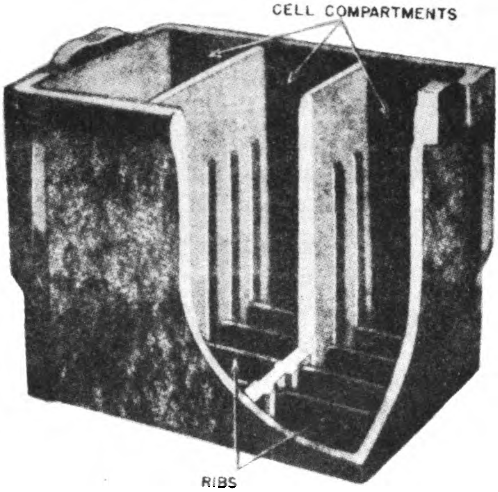

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Figure 130. One-piece Battery Container Having Three Cell Compartments.

should be used sparingly until the battery is again fully charged. Readings between 1125 and 1140 indicate that the battery is nearing a discharged condition and immediate charging is necessary, otherwise serious damage will result.

(4) *Temperature correction.* All hydrometer readings given are usually based on the normal temperature of 80°F. for the electrolyte. This refers to the temperature of the liquid itself and not to the temperature of the surrounding atmosphere. To make temperature correction, add 1 to the hydrometer reading for every 2.5° above 80°F. and subtract 1 for every 2.5° below 80°F. For example, if the reading is 1250 at 100°F., add 8 to give a corrected reading of 1258. If the reading is 1270 at 20°F., subtract 24 to give a corrected reading of 1246. Some storage battery manufacturers use other than 80°F. as a base for temperature correction. It is usually unnecessary to make allowance for temperature variations, but it is well to bear them in mind, otherwise the hydrometer reading will be misleading.

f. CONTAINER. (1) A battery container is a receptacle for the cells that make up the battery. It is made of hard rubber or a composition material which is resistant to acid and mechanical shock. Most motor vehicle batteries are assembled in a one-piece container with three or six compartments for the individual cells (fig. 130). One element and enough electrolyte to cover the plates are inserted into each cell compartment.

(2) Stiff ridges or ribs molded in the bottom of the container form a support for the plates and a sediment recess for the flakes of active material which drop off the plates during the life of the battery. The

sediment is thus kept clear of the plates so that it will not cause a short circuit across them.

g. Cover. A hard rubber cover, provided with openings for the two terminals of the element and for a vent plug, is placed on each cell (fig. 131). The cells are then sealed with pitch-like compound and connected in series by burning cell connectors on the terminals. The vent plug allows accumulated gas to escape and prevents the electrolyte from splashing outside the battery. Checking and filling the battery can be done by unscrewing the vent plug.

109. Principle of Operation

When a cell is fully charged, the negative plate is spongy lead, the positive plate is lead peroxide, and the electrolyte contains a maximum amount of sulphuric acid. Both the negative and positive plates are very porous and are readily acted upon by the acid. A cell in this condition can produce electrical energy through reaction of the chemicals.

a. Discharge. If the terminals of the battery are connected to a closed circuit, the cell discharges to supply electric current. The chemical process that occurs during discharge changes both the lead (Pb) of the negative plate and the lead peroxide (PbO_2) of the positive plate to lead sulphate ($PbSO_4$) and the sulphuric acid (H_2SO_4) to water (H_2O). Thus the electrolyte becomes weaker during discharge, since

Figure 131. Battery Components.

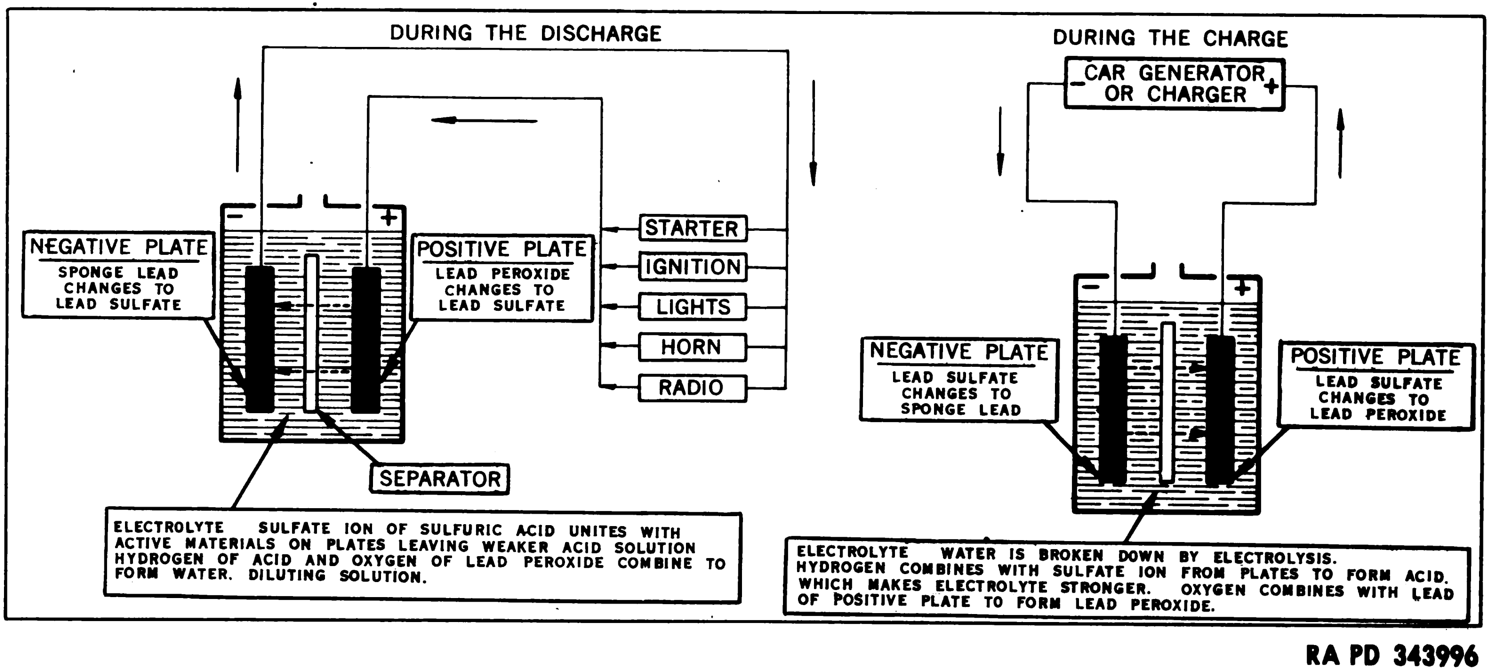


Figure 132. Chemical Action in a Storage Battery.

the water increases and the sulphuric acid decreases. As the discharge progresses, the negative and the positive plates finally contain considerable lead sulphate. The discharge should always be stopped before the plates have become entirely changed to lead sulphate.

b. CHARGE. (1) *Chemical action.* To charge the cell, an external source of direct current must be connected to the battery terminals. The chemical reaction is then reversed and returns the positive and negative plates and the electrolyte to their original condition. When all the sulphate (SO_4) on the plates has been returned to the electrolyte to form acid (H_2SO_4), the cell is fully recharged and ready to be used for the next discharge. Charging must be started before both plates have become entirely sulphated. If this is not done, the plate surfaces are no longer chemically different and will not respond to the charging current since two dissimilar plates must be in the electrolyte to produce the action. The chemical processes in the cell during discharge and charge can be followed from figure 132.

(2) *Electrical.* A storage battery can be charged by direct current only. If only alternating current is available, a motor-generator or a rectifier must be used to convert it into direct current. In charging, the positive wire of the charging circuit must always be connected to the positive (+) terminal of the battery and the negative wire to the negative (—) terminal. The electrolyte in each cell should be brought to the proper level by the addition of pure water before the battery is connected for charging.

c. CAPACITY. All batteries are given a normal capacity rating according to the ampere-hours obtainable from the battery under certain working conditions. The capacity of a battery is the number of amperes delivered multiplied by the number of hours the battery is capable of delivering this current. One of the inherent characteristics of a storage battery is that its ampere-hour capacity depends upon the rate of discharge. A battery will give more ampere-hours at a long, low, or intermittent discharge rate than at a short, high, or continuous discharge rate. This is because the voltage drops relatively faster at higher rates. Like other chemical processes, that of the battery is much less efficient in cold weather than in hot weather. At 0°F. a battery has only about 40 percent of the full cranking capacity available at 80°F. In an emergency, little if any permanent harm will result if the battery is discharged at a very high rate, provided that it is promptly recharged. The battery is likely to deteriorate if left in a discharged condition.

Section II. GENERATING SYSTEM

110. The Generator

a. DEFINITION AND USE. The generator is a machine (dynamo) in which the principle of electromagnetic induction is used to convert mechanical energy into electrical energy. The generator restores to the battery the current used in cranking the engine, and it also supplies current to carry the electrical load of the lights, ignition, radio, horn and so forth, up to the limit of the generator's capacity. A generator and a motor are fundamentally the same in construction and utilize the same electrical principles; however, their operation is opposite. By reversing the operation, one unit may be made to serve both purposes.

b. COMPONENTS. The generator consists essentially of an armature, a field frame, field coils, and a commutator with brushes, or collector rings with brushes, to establish electrical contact with the rotating element. The magnetic field of the generator is usually produced by by electromagnets or poles magnetized by current flowing through the field coils. Soft iron pole pieces are contained in the field frame that forms the magnetic circuit between the poles. Two- and four-pole frames are the most common although machines may be designed to have any even number of poles.

c. FIELD FRAMES. Figure 133 shows several types of field frames most commonly used and the magnetic circuits in each. On some frames, the field coil is wound on each pole to produce the magnetic field, (A) while in the others there is but one large field coil, (B). In the two-pole

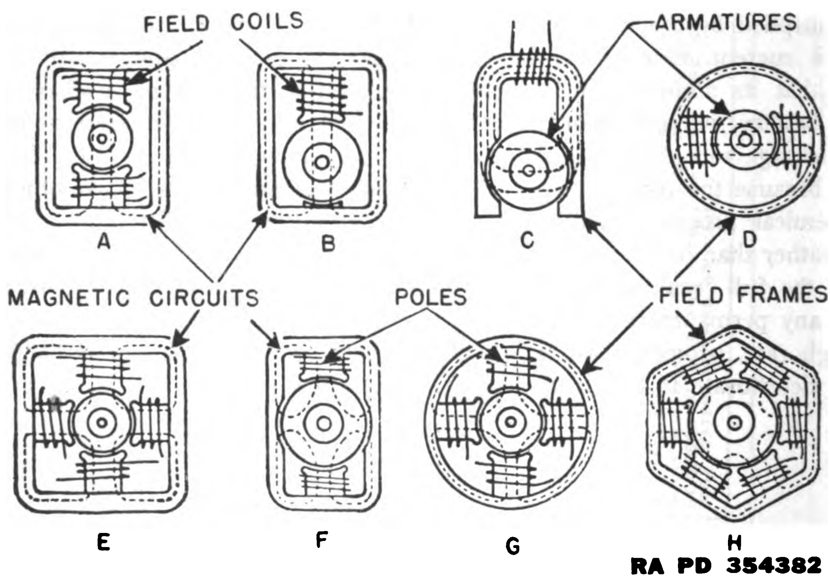


Figure 133. Types of Field Frames and Their Magnetic Circuits.

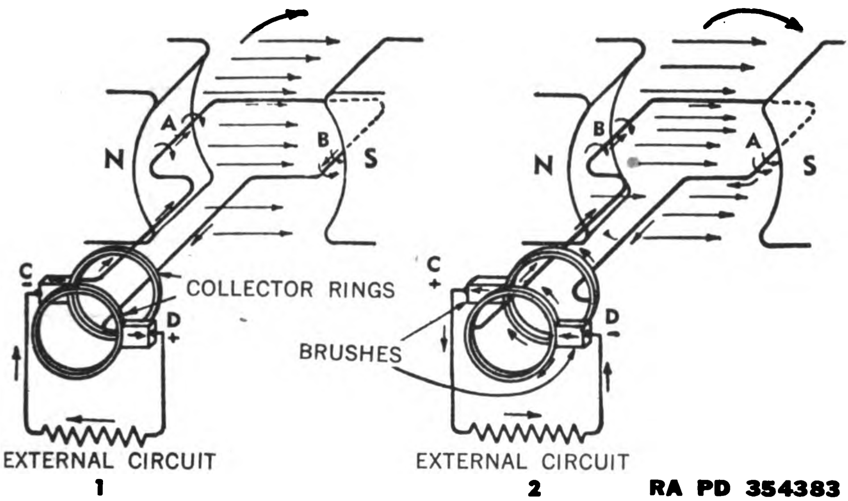


Figure 134. Simple Alternating Current Generator.

type of frame the magnetic circuit flows directly across the armature, (A, B, C, and D), while in the four- and six-pole types each magnetic circuit flows through only a portion of the armature core (E, F, G, and H). For this reason the armature must be constructed in accordance with the number of field poles, since current is generated when the coil winding on the armature cuts each magnetic circuit.

d. BRUSHES, COMMUTATOR, COLLECTOR RINGS. The current is collected from the armature coils by the brushes (usually made of carbon) which make rubbing contact with a commutator or collector rings. The commutator consists of a series of insulated copper segments mounted on one end of the armature, each segment connecting to one or more armature coils. The commutator converts the alternating current generated in the armature coils into direct current for charging the battery. The armature coils of an alternating-current generator are connected to collector rings which collect the current in the same form as it is generated in the armature windings.

111. Simple Alternating Current Generator

a. INDUCED ELECTRICAL PRESSURE. If a single loop of wire is revolved in the magnetic field between a north pole and a south pole, there will be an electrical pressure induced in the two sides of the loop, and the voltage and current induced will be in definite relation to the direction of the magnetic field and the direction of rotation. If each end of the loop is connected to a metal collector ring upon which a brush rests (fig. 134, C and D), this induced electrical pressure will cause a current to flow through any external circuit which may be connected across the two brushes.

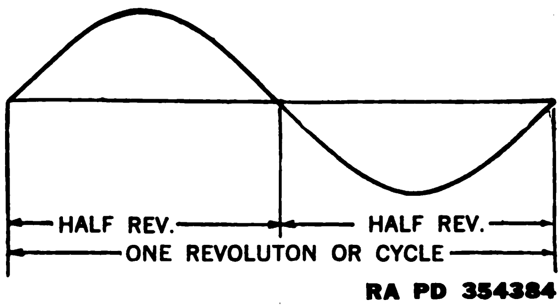


Figure 135. Current Wave from Simple Alternating-Current Generator.

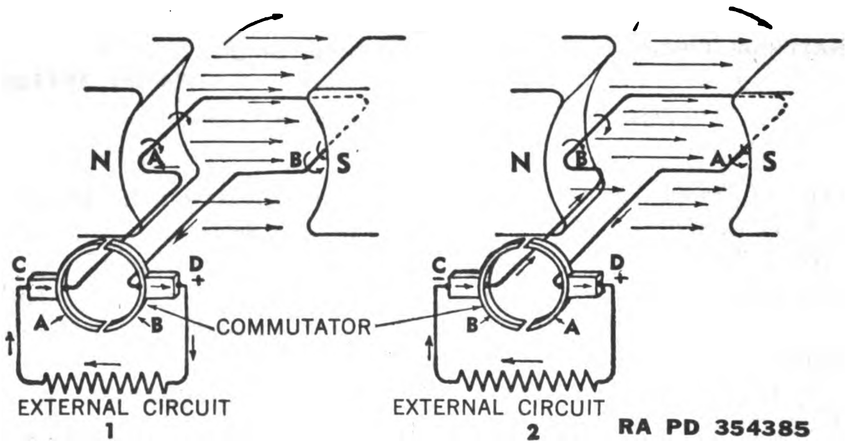


Figure 136. Simple Direct Current Generator.

b. Induced Alternating Current. If the loop is rotated through a complete revolution, sides A and B will cut magnetic lines of force first in one direction (fig. 134 (1)) then in the other (fig. 134 (2)), inducing an alternating voltage across the brushes and causing an alternating current to flow through the external circuit. A study of figure 134 shows the current will make one complete reversal or cycle in one revolution of the loop. The value of the current during one complete revolution of the loop may be represented graphically by the curve (fig. 135) known as the sine curve. The highest and lowest points of the curve represent the current at its maximum value which is reached when the loop is in line with the field poles.

112. Simple Direct Current Generator

a. Converting to Direct Current. The alternating current produced in the loop may be converted into direct current in the external circuit by replacing the two collector rings with a simple two-segment com-

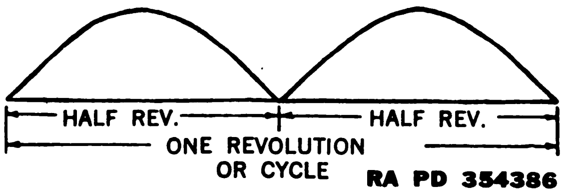


Figure 137. Current Wave from Simple Direct Current Generator.

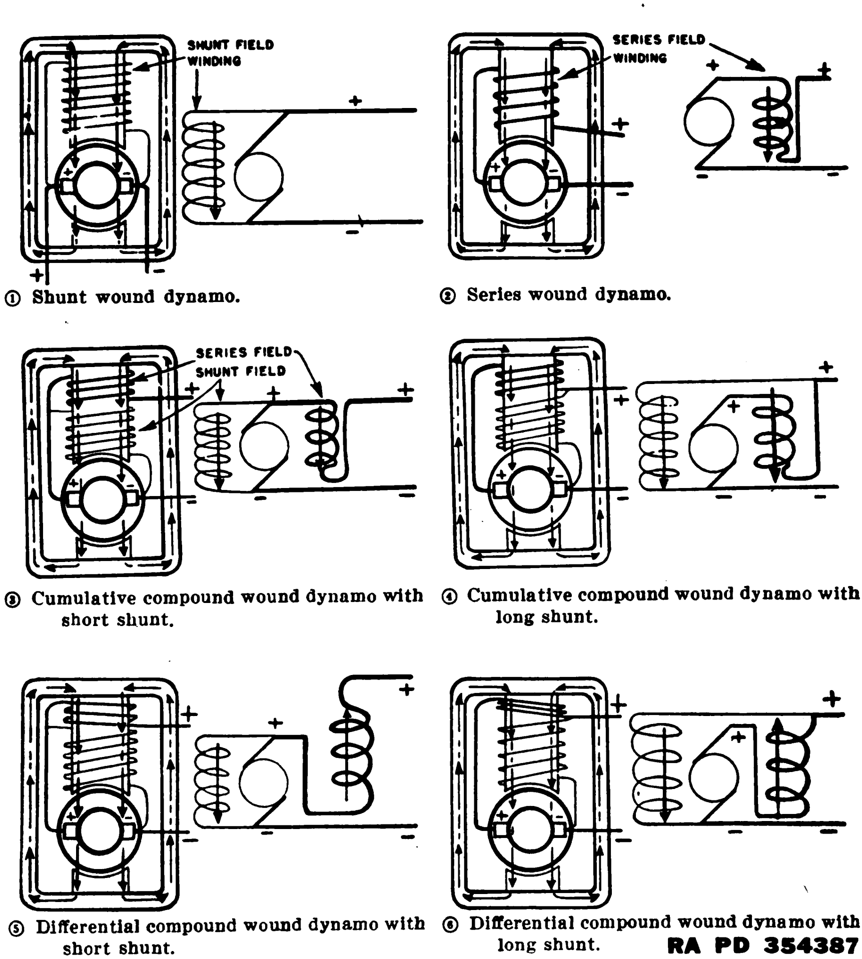
mutator (fig. 136). The two segments of the commutator are connected to the two ends of the loop but insulated from each other. The only connection between the commutator segments, besides the one through the armature loop, is through the brushes and the external circuit. The brushes remain stationary and make rubbing contact first with one segment and then with the other, as the commutator and loop rotate as a unit. With this arrangement, the segments change connection with the brushes as the induced voltage reverses in the loop. As a result, the current is always made to flow through the external circuit in the same direction. The current thus obtained is a direct current, graphically represented in figure 137. Comparing figures 137 and 135, it can be seen how use of a commutator produces direct current by reversing one of the impulses of current generated in the generator.

b. Armature Core. In practice, the armature core, which is in the form of a laminated iron cylinder, is wound with a great many coils equally spaced around its circumference, each coil being connected to a pair of segments in the commutator. These coils are connected so that the current impulse of one coil overlaps the current impulse of the next much the same as the power impulses overlap in an eight- or twelve-cylinder engine. The result is practically a continuous flow of current.

113. Field Windings

a. Series and Shunt Field Winding. (1) The field winding may be connected in parallel with the armature winding, that is, across the brushes, in which case it is known as a shunt field winding. It may also be connected in series with the armature winding, in which case it is known as a series field winding. The magnetic field of a generator or motor is produced by a field winding of the shunt or series type or a combination of the two. Various methods may be used in winding the field poles of a generator or motor to suit the purpose for which it is to be used. Figure 138 shows the different ways in which the shunt and series field may be connected on the same type of frame. The markings and arrows refer in each case to the direction of current for a generator. The small diagram to the right of each main sketch is the conventional way of indicating in electrical symbols the particular type of field winding.

(2) The shunt type of winding (fig. 138 (1)) is the type of field winding generally used for automotive generators. The series type of winding (fig. 138 (2)) is particularly adapted to the starting motor because all the current passing through the armature must also flow through the field winding, thus producing full field strength and giving the motor the greatest possible cranking power. Types shown in figure 138 (5) and (6) are particularly adapted for motor generators used on the one-unit system. When operating as a generator, the windings function differentially, the series field bucking the shunt field to produce a regulating effect. When operating as a starting motor, the windings function cumulatively since the current reverses through the armature and the series winding but not through the shunt winding.



① Shunt wound dynamo.

② Series wound dynamo.

③ Cumulative compound wound dynamo with short shunt.

④ Cumulative compound wound dynamo with long shunt.

⑤ Differential compound wound dynamo with short shunt.

⑥ Differential compound wound dynamo with long shunt.

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Figure 138. Types of Field Windings.

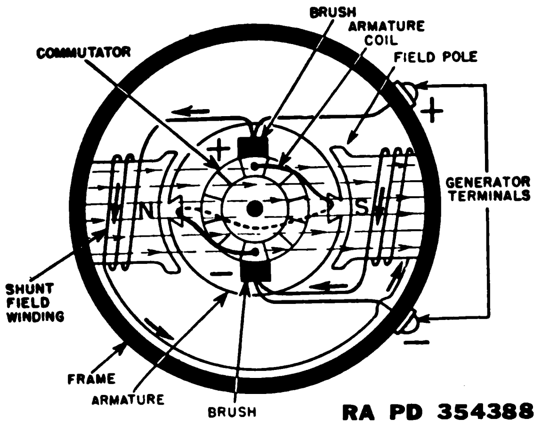

Figure 139. Diagram of a Shunt Wound Generator.

b. Cumulative and Differential Winding. By applying the right hand rule to determine the magnetic polarity of an electromagnet, it will be seen that in figure 138 (1) and (4) the shunt and series windings produce magnetism in the same direction. They are, therefore, said to be cumulatively wound. In figure 138 (5) and (6), the magnetism produced by a current flowing in the series field winding is opposite to that produced by the shunt winding, and the dynamos are said to be differentially wound.

c. Short and Long Shunt Connection. The shunt field may be connected either inside or outside the series field winding. When it is connected inside (fig. 138 (3) and (5)), it is known as a short shunt connection. When it is connected outside (fig. 138 (4) and (6)), it is known as long shunt connection. The principle of each is similar, the difference being that in a short shunt connection the shunt field current does not pass through the series winding. In practice, generators represented by figure 138 (3) and (4) are not used on the automobile because the generator must necessarily run at variable speeds, and any increase in armature speed and voltage would increase the field strength, and consequently, the armature output would increase to a point where it would overload the generator as well as overcharge the battery.

d. Windings. When a generator is differentially wound, the series winding, which is commonly known as a reverse or bucking series, is used only for regulating purposes, the shunt winding being the prevailing winding and controlling the direction of magnetism. The shunt field winding may be readily distinguished from the series type, since it consists of a large number of turns of small wire, while the series winding consists of a comparatively few turns of large wire. Windings must be well insulated. In some cases, they are impregnated with a special insulating compound to make them water and oil resistant.

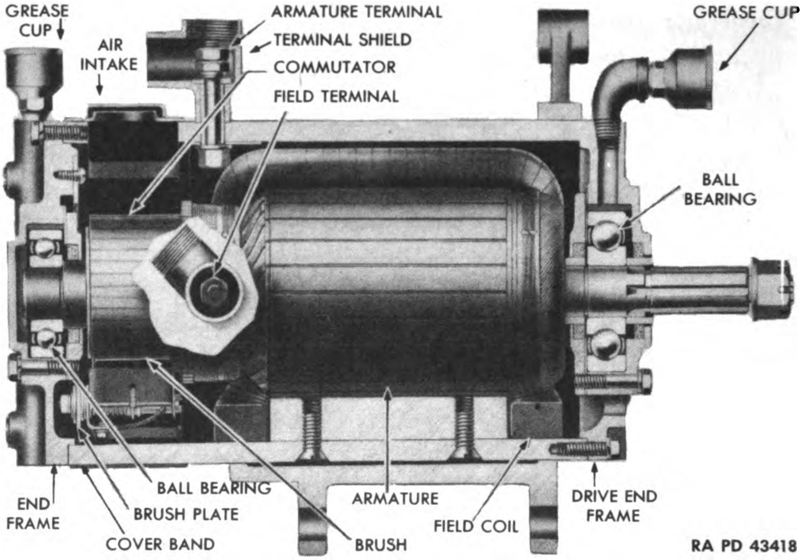

Figure 140. Generator Cross Section.

114. Shunt Wound Generator

Most motor vehicle generators are shunt wound with an outside means of regulating the voltage output. About 8 to 12 percent of the total current generated by the armature is shunted through the field coils for producing the field magnetism. Figure 139 represents a shunt wound generator with only one armature coil. The armature is actually wound full of similar coils distributed at equal intervals around it, the end of each coil being connected to a segment of the commutator in the same manner as the one shown.

a. Principle of Operation. In figure 139, let it be assumed that the armature rotates in a clockwise direction and that the magnetism flows from the north pole piece N to the south pole piece S as indicated by the arrows. When the armature is rotated, the armature coils will cut the weak magnetic field (residual magnetism) retained by the poles and set up a slight voltage across the brushes, usually 1 to 1½ volts, making in this particular case the upper brush positive (+) and the lower brush negative (—). This voltage is sufficient to cause a small current to flow from the positive brush through the field winding around the pole pieces to the negative brush. If the magnetic effect of this field current is of the same polarity as the residual magnetism, the pole strength will be increased. This, in turn, will increase the magnetic field through the armature. Since the armature coils will then be permitted to cut more magnetic lines of force per revolution, the voltage across the brushes will be increased. An increase in brush voltage increases the field strength, which in turn, increases the armature output. Thus, the armature voltage helps the field, and the field helps the armature voltage until the generator reaches its normal operating voltage at the particular running speed. This process is called "building up" the generator voltage.

b. Residual Magnetism. (1) In the above description of generator operation, the importance of the magnetism retained by the poles should be noted as it serves as a foundation for building up the generator voltage.

(2) Residual magnetism is the name given to the magnetism remaining in the pole pieces and field frame after the field magnetizing current has died out. The direction of the residual magnetism may be tested by holding a pocket compass near the poles when no current is passing through the field windings or the armature. The north end of the compass needle will point to the south field pole and the south end to the north field pole.

(3) In case the field frame should lack proper residual magnetism, which may be due to its being a new machine, connecting the field winding with alternating current supply, excessive temperature, or vibration, the generator may be given residual magnetism by simply sending direct current through the shunt field winding in the proper direction from either a storage battery or dry cells. This residual magnetism may be reversed by merely reversing the direction of the magnetizing field current. It may also be reversed by the magnetizing effect of the armature coils when a heavy direct current from a battery is sent through the generator armature with the field winding disconnected or open circuited.

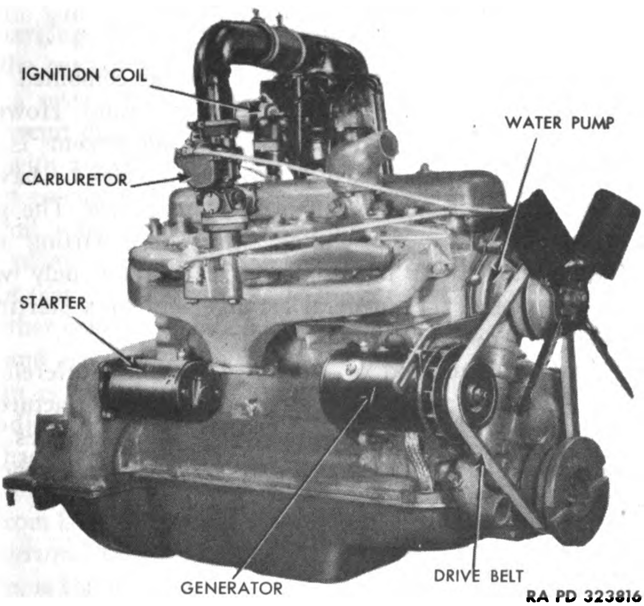

Figure 141. Typical Arrangement of a Starter and Generator on Engine.

(4) Several conditions are necessary for the generator to build up a voltage. Two of the most important requirements are that the field frame have residual magnetism as a foundation on which to build, and that the current in each field coil be in such direction around the pole that it will produce magnetism to assist and not oppose the residual magnetism. If the field current opposes it, the voltage built up will not be higher than that produced by the residual magnetism.

c. CONSTRUCTION. (1) The armature core is made of sheets of iron insulated from each other so that the magnetic field will not induce eddy currents in the core. (Eddy currents will flow around a core made of one solid piece of iron, and will heat the armature.)

(2) The armature core is wound with coils of copper wire and mounted on a shaft with a commutator on one end (fig. 140). Field coils are made of many coils of fine wire arranged for shunt connection. The field frame, usually two or four poles with brushes, brush holders, and end housings with bearings, completes the essential parts of the generator.

d. GENERATOR DRIVES. (1) The method of mounting and driving the generator depends to a large extent upon the construction and design of the engine. It is usually mounted on the side of the engine and driven at one to one and one-half times the crankshaft speed by belt, silent chain, or gears.

(2) The present trend is to have the radiator cooling fan, water pump, and generator driven by a V-belt from the pulley on the forward end of the crankshaft (fig. 141). Pivoting the generator on the generator mounting studs permits adjustment of the belt tension. A rotary fan is usually contained on the generator pulley to draw cooling air through the generator.

(3) The generator and starting motor can be combined into one machine known as a motor-generator or starter-generator. However, this use of one machine for the starting and generating systems is obsolete. More efficient operation is obtained in modern vehicles by having generator and starting motor as two independent machines. The generator is driven continuously by the engine, while the starting motor is normally disconnected from the engine and operates only when the starting switch is closed. The general arrangement of a starting motor and a generator is shown in figure 141.

(4) The single-wire method of wiring is used in preference to the two-wire method by practically all motor vehicle manufacturers since the use of the frame in place of one wire greatly simplifies both the wiring of the vehicle and in many cases the construction of the starting and generating apparatus.

115. Reverse Current Cut-out

a. GENERAL. (1) The reverse current relay or cut-out is simply an automatic electromagnetic switch connected in the battery charging

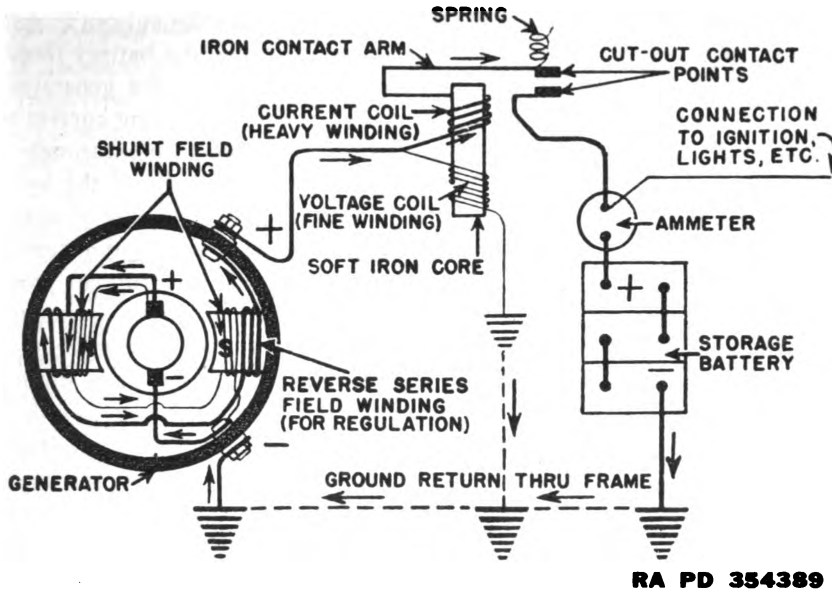

Figure 142. Cut-out Relay Circuit Diagram.

circuit between the generator and the storage battery of the electrical system. Its function is to connect the generator automatically to the battery when the voltage of the generator is sufficient to charge the battery, and to disconnect them when the generator is not running or when its voltage falls below that of the battery, to prevent the battery from discharging through the generator windings. In these respects the action of the cut-out is very similar to that of a check valve between a pump and a reservoir.

(2) A circuit diagram of a typical cut-out is shown in figure 142. It is connected with a generator wound differentially to limit voltage output. The cut-out consists of a soft iron core, a fine shunt winding known as a voltage coil, a heavy series winding known as a current coil, and a set of contact points. One of the contacts is carried on one end of an iron contact arm that is mounted close to the core and held by spring tension, while the other contact is stationary. The contact points are thus normally held open and are closed only when the magnetic pull of the core on the contact arm is sufficient to overcome the tension of the spring. The spring is adjusted so that the contacts will close when the voltage of the generator has reached from 6½ to 7 volts in a 6-volt system, or 13 to 14 volts in a 12-volt system. These voltages are usually reached at a car speed of from 8 to 10 miles per hour in direct drive or high gear.

b. Operation. (1) The voltage coil, which consists of many turns of fine wire, is connected across the generator terminals to receive the full voltage of the generator. When the generator attains a speed at which it develops approximately 6½ to 7 volts, the core is sufficiently mag-

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netized to overcome the spring tension and to close the cut-out contacts. This completes the circuit between the generator and the battery through the current coil and the contacts. Since the voltage of the generator at this time is higher than the voltage of the battery, a charging current will flow from the positive (+) terminal of the generator, through the current coil and contacts of the cut-out, through the cells of the battery from positive (+) to negative (—), returning through the ground or frame to the negative terminal of the generator. The negative terminal of the battery is assumed to be grounded. The charging current flowing through the current coil flows around the core and creates a magnetic effect in it in the same direction as that produced by the voltage coil. The cumulative effect of these two windings greatly increases the magnetic pull on the contact arm and holds the contacts firmly closed.

(2) When the speed of the generator is decreased so its voltage is lower than that of the battery, that is, below 6 volts, the battery will discharge back through the cut-out and the generator in a reverse direction to the charging current. Any reverse current through the cut-out will cause the current to reverse through the current coil but not through the voltage coil, thus producing a differential action between the two windings that partly demagnetizes the core. The instant the core is slightly demagnetized, the spring, which is under constant tension, pulls the contact arm away from the core and opens the circuit. The contacts will remain open by spring tension until the generator again attains sufficient voltage to close them, thus preventing discharge of the battery through the generator at all times. The ammeter is usually connected as shown in figure 142 so that it will register the amount of current either charging or discharging from the battery. The ammeter then serves as a check on the proper operation of the cut-out since it will indicate when the generator takes the load away from the battery and stops or reduces discharge of the battery.

(3) The air gap between the contact arm and the iron core of the relay has little or no effect upon the voltage at which the cut-out opens, since the spring tension governs this almost entirely, while on the other hand, the voltage at which the cut-out closes is governed by both the air gap and the spring tension.

(4) The normal air gap betwen the contact arm and the core on the average cut-out should be 0.015 inch to 0.020 inch with the contacts closed. The cut-out should be adjusted as specified by the manufacturer. It is designed to close at a predetermined voltage and to open usually when a small reverse current is flowing. The car speed at which the cut-out opens should be 2 to 3 miles per hour below the closing speed to keep the contact points from "chattering" when the car is being driven at the critical "cut-in" speed. The contact points are usually made of silver, copper, or tungsten and should meet squarely so that good electrical contact is made over the entire contact surface when closed. The cut-out unit is often mounted on top of the generator.

116. Regulation of the Generator

a. Importance. The fields of the generator depend upon the current derived from the armature of the generator for their magnetization. Since the current developed by the generator increases in direct proportion to its speed, the fields become stronger as the speed increases and correspondingly more current is generated by the armature. The extreme variations in speed of the automotive engine make it necessary to regulate the output of the generator to prevent excessive current overload. On the average motor vehicle, a charging current in excess of 12 to 15 amperes may be harmful to a fully charged battery if continued too long. With the increased use of electrical accessories, generators have been increased in output until they are capable of producing 25 to 35 amperes. Regulation today is therefore more vital than ever before.

b. Reverse Series Field. (1) Since the output of the generator depends upon the number of conductors in the armature, their speed of rotation and the strength of the magnetic field in which they rotate, varying the strength of this field is the only convenient method of regulation. One of the simplest methods, although not commonly used today, was the use of a reverse series field for differential action as shown in figure 142. A shunt field is connected acrooss the brushes to produce the magnetizing action. Charging current going through the reverse series field, however, has a demagnetizing action, so that as the current increases it tends to restrict the rise of current above a reasonable value.

(2) Such a differentially wound generator has disadvantages which limit its use on motor vehicles. If a break should occur in the charging circuit (excepting normal cut-out operation) thus destroying generator regulation by the series field, the voltage will become excessive, usually resulting in damage to the field and armature winding and to the voltage winding of the cut-out. One outstanding disadvantage is that there is usually no convenient method provided for increasing or decreasing the charging rate. By decreasing the number of turns in the reverse series field, the maximum generator output can be increased. Increasing the number of turns will decrease the output.

c. Methods. There are at the present time two popular methods of regulating the output of a generator. These are the vibrating relay method and the third brush method. A number of other forms have been used in the past but most of these are now obsolete.

117. Vibrating Relay

a. Current Regulation. (1) The vibrating relay can be used to regulate the current or the voltage, depending on how the regulator coil is connected. A circuit diagram of a typical vibrating relay regulator used for limiting the current from the generator is shown in figure 143. The regulating relay consists of a soft iron core, a heavy winding or current coil around the core, a set of regulator contact points normally

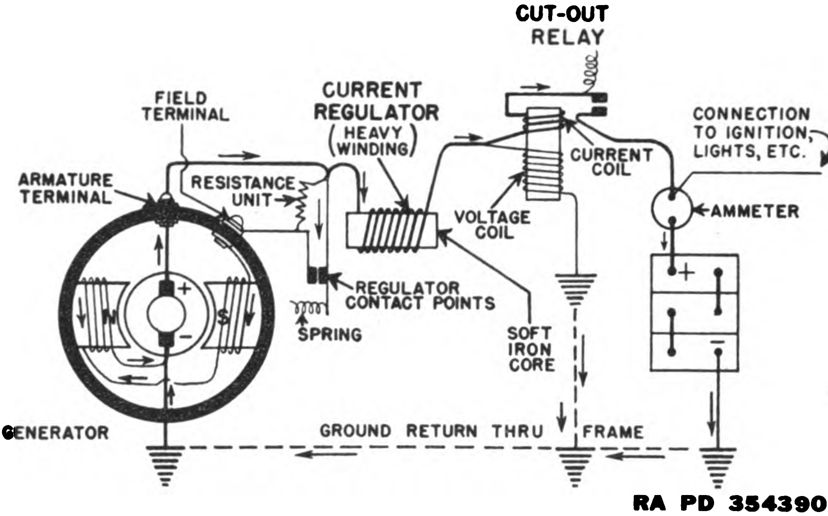


Figure 143. Vibrating Current Regulator Circuit Diagram.

held closed by spring tension, and a resistance unit connected across the two regulator contact points.

(2) As the generator speed increases, this vibrating relay controls the current output of the generator by cutting a resistance intermittently in and out of the shunt field circuit as the regulator contact points open and close due to the varying magnetic pull of the core. The resistance unit is connected in the shunt field circuit but is normally short circuited by the regulator contacts when they are closed, one of which is mounted on a soft iron contact arm to which is attached the spring for holding the points in contact. The generator, when driven by the engine, builds up as a simple shunt wound generator, the shunt field current flowing from the positive (+) brush through the contact points, through the field winding to the negative (—) brush. When the speed and voltage of the generator are increased sufficiently to close the cut-out, the generator will begin to charge the battery, the charging current flowing through the regulator winding. This current flowing through the regulator winding will magnetize the core, which in turn exerts a magnetic pull on the regulator contact arm tending to separate the contacts. When the battery charging current reaches the value for which the regulator is adjusted, the core is sufficiently magnetized to attract the contact arm, overcoming the pull of the regulator spring. This separates the contact points which inserts the resistance unit in series with the shunt field winding and weakens the field strength. This causes a drop in voltage generated in the armature and consequently the charging current decreases. When the current decreases to a predetermined amount, the current coil does not magnetize the core sufficiently to overcome the pull of the spring which then closes the contacts. With the contacts closed, the

resistance unit is once more short circuited and the full field strength is restored, causing the charging current to increase again. The regulator will continue to repeat this cycle. Under operating conditions, the contact arm vibrates rapidly enough to keep the generator output constant. As a result, the generator will never charge the battery above predetermined rate (for example, 20 amperes), no matter how high the speed of the car. This will be true regardless of whether the battery is fully charged or completely discharged.

(3) This method of generator regulation is termed current regulation, since the current output of the generator is used for regulation. It is, therefore, very important that no breaks occur in the charging circuit after the generator reaches a voltage sufficient to operate the cut-out. If a break does occur, no current will flow through the current coil to operate the vibrating points and the generator will build up an excessive voltage at high speeds due to lack of regulation.

(4) In all electrical systems controlled by a vibrating relay, the charging rate of the generator can be easily adjusted. To increase the maximum charging rate, the spring tension on the vibrating contact arm should be increased slightly, and to decrease the maximum charging rate, the spring tension should be decreased. Care must be taken that the generator output does not exceed that for which it was designed.

b. Voltage Regulation. (1) A circuit diagram of a typical vibrating relay voltage regulator is shown in figure 144. Although the construction of this relay does not differ materially from that of the current regulator, the principle of operation is somewhat different. With this regulator, the voltage output of the generator is used for automatic regulation. By comparing figures 143 and 144, it will be seen that the principal difference

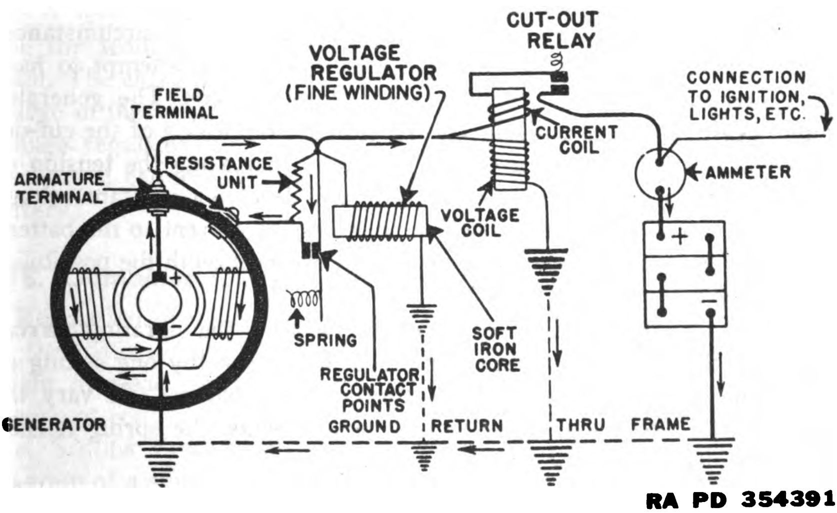


Figure 144. Vibrating Relay Voltage Regulator Circuit Diagram.

in the two relays is in the winding of the controlling coil and its connections. In the voltage regulator, the charging current does not flow through the regulator winding. The winding on the core consists of a voltage coil of fine wire, the two ends of which are connected across the generator brushes and in parallel with the battery instead of in series with it as in the current type of regulator. The iron core, regulator points, and resistance unit, however, are practically the same.

(2) The current flowing in the regulator coil and the resulting magnetic pull of the core on the contact arm depend upon the voltage developed by the generator. In a 6-volt system, the regulator is adjusted to hold the generator voltage constant at 7.5 to 7.75 volts, usually 7.5. With increasing generator speed, the voltage tends to rise above 7.5 volts. If, however, this value is exceeded by a small amount the increased magnetic pull of the core on the contact arm, due to the current flowing in the voltage coil, will overcome the spring tension and pull the contact arm toward the core, thus opening the contacts and inserting a resistance in the generator field circuit. This added resistance decreases the current in the field winding, and the voltage developed by the armature tends to drop below 7.5 volts.

(3) When the voltage drops, the pull of the spring on the regulator contact arm overcomes the magnetic pull of the core and closes the contacts. This short circuits the resistance unit and permits the field current to increase. The cycle of operation is repeated rapidly, preventing the generator voltage from rising above that for which the regulator is set. Should an opening occur in the charging circuit, the regulator will prevent the generator from building up an excessive voltage. If a break occurs in the voltage regulator circuit, regulation of the generator will be lost and an excessive charging rate will result at high speeds.

(4) It is obvious that increasing the tension of the regulator spring will increase the output voltage of the generator. Under no circumstances should the regulator spring tension be increased in an attempt to have the generator charge at a higher rate at lower speeds. The generator cannot begin to charge until the cut-out closes. The closing of the cut-out is independent of the action of the regulator. Increasing the tension of the regulator springs so that the generator will develop a constant voltage in excess of 7.75 volts will usually send excessive current to the battery overcharging it, or causing the generator to overheat, with the possibility of burning it out.

c. CHARGING RATE. (1) *Current regulator.* With the vibrating current regulator, the charging current remains constant for any one setting of the regulator, regardless of the condition of the battery. To vary the charging rate according to the battery requirements, the spring tension of the regulator must be adjusted.

(2) *Voltage regulator.* (*a*) The main advantage of the voltage regulator is that the output of the generator is controlled to a great extent

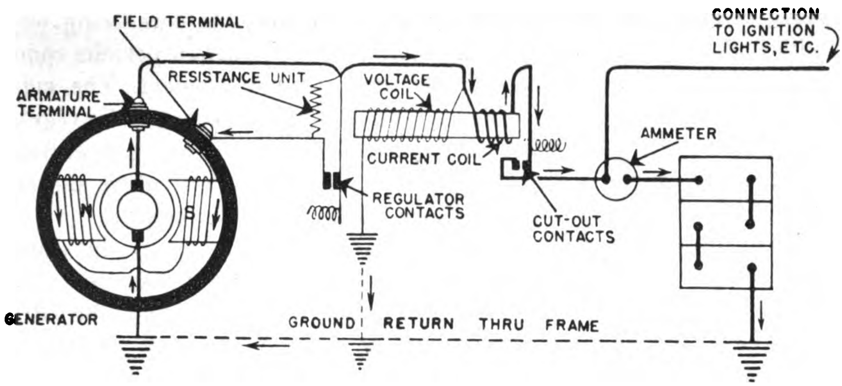


Figure 145. Combined Regulator and Cut-out Relay (One Element) Circuit Diagram.

by the amount of charge in the battery. When the generator reaches a speed at which it develops the regulated voltage, there will be no further increase in voltage with increasing speed. The voltage will be maintained constant at all loads and at all higher speeds.

(*b*) During the time the generator is connected to the battery, the difference in voltage between the two is the voltage available for sending current into the battery. In a discharged battery, the difference in voltage between the generator and the battery will be relatively great, so that a comparatively high charging current will pass from the generator to the battery. As the charge continues, the voltage of the battery increases, so that the difference in voltage between the generator and the battery is continually diminishing. With a fully charged battery, the voltage is nearly equal to that of the generator, and the difference between the two is very slight. As this slight difference in voltage is all that is available for sending current into the battery, the charging current will be small. The charging current, therefore, is variable and depends upon the charge in the battery. In practice, the charging current with the constant voltage regulator varies from a maximum of 25 to 35 amperes for a discharged battery, to a minimum of 4 to 6 amperes for a fully charged battery.

118. Combined Current and Voltage Regulation

Regulation of voltage only might be satisfactory from the standpoint of the battery, but if the battery were badly discharged, the generator might overload itself to supply the heavy charging current. Therefore a current control is usually needed in addition to a voltage control.

a. SINGLE VIBRATING CONTACT (COMBINED CONTROL). (1) A circuit diagram of a single vibrating relay for obtaining both current and voltage regulation of the generator is shown in figure 145. The winding of the relay is merely a combination of the other two, the core being wound with both a current and a voltage coil. This construction permits combining the cut-out and the regulator into a single element. The cut-out contacts (fig. 145) are mounted on one end of the core and the regulator contacts on the other end, the two sets of contacts being operated by independent springs. The cut-out is made to function before the regulator by the use of a weaker spring on the cut-out contacts.

(2) The operation of the regulating relay is practically the same as that of the voltage regulator, except that the generator current output is also controlled by the charging current flowing through the current coil. Both the windings carry current around the core in the same direction, the magnetizing force of both combining to operate the regulator and the cut-out contact points. In this manner, the combined characteristics of both current and voltage methods of regulation are obtained. The proper functioning of the relay, however, depends upon the combined effect of both windings. Consequently either high voltage, excess current, or normal limits of both voltage and current would be effective in limiting the output of the generator.

b. TWO VIBRATING CONTACTS (INDIVIDUAL CONTROL). (1) Instead of combining the current and voltage regulator into one unit on the same core, the present tendency is to use separate elements so that individual adjustments can be made for better control of the generator output. Such a control unit consists of three elements mounted on one base with

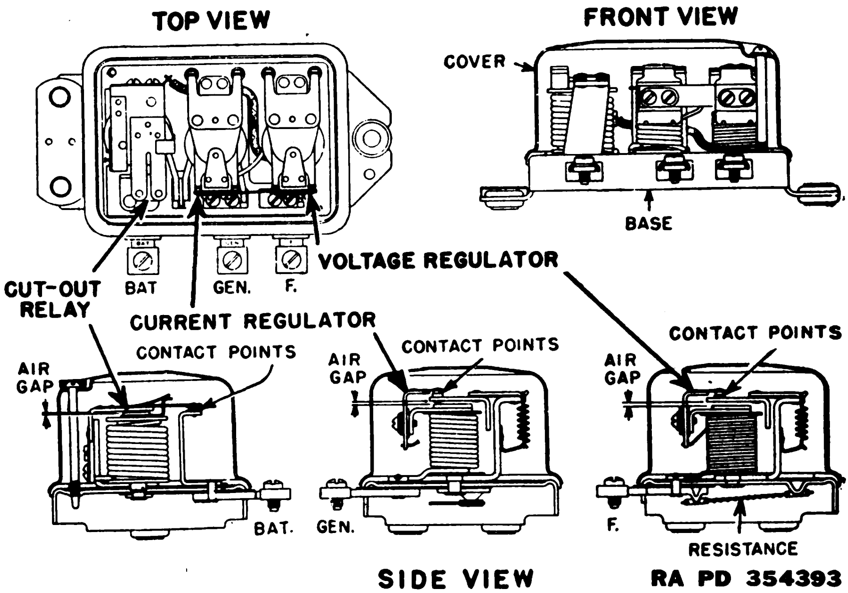


Figure 146. Individual Current and Voltage Regulators and Cut-out Relay (Three Elements).

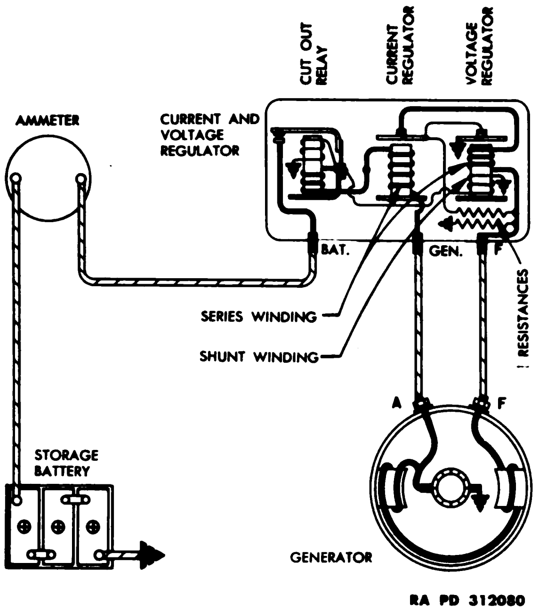


Figure 147. Individual Current and Voltage Regulators and Cut-out Relay Circuit Diagram.

a common cover (fig. 146). The cut-out, current regulator, and voltage regulator each contains a separate core, coil, and set of contacts.

(2) Operation of the control unit can be understood by following through a typical circuit diagram (fig. 147). Voltage built up by the generator causes a small current to flow from the generator armature terminal A, through the current regulator coil and current winding of the cut-out to the cut-out frame which is insulated, and from there through the voltage winding of the cut-out to the ground return. When the generator builds up a voltage which sufficiently magnetizes the cut-out to close its contacts, charging current will flow through the cut-out frame and across the cut-out contacts to the battery. This current flows through the current regulator and will operate its vibrating contacts to limit the current output of the generator. The voltage regulator coil is connected to the cut-out frame so the voltage regulator vibrating contacts limit the generator voltage. Sometimes the voltage winding of the voltage regulator is connected to the ignition switch to obtain a close regulation of the battery voltage. Such a connection should be made to the "off" side of the ignition switch so that the voltage coil will not drain the battery when the switch is "off." The voltage regulator also contains a winding in series with the field which aids in operating the voltage regulator contacts to prevent excessive field current.

(3) The field circuit is completed when there is a connection from the field, F, terminal of the generator to the ground, as the other end of

the field winding is connected to the live brush in the generator. When the generator is not producing enough output to operate the current or voltage regulators, the field circuit is completed through its winding on the voltage regulator and across the current regulator and voltage regulator contacts to the ground. The field then has no outside resistance in the circuit and receives maximum current to help increase generator output. Operation of the current or voltage regulator contacts will open this circuit so that the field current must go through the resistance to the ground which will lower the field strength. Thus normal limits of either current or voltage will regulate generator output. In some regulators, two resistances are used to provide more resistance in the field circuit when the voltage regulator operates than when the current regulator operates. Heavy current output can then be obtained with a pronounced control of the voltage. Preventing the generator from building up too high a voltage is the most important function of the regulator.

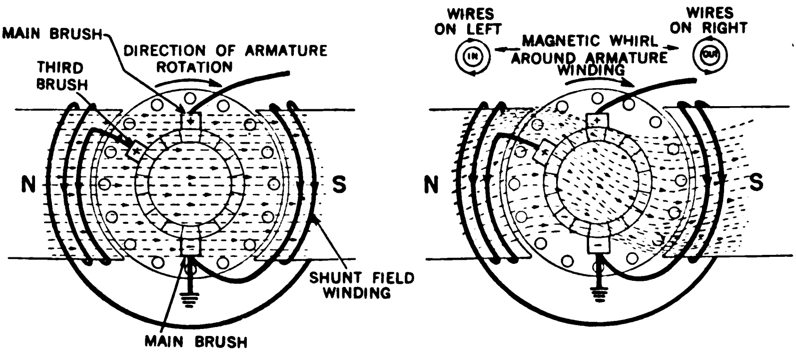
119. Third Brush Regulation

Third brush regulation is much simpler in operation and less expensive to manufacture than other methods of control. Generators with this type of control have an extra brush called the "third brush," located between the two main brushes.

a. Arrangement. Arrangement of a typical two-pole, third brush type of generator is shown in figure 148. One end of the shunt field winding is connected to the third brush, the other end is grounded. Only a part of the total voltage generated is supplied to the field by the third brush.

b. Operation. (1) When the generator is running at a low speed and little or no current is flowing in the armature winding, the magnetic field produced by the field winding is approximately straight through the armature from one pole piece to the other (fig. 148 (1)). The voltage generated by each armature coil is then practically uniform during the time the coil is under the pole pieces.

(2) As the generator speed and charging current increase, the armature winding acts like a solenoid coil to produce a cross magnetic field. The magnetic whirl around the armature winding distorts the magnetic field produced by the shunt field winding, so that the magnetism is not equally distributed under the pole pieces (fig. 148 (2)). With this distortion of the magnetic field, the armature coils no longer generate a uniform voltage while passing under the different parts of the pole. Although the voltage across the main brushes remains nearly the same, a greater proportion of this voltage is generated by the coils between the positive brush and the third brush than was generated between them when little current was flowing through the armature winding. This is due to the distortion of the magnetic field which crowds more magnetic lines of force between the positive and third brush.



(1) LITTLE OR NO CURRENT FLOWING (LOW SPEED). (2) LARGE CURRENT FLOWING (HIGH SPEED).
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Figure 148. Third Brush Generator Regulation.

(3) The coils which connect the commutator between the negative and third brushes are in the region of the weakened field and generate a lower proportion of the voltage. The result is a dropping off of the voltage between the negative and third brushes, which is applied to the shunt field winding, thereby weakening the field strength. As the field strength decreases with increased generator current, the result will be an automatic regulation of the current output.

c. CHARGING RATE. (1) One of the outstanding characteristics of generators with third brush regulation is that the charging rate of the generator increases gradually with each increase in speed up to a car speed of 25 to 30 miles per hour. After this, the charging rate falls off as the speed continues to increase due to pronounced field distortion. At speeds of 50 to 60 miles per hour, the charging rate is approximately one-half its maximum value. This is an advantage, in that the maximum charging rate is obtained at normal driving speeds, while at high speeds, such as during cross-country driving when the starter and lights are seldom used, the decreased charging rate tends to prevent overcharging of the battery and overheating of the generator.

(2) In practically all generators which have third brush regulation, provision is made for changing the charging rate to suit the conditions under which the generator is operated. This can be done by moving the position of the third brush on the commutator. It is evident that the average voltage applied to the field winding will depend upon the number of armature coils spanned by the brushes which collect the field current. Thus, moving the third brush in the direction of the armature rotation increases the average current delivered to the shunt field winding and consequently the output of the generator. Moving the brush against the direction of armature rotation decreases the output. Whenever this brush is moved, care should be taken to see that it makes perfect contact with the commutator.

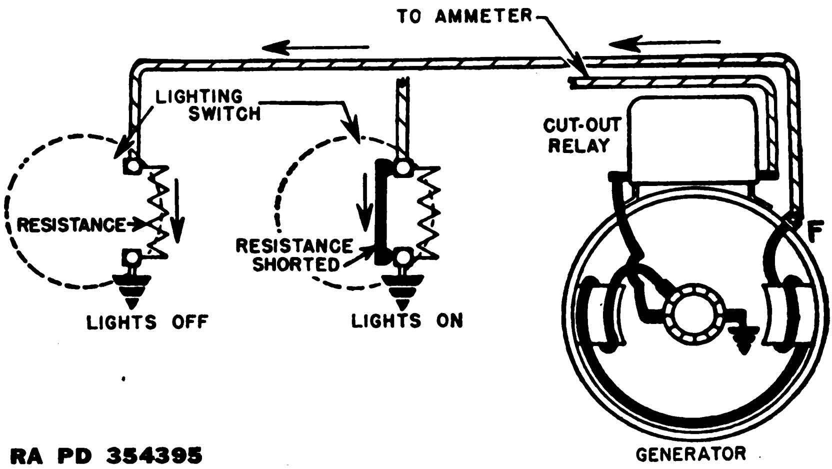

Figure 149. Lighting Switch Control of Third Brush Generator.

(3) Since the third brush generator depends upon the charging current flowing through the armature winding to produce the field distortion necessary for regulation, it is obvious that it is current regulated internally (as distinct from external current regulation). It must, therefore, have a complete charging circuit available through the battery at all times, otherwise regulation would be destroyed and excessive field currents would burn out the generator windings. Should the third brush generator be disconnected from the battery for any reason, the generator terminals must be grounded.

120. Control of Third Brush Generator

To guard against the possibility of the third brush generator burning up, a fuse is usually provided in the field circuit. It is placed either in the generator end plate or in the regulator control unit when used. If the battery becomes disconnected, there is a rise in voltage at the generator. This in turn sends an abnormally heavy current through the field winding and this field current burns out the fuse. As soon as the fuse is blown, the field circuit is open and no current can flow through it. The generator then merely turns, producing practically no voltage, and does no harm. The third brush generator provides current regulation only and does not take battery voltage into consideration. In fact, a fully charged battery which has a high voltage will actually get more current from a third brush generator than a battery which is completely discharged, because the high voltage holds up the voltage at the generator, makes the field stronger, and causes the generator output to increase. This, combined with the varying demands of radio sets and other current-consuming devices, necessitates more accurate regulation than a third brush generator alone can give.

a. Switch Control. Practically all systems of regulation provide a means for inserting a resistance in series with the third brush field. A simple way of accomplishing this is shown in figure 149. A resistance is mounted on the back of the lighting switch and connected in series with the field. When the lights are off, the generator output current is limited by the resistance in the field circuit. When the lights are turned on, the resistance is shorted so that the generator delivers full current to take care of the additional lighting circuit load. This is just a two-step arbitrary system of regulation, however, which will not meet the varied load requirements of a modern vehicle operation.

b. Step Voltage Control. (1) The purpose of step voltage control is to increase or decrease the output of a third brush generator in accordance with the requirements of the battery and the connected electrical load. It is really a two-stage regulator in which the change from one charging rate to the other is controlled by the generator voltage, which, in turn, is controlled by battery voltage.

(2) A step voltage control unit is shown in figure 150. A fine winding voltage coil, connected to the generator armature terminal A so that it receives the armature voltage, is the controlling element. Contacts are connected in series with field terminal F and have a resistance unit connected across them. When the battery is fully charged, or nearly so, its voltage raises the generator voltage to such a value that sufficient magnetizing current flows through the fine winding on the control unit to pull the contact points apart. When this happens, the resistance across the contacts is connected in series with the field winding to lower the field strength and consequently reduce the generator voltage and the current output. When the voltage is lowered sufficiently, spring tension will close the contact points and the higher charging rate will be restored.

(3) When there is sufficient electrical load, such as lights, radio, heater, etc., to require a higher generator output the contact points will close since the load current will lower the generator voltage and the generator will produce its maximum output for the position of the third brush selected and the speed at which it is driven.

c. Vibrating Regulator Control. A vibrating regulator can also be used with a third brush generator. Such a regulator is controlled by a voltage coil which operates vibrating contacts. When the battery is discharged there is not sufficient voltage to operate the regulator. The generator output is then controlled only by the third brush. As the battery becomes charged, the voltage of the system will increase and more current will be forced through the regulator coil. The regulator points then begin to vibrate, connecting a resistance in the generator field circuit and cutting down the output to a fairly constant value.

d. Thermostatic Control. (1) Another type of control for the third brush generator uses a thermostat blade to control the field strength. If the generator is set to give the greatest possible current to take care of

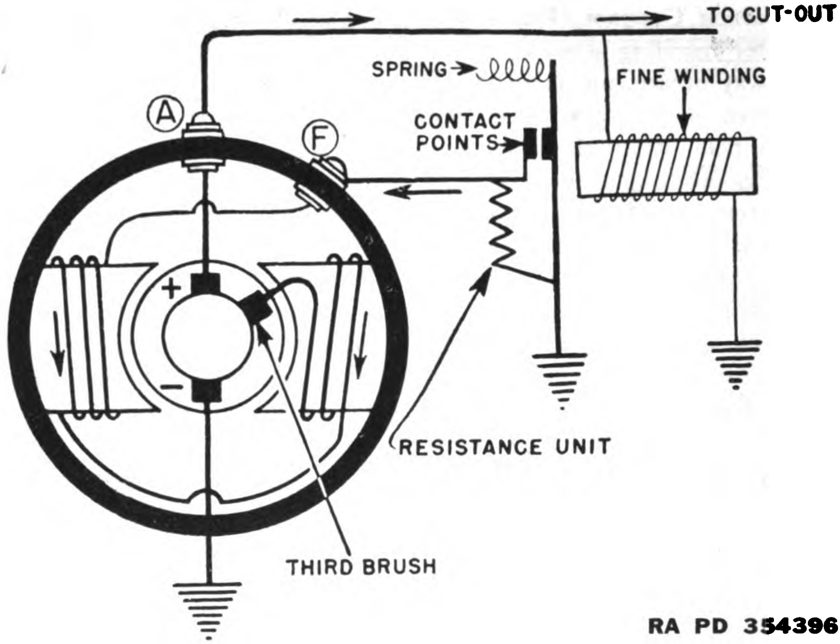

Figure 150. Step Voltage Control of Third Brush Generator.

demands during the winter, in warm weather the battery would be in a constant state of overcharge and would soon be ruined. The thermostat blade automatically takes care of the changing current demands under different conditions.

(2) It consists of a bimetal thermostat blade made of a strip of spring brass welded to a strip of nickel steel. The blade warps or bends when heated due to the greater expansion of the brass side. The blade is set so that a contact on its end is held firmly against a stationary contact at low temperatures. When the temperature rises to approximately 160° to 165° F., the blade bends and separates the contacts.

(3) The thermostat is connected in the third brush field circuit (fig. 151) so that the full field current passes through the thermostat contacts when closed, permitting full current from the generator. After the engine has been run long enough for the high charging rate to heat the generator, the thermostat contacts open, due to the bending of the thermostat blade, causing a resistance unit across the contacts to be connected in series with the third brush field thereby reducing the current output. The charging rate is reduced approximately 30 percent when the thermostat contacts are opened.

(4) The chief advantages of thermostatic control are that it gives a large battery-charging rate in cold weather when the efficiency of the battery is lower than in warm weather, and also a larger charging rate when the car is being driven intermittently, and the demands on the

battery are greater because of frequent use of the starting motor. It also prevents the generator and the battery from overheating in the summer by reducing the charging rate when the temperature rises.

121. Split Series Field Generators

a. Generator regulation is sometimes accomplished by means of a split series field. A generator with this method of regulation combines third brush, reversed series (differential), and cumulative compound principles. The series field winding is divided so that the generator output is changed according to the load.

b. With lights off, no current flows through one part of the series field (marked 1 in fig. 152). The current going to the battery flows through the remainder of the series field (marked 2 fig. 152) in the opposite direction to the shunt field current. This weakens the total field strength, keeping the generator output down for the delivery of a reasonable charging rate.

c. When the lighting switch is closed, the entire lighting current flows through section 1 of the series field in the same direction as the shunt field. The strength of the field is thereby increased, giving a higher generator output to take care of the lighting load.

d. If the lights are turned on before the generator cut-out closes, the entire lighting current is supplied by the battery. This current then flows through all of the series field, instead of section 1 only, in the same direction as the shunt field, making the total field strength still greater. This will build up the generator voltage to close the cut-out. The entire current output of the generator, which passes through the cut-out, flows to the center tap of the series field where it divides, part of the current flowing in one direction through to the battery and the remainder to the lights.

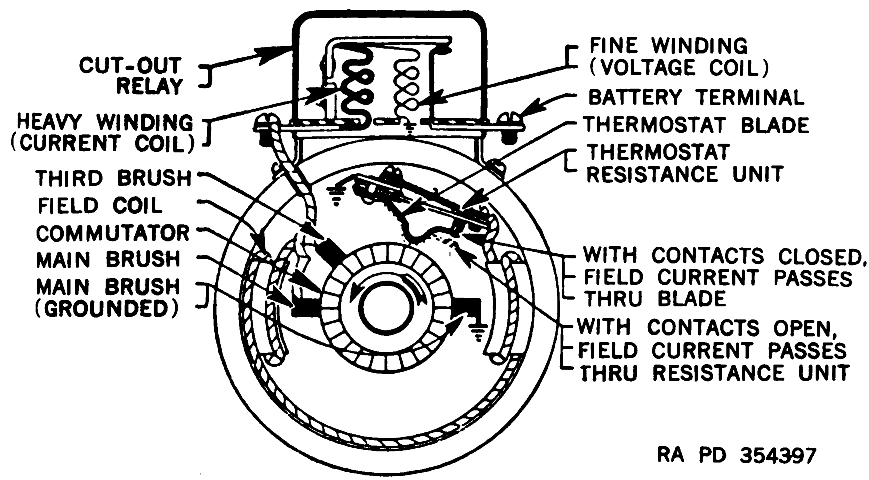

Figure 151. Thermostatic Control of Third Brush Generator.

e. As soon as the cut-out closes, the generator begins to pick up the lighting load. This lessens the drain on the battery and thereby reduces the current flowing through section 2 of the series field. When the generator output just equals the lighting current, the current in section 2 is zero, and as the generator output increases further, current begins to flow in the reverse direction through section 2 to the battery. This tends to weaken the field built up by the shunt winding and section 1 of the series winding. By obtaining the proper relationship between the shunt winding and the two sections of the series winding, results quite similar

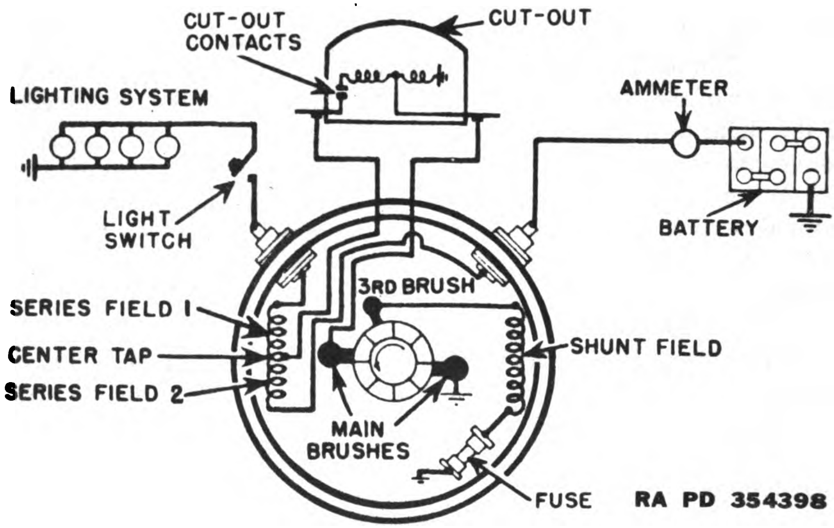

Figure 152. Split Series Field Generator.

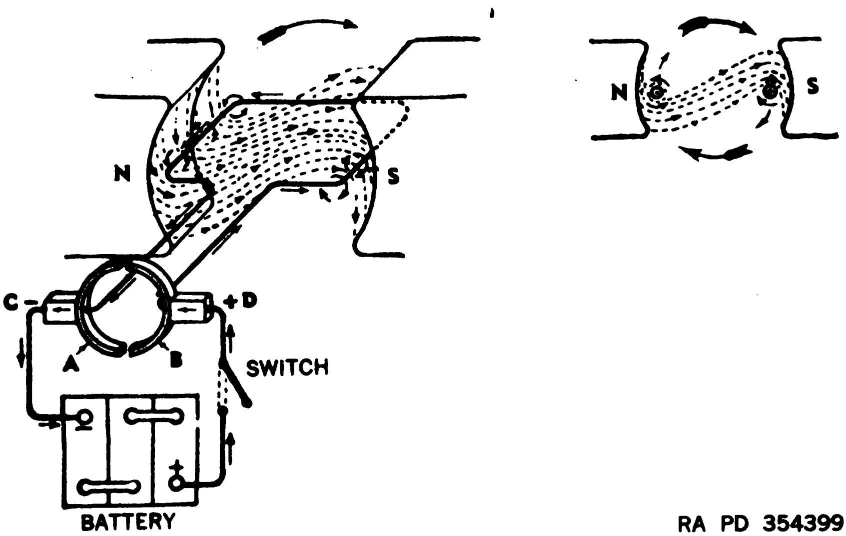

Figure 153. Simple Direct-current Motor.

to those obtained from voltage regulation are secured, and the battery is kept in a charged condition.

f. The charging rate of the split series field generator may be adjusted by shifting the third brush as in the regular third brush generator. In some generators of this type separate coils are used for the two sections of the series field. In others the two sections are combined into one coil. Generators of this type do not have standard connections and must not be confused with the ordinary third brush generator. Neither binding post should be grounded under any circumstances. Proper connections are shown in figure 152.

Section III. STARTING SYSTEM

122. Electric Starter

The electric starter, having supplanted the mechanical and air starters, is now furnished as standard equipment on all passenger cars, most trucks, and on some tractor, airplane, and marine engines. The electric starter is a low-voltage direct-current motor capable of developing high torque, and is supplied with current from the battery.

123. Simple Direct-current Motor

a. Fundamentally, an electric motor is constructed the same as a generator. If the brushes of the simple generator are connected to a battery and current permitted to flow through the loop of wire (fig. 153), the loop of wire will rotate in the direction indicated by the arrow. Briefly, this rotation is due to the repulsion between the field magnetism and the magnetic whirl set up around the loop of wire by the current.

b. The repulsion is caused by all the magnetic lines of force tending to flow around the conductor in the same direction. This distorts and crowds the magnetic lines on one side of the conductor more than on the other, which results in a repulsion of the conductor (fig. 154 (1)). If the magnetic field is reversed, with the direction of current unchanged, the magnetic lines of force will crowd to the other side of the conductor, and it will be repelled in the opposite direction (fig. 154 (2)). The same action would result if the current, instead of the magnetism, were reversed. Thus in figure 153, owing to the current flowing in the two sides, A and B, of the loop in reverse directions and the consequent field distortion (fig. 153 (2)), A will be repulsed upward and B downward, and the loop will rotate in a clockwise direction.

c. In practice, the motor armature has many armature coils equally spaced around the entire circumference of the armature core, each of which carries current and, consequently, exerts a force to rotate the armature as it passes the pole pieces. The result is a comparatively high turning power or torque which, if applied through suitable gear reductions, is sufficient to crank the engine.

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124. Starting Motor Drives

The starter motor may drive the engine through a pinion or by a dog clutch attached to the motor armature shaft, which is brought into mesh with teeth cut on the rim of the flywheel or into mesh with the mating half of the dog clutch. The drive must be equipped with an overrunning clutch or some other means of quick disengagement. Owing to limitations of size and capacity of the battery, a high-speed starting motor with a high gear reduction is used to obtain the necessary power. The great speed reduction required is effected in the majority of cases by utilizing the flywheel as a driven gear. In some instances, the gear is bolted or shrunk on the flywheel, while in others the gear teeth are cut directly in the rim of the flywheel itself. The starting motor is mounted on the flywheel housing.

a. GEAR REDUCTION. The gear reduction obtained through the flywheel gear with a single reduction is usually about 11 : 1 or 12 : 1 (sometimes it is as high as 16:1); that is, the speed of the motor armature is 11 or 12 times that of the flywheel. The pinion gear on the armature shaft meshes directly with the gear teeth on the flywheel. In some cases, however, a double reduction is used in which the gear ratio may be as high as 25:1 or even 40:1. With double reduction, the gear on the armature shaft does not mesh directly with the teeth on the flywheel but with an intermediate gear which drives the flywheel driving pinion. The double-reduction drive permits the use of a very small starting motor running at high speed, but it has the disadvantage of requiring a more complicated mechanism than the single-reduction drive.

b. PEDAL SHIFT. (1) With this type of starting mechanism, the starter pinion is meshed when the driver presses the starter pedal. Such a system is shown in figure 155. This system includes an overunning clutch type of drive so that the pinion is automatically disengaged from the flywheel at the instant the engine begins to fire.

(2) When the shift lever is moved by the action of the driver in stepping on the starter pedal, the pinion gear is shifted into mesh with the flywheel gear. After the gears are in mesh, continued movement of the pedal operates the starter switch and causes the motor to crank the engine. In case the pinion does not mesh perfectly with the flywheel, further motion of the shift lever compresses a spring so that the pinion will snap into mesh the instant the starting motor armature begins to rotate. After the engine has started, releasing the starter pedal will pull the pinion out of the mesh.

c. OVERRUNNING CLUTCH. Power can be transmitted through the overrunning clutch in only one direction, which prevents the engine from driving the starting motor. The outer race of the clutch (fig. 156) is driven by the starting motor shaft, the inner portion or clutch rotor being connected to the pinion which meshes with the teeth on the engine flywheel. Sometimes the outer race and rotor are connected in the opposite

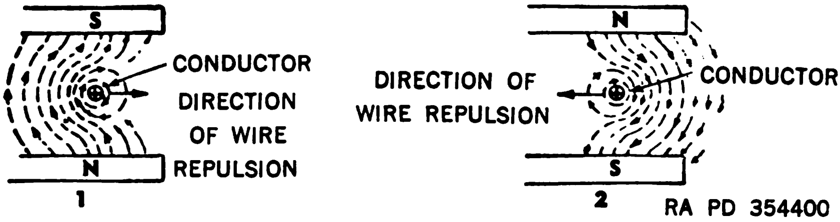

Figure 154. Wire Repulsion in Magnetic Field (Current Going In).

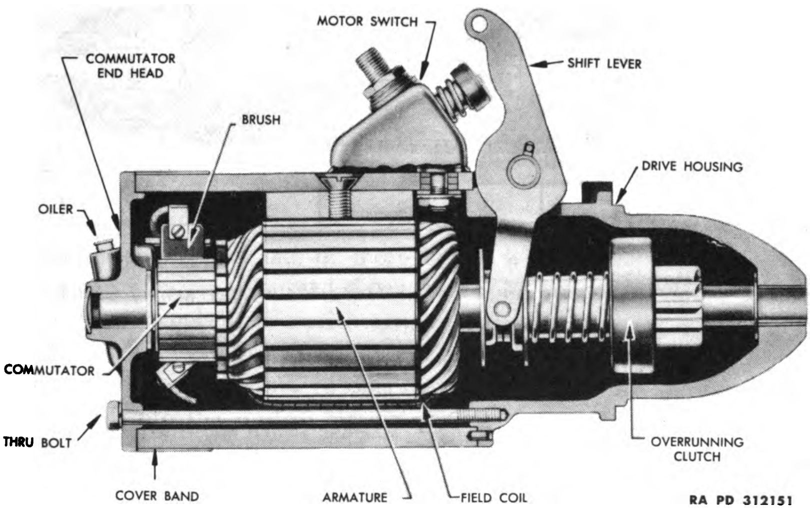

Figure 155. Pedal Shift Starter Drive with Overrunning Clutch.

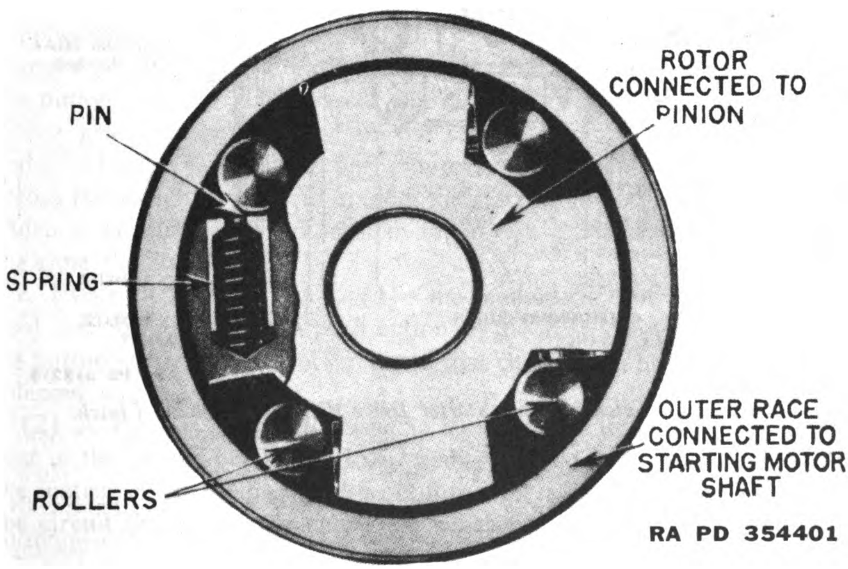

Figure 156. Typical Overrunning Clutch Construction.

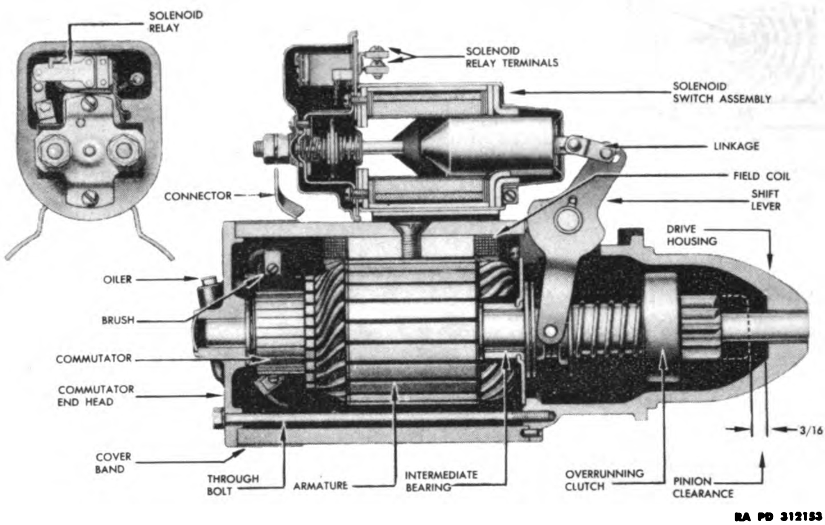

Figure 157a. Solenoid Shift Starter Drive With Overrunning Clutch.

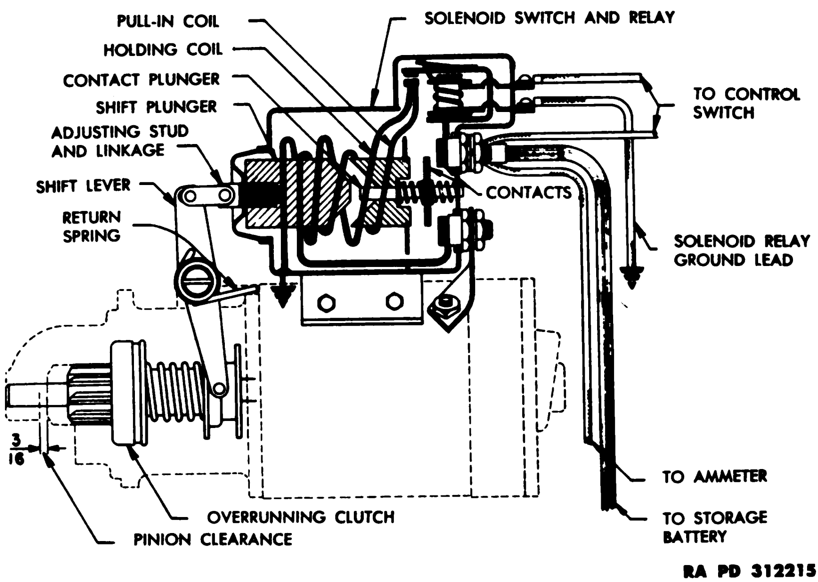

Figure 157b. Solenoid Shift Starter Drive With Overrunning Clutch.

manner. Steel rollers are located in wedge-shaped spaces between the rotor and the outer race. Springs and pins normally hold the rollers in position within the wedge spaces. When the starting motor shaft turns, the rollers are jammed between the wedge-shaped surfaces causing both the inner and the outer members to rotate as a unit and the motor to crank the engine. As soon as the engine tends to transmit power through the pinion in a reverse direction, the inner portion of the assembly (fig. 156) is driven by the flywheel and tends to work the rollers back against the pins to where the space is greater, thereby causing a slipping or overrunning action. As a result, the clutch cannot be driven in this direction. This prevents excessive speeds of the starting motor.

125. Solenoid Shift

Shifting the pinion gear into mesh with the flywheel gear is made automatic on a good proportion of modern vehicles by the use of a solenoid.

a. Definition of Solenoid. A solenoid is a coil of wire wound in the form of a helix of one or more layers which produces a magnetic field when a current is passed through it. The magnetic field thus produced flows in concentric circles around the wire.

b. Operation of Solenoid Shift. A remote control switch of one type or another is necessary to operate the solenoid. The ignition switch is connected into the control circuit so that the starting motor will not operate until the ignition is on. The solenoid shift unit is rigidly mounted on the starting motor field frame. Inside the solenoid coil is a heavy plunger connected to the shift lever (fig. 157). The two larger terminal posts on the shift unit are connected in series with the starting motor. The smaller terminal which leads to the solenoid is connected into the remote control circuit. When the remote control circuit is closed to supply current to the solenoid coil, the solenoid exerts a pull on the shift plunger which shifts the pinion into mesh with the flywheel teeth. After the pinion shift lever has moved the distance required for meshing the pinion gear, the pointed end of the shift plunger presses against the end of a contact plunger and pushes a contact disk on the contact plunger across the switch contacts to operate the starting motor. An overrunning clutch is required with this system to prevent damage to the starter at the time the engine fires.

c. Push Button Control. (1) One method of controlling the solenoid shift is by means of a push button on the instrument panel. Pushing the button closes the control circuit so that current can be supplied to the solenoid coil.

(2) A relay is frequently used in the control circuit to supply current to the solenoid coil (fig. 157). Only a low current control circuit to the instrument panel push button is then necessary. The relay will close the circuit through the solenoid coil which carries a larger current.

d. VACUUM CONTROL. (1) A vacuum switch, operated by movement of the accelerator in combination with a control relay, is another method of controlling the solenoid. This combination, when properly adjusted, eliminates the possibility of the starting motor operating while the engine is running.

(2) Vacuum switch control of the starter solenoid is shown in figure 158. When the ignition switch is on and the vacuum switch contact points are closed, current will flow through the control circuit as indicated by arrows in figure 158. The solenoid relay is then energized and its contacts close to supply current to the solenoid shift unit which operates the starting motor. The control circuit is completed through generator brushes or field to the ground connection on the generator.

(3) Depressing the accelerator pedal operates a linkage which turns the throttle cam (fig. 158) counterclockwise and moves the push rod away from the contact blade. When the engine is not operating, the blade will move with the push rod to close the vacuum switch contacts. The vacuum produced in the manifold when the engine starts causes the diaphragm to compress the spring and rotate the switch cam. The lug on the switch cam opens contact points and latches on an insulated pin on the contact blade, holding the points open. When the engine stops or stalls, there is no vacuum in the intake manifold, and the spring tends to push the diaphragm back to its original position, but it is held by the latched switch cam. When the foot is taken off the accelerator pedal, the push rod pushes against the contact blade sufficiently to unlatch the cam and allows the vacuum diaphragm to return to its original position. The contact points are held open by the push rod, but when the accelerator is depressed to start the engine, the push rod moves away from the contact blade and the points close to operate the starter solenoid.

(4) The solenoid relay is mounted on the solenoid shift (fig. 158). In some cases, it is mounted on top of the generator with the cut-out relay. The contact points in the solenoid relay close at 4.3 to 4.7 volts and remain closed while cranking until the battery voltage becomes 2.0 volts or less. After the engine starts, the generator voltage builds up, and as soon as the difference between the generator voltage and the battery voltage is 2.0 volts, or less, the relay contact points open.

126. Bendix Drive

The Bendix drive is a starting mechanism used on many cars. This automatic screw pinion shift mechanism is built in two distinct styles: the inboard type, in which the pinion shifts toward the motor to engage the flywheel; and the outboard type (fig. 159), in which the pinion shifts away from the motor. The same general construction is used in both types. A sleeve having screw threads (usually a triple thread), with stops at each end to limit the lengthwise travel of the pinion, is mounted

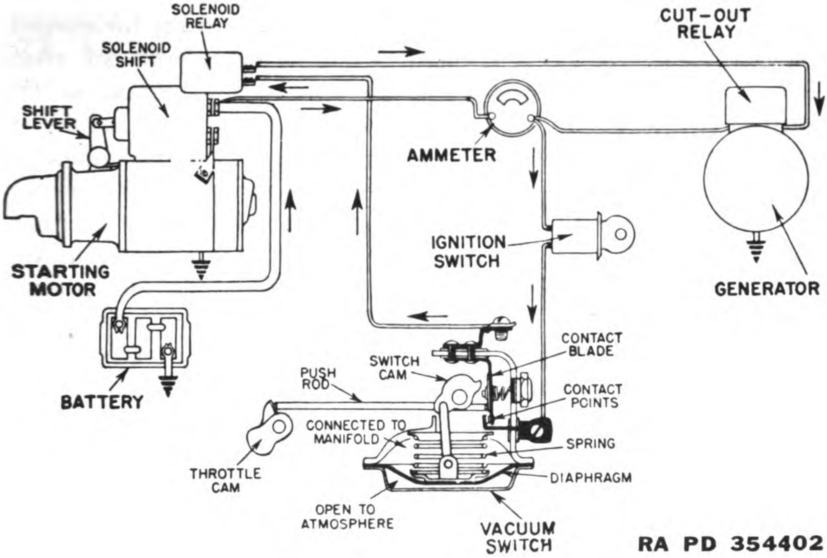

Figure 158. Vacuum Switch Control of Solenoid Shift.

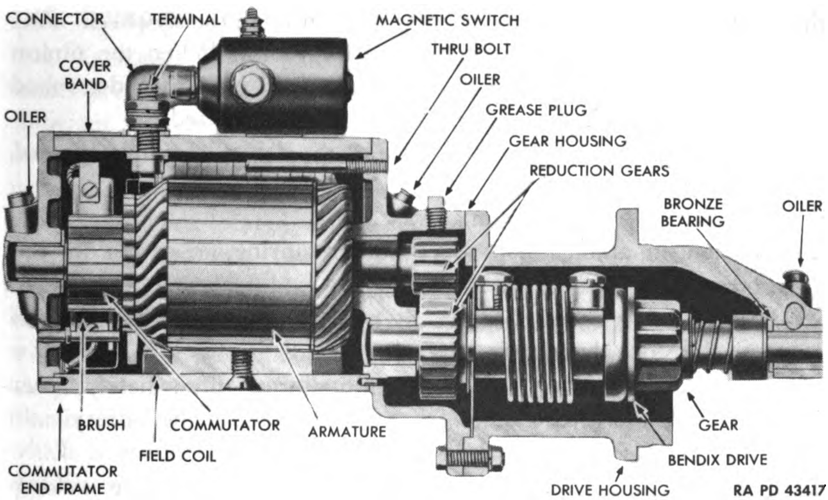

Figure 159. Starter Bendix Drive, Outboard Type.

on the extended armature shaft. The pinion gear, which is unbalanced by a weight on one side, has corresponding internal threads for mounting on this sleeve. The sleeve is connected to the motor armature shaft through a special drive spring attached to a collar pinned to the armature shaft.

a. Operation. When the starting motor is not running, the pinion is out of mesh and entirely away from the flywheel gear. When the starting switch, which may be foot- or hand-operated, is closed and the total available battery voltage is impressed on the motor, the armature immediately starts to rotate at high speed. The pinion, being weighted on one side and having internal screw threads, does not rotate immediately with the shaft, but because of its inertia, runs forward on the revolving threaded sleeve until it meets or meshes with the flywheel gear. If the teeth of the pinion and the flywheel meet instead of meshing, the drive spring allows the pinion to revolve and forces it into mesh with the flywheel. When the pinion gear is fully meshed with the flywheel gear, the pinion is then driven by the motor through the compressed drive spring and cranks the engine. The drive spring acts as a cushion while the engine is being cranked against compression. It also breaks the severity of the shock on the teeth when the gears mesh and when the engine kicks back due to early ignition. When the engine fires and runs on its own power, the flywheel drives the pinion at a higher speed than does the starting motor, causing the pinion to turn in the opposite direction on the threaded sleeve and automatically demesh from the flywheel. This prevents the engine from driving the starting motor. When the pinion is automatically demeshed from the flywheel, it is held in a demeshed position by a latch until the starting switch is again closed.

b. Advantages. Among the chief advantages claimed for this type of motor drive are:

(1) Simplicity of construction.

(2) Mechanism automatic in operation, requiring no action by the operator other than pressing the starter switch.

(3) High starting speed, because the starting motor is permitted to pick up speed before the load is applied.

(4) The engine is given a high cranking torque immediately, thus requiring little cranking and minimizing the demand on the battery.

c. Disadvantages. Among the disadvantages are:

(1) The quick impulse given to the pinion is likely to cause nicking or breaking of the teeth when the pinion does not mesh properly on first contact with the flywheel teeth.

(2) Breakage or nonfunctioning of the pinion latch will cause the pinion to drift toward the flywheel teeth which is likely to cause damage if the engine is running.

(3) All of the starting motor torque is transmitted through the drive spring which puts it under considerable strain.

Section IV. LIGHTING SYSTEM

127. Motor Vehicle Lighting

The history of automobile lighting runs parallel with the history of the lighting of houses and buildings; oil lamps and gas lamps having been used in the early automobile. With the development of a satisfactory electrical system, electric lighting has become the standard means of lighting motor vehicles.

a. COMPONENTS. The lighting system as found on most modern motor vehicles consists of the following:

(1) Two head lights for illuminating the road ahead of the vehicle.

(2) Two parking or side lights for indicating primarily the location of the vehicle when parked.

(3) Tail lights to illuminate the rear license number plate and to show a red light to the rear.

(4) Instrument panel lights to illuminate the instruments.

(5) Body lights, such as dome and step lights, to light the interior of the vehicle.

(6) Special lights, such as spot lights, signal lights, blackout lights, stop and backing lights.

(7) Wires and control switches to connect these lights and lamps to the current source.

128. Lamps

a. GENERAL. Small gas-filled incandescent lamps with tungsten filaments are used on motor vehicles. The filaments supply the light when sufficient current is flowing through them. The lamps are designed to operate at low voltage, that is 6 or 12 volts (corresponding to the voltage of the electrical system used), and are wired to operate from control switches located within convenient reach of the driver.

b. CONSTRUCTION. Most lamps are provided with a single contact for each filament within the lamp, the current through each filament being completed to the shell of the lamp base. A double filament lamp with the single contact construction is shown in figure 160. Two contacts are provided on the lamp base, each one being connected with one of the filaments. The return from both filaments is to the lamp base shell which is grounded through the lamp socket. Thus there are two separate circuits with two contacts on the base, each of which might properly be termed a single contact, for a grounded circuit.

c. SIZE. Lamps range in size from the small ½-candlepower instrument panel lamps to the large 50 or more candlepower driving lamps. Inasmuch as the voltage used is low and the current required as a result is high, the filaments are much shorter and stronger than those used for standard house lighting lamps. A short and thick rather than a long and thin filament naturally stands more rough treatment, and this is

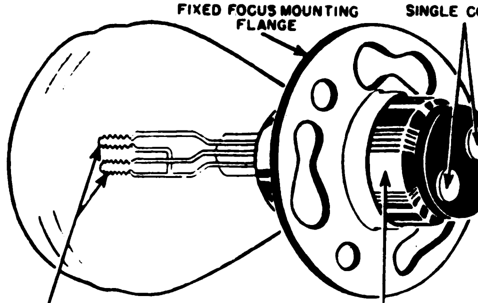

Figure 160. Double Filament Headlight Lamp.

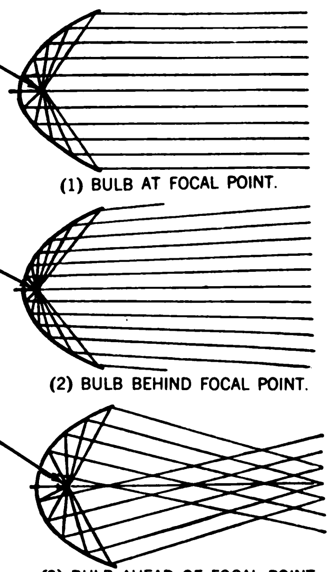

Figure 161. Effect of Lamp Position in Parabolic Reflector.

desirable in the case of a lamp subjected to the vibrations of a motor vehicle. A short filament also provides a concentrated light source that will give a better focus. The candlepower (measure of light intensity) delivered by a lamp depends upon the voltage and amperage consumed. The 2-candlepower lamp consumes 0.43 ampere at 6 volts. The 4-candlepower lamp consumes 0.85 ampere at 6 volts. A lamp similar to the one shown in figure 160 having two filaments, one of 32 candlepower and the other of 21 candlepower, will draw 3.9 and 2.8 amperes.

d. Current Requirements. One reason for the rapid discharge of storage batteries in winter is the increased number of hours which lamps

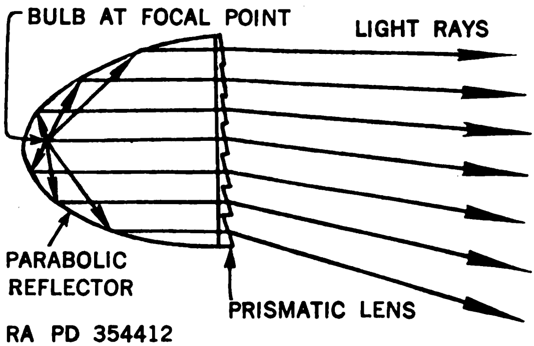

Figure 162. Rays of Light from Head Light Distributed by Prismatic Lens.

are used. Naturally there is a direct relation between the total current consumption and the number of lamps used. All storage batteries are rated by ampere hours; that is, the number of hours a battery can be used at a certain discharge amperage before it becomes depleted. For instance, two head light lamps burning at 4 amperes each, a total of 8 amperes, would discharge a storage battery rated at 80 ampere hours in approximately 10 hours unless the generator charged the battery.

129. Light Beams

a. Use of Reflector. A lamp bulb is mounted within a reflector so that the light can be gathered and directed in a confined beam. The best light beam from a lamp is obtained by the use of a parabolic reflector which is the type in general use. There is a focal point near the rear of the parabolic reflector at which the light rays from the lamp are picked up by the polished surface of the reflector and directed in paralleled lines to give a beam with a circular cross section. Any other position of the lamp will not give as confined a beam but will tend to scatter the light as shown in figure 161.

b. Use of Prismatic Lens. The light beam is distributed over the road by means of a prismatic lens. The effect of a prismatic lens fitted to parabolic reflector is shown in figure 162. The lens bends the parallel rays from the reflector so that the light is distributed over the road. The vertical flutes of the lens spread the light rays so that the beam is flattened, with the edges thrown out toward the side of the highway.

c. Combinations of Beams. Many combinations of light beams are possible. One combination of head light beams that has been commonly used is shown in figure 163. The beam from the right head light (fig. 163 (1)) is projected high to the right side of the road and low to the left side, and the beam from the left head light (fig. 163 (2)) is projected high to the left side and low to the right side. Portions of the beam are deflected lower than other portions due to the design of the lens. When the right and left beams are not the same (fig. 163 (1) and (2)), the lenses for right and left head lights are not interchangeable. These beams combine to give a nearly symmetrical beam for driving (fig. 163 (3)).

With some head lights, the left-hand light illuminates the right-hand side of the road, while the right-hand light illuminates the left-hand side of the road. Both lights together give a symmetrical beam somewhat similar to figure 163 (3).

The present tendency is toward a spreading beam which illuminates a wide area rather than a concentration of the beam directly in front of each head light as shown in figure 163.

130. Head Lights

a. General. (1) In head lights of the older type, means are provided for focusing and directing the light. By focusing is meant bringing the filament of the lamp to the focal point of the reflector; by directing is meant aiming the light properly.

(2) Later developments brought into general use a two-filament lamp having its position fixed with respect to its mounting socket at the rear of the reflector so that the filaments remain fixed at the proper focus (fig. 160). To improve the lighting of the roadway, it is necessary only to direct the light.

b. Parts. The principal parts of an automobile head light are the

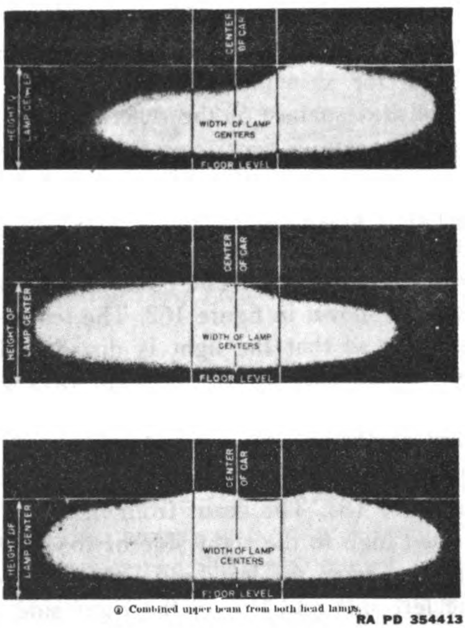

Figure 163. Head Light Beams.

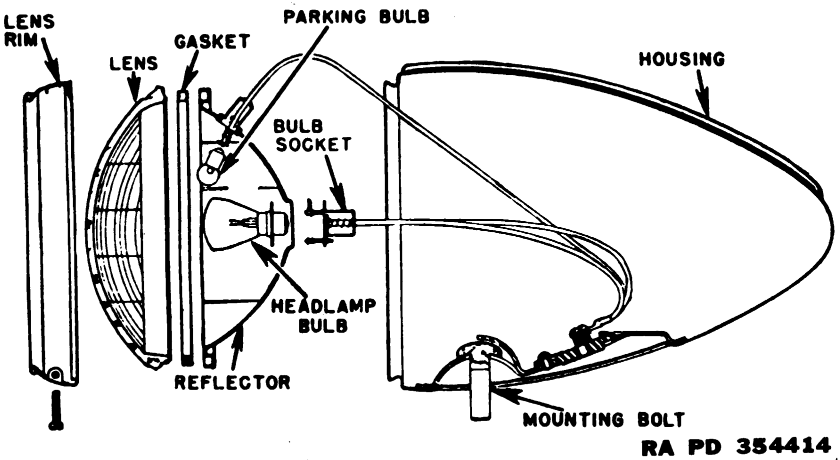

Figure 164. Head Light Construction.

housing, with some means provided for mounting the housing; lamp and socket; reflector; and lens with rim and gasket to hold the lens in place and to keep dust out of the head light interior. These parts are shown in figure 164. One of the lamp filaments, a larger filament, is placed close to the focal point to obtain a good beam for driving on the highway, while a second filament is placed just off the focal point so that a depressed beam is obtained for passing other cars and for city driving. A parking lamp is at times also incorporated within the head light as shown.

c. SEALED BEAM. (1) A superior head light that has been adopted is the sealed beam head lamp unit. Not only does it provide far better and more powerful illumination than previous lamps, but it maintains its initial brilliancy with only a slight loss throughout its life. This is because the lens glass is permanently sealed to the reflector, effectively barring moisture which corrodes the reflector and preventing the entrance of dust and dirt.

(2) When a filament burns out, the whole unit must be renewed. However, it has a greater filament life than other type lamps and requires no maintenance to keep the lamp in good condition.

(3) The sealed beam head lamp unit is made in two types, one with a silver-plated metal reflector and the other with an aluminum surfaced glass reflector. The metal type contains a conventional double filament lamp which is mechanically sealed in the unit, whereas the glass type is its own lamp since the lens and reflector are fuzed together forming a gastight unit with the filaments sealed into the reflector (fig. 165).

(4) Two filaments are provided in the sealed beam head lamp unit, one furnishing an upper beam for country driving, and the other giving a depressed beam for passing or city driving. With the upper beam in use, the new sealed beam lamp units provide 50 percent more light than previous 32-candlepower lamps and also distribute the light more effectively. The upper beam filament requires 40 to 45 watts, and the

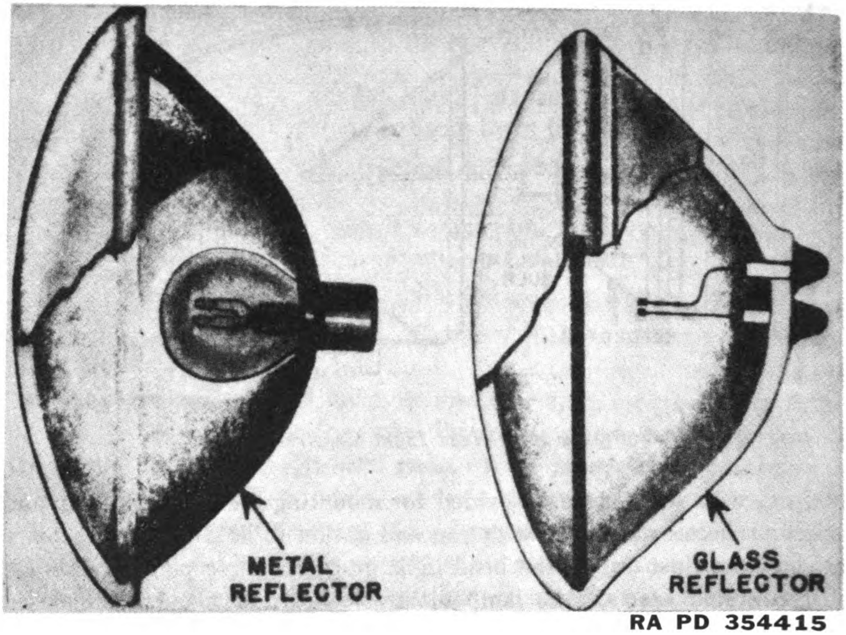

Figure 165. Sectional Views of Sealed Beam Head Light Lamp-units.

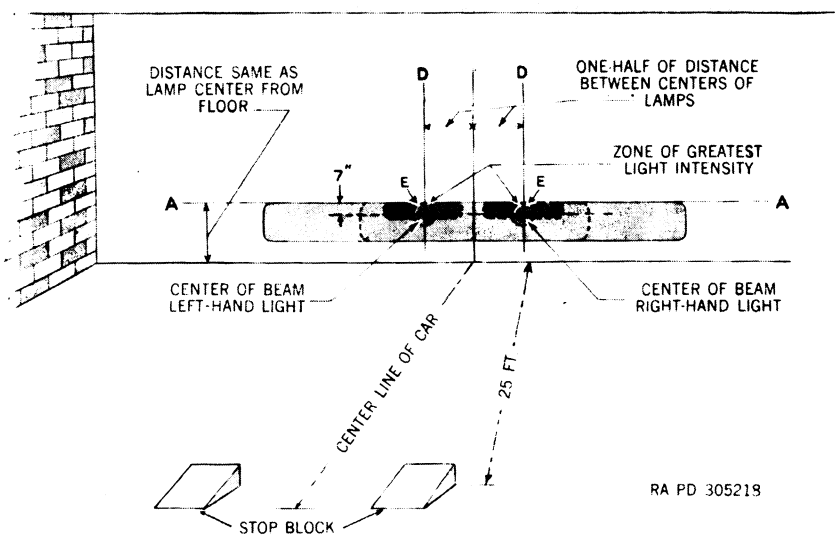

Figure 166. Head Light Aiming Chart.

depressed beam filament requires 30 to 35 watts which is more current than that required by the 32-candlepower lamps. Directing the head light to the roadway is the only adjustment required on sealed beam head lamps. Parking lights are separate.

d. MOUNTING. The two head lights are mounted so that their centers are between 32 inches and 42 inches from the ground. The lights are supported by brackets from either the fender or chassis frame or both and are usually sufficiently adjustable to permit changes in the vertical and the horizontal angle of the head lights to aim the beam correctly.

131. Elimination of Glare

a. Cause of glare. Any light source is said to produce glare if it appreciably reduces the distinctness of vision of anyone looking toward it. Practically speaking, the blinding or dazzling effect of light is not due so much to the brilliancy of the light as to the lack of illumination in the immediate vicinity through which the rays are projected. The head light, for example, which produces glare on a dark road at night would not produce glare on a well-lighted street, and in the daytime with the sun shining it would hardly be noticed. Glare at night is caused by directing strong beams of light into the eyes of approaching drivers and pedestrians. If the strong light rays can be kept below the eye level, the nuisance of glare will be largely eliminated.

b. ELIMINATION. Many tests have been conducted by the Society of Automotive Engineers and by manufacturers to eliminate head light glare as much as possible and still have sufficient illumination for safe driving. Two beams are specified to meet these requirements; an upper beam to provide sufficient illumination in front of the vehicle while driving, and a depressed beam to avoid dangerous glare under normal conditions of passing. The driver is responsible for selecting the proper beam. The maximum and minimum intensity at important points of both beams are definitely specified and can be checked with the light intensity or foot-candle meter.

132. Road Illumination

Until recently, many of the States had laws prohibiting the use of lamps of over 32 candlepower in head lights. Modern development has brought about a radical change in what is considered good road illumination. The high intensity beam of light has given way to the principle of more illumination and lower general intensity. The 32-candlepower lamp is sufficient with a narrow, high intensity beam but with the general flood lighting effect desired today, a larger light source is necessary. The sealed beam head lamp has been developed to meet these requirements. With the increased use of high-powered lamps have naturally come laws enforcing the proper focusing of the lights and the use of dual-beam head lamps.

133. Focusing

a. When focusing head lights, it is desirable to place the vehicle on a level surface in front of a focusing screen. The type of adjustment provided on the head light must be determined. If the head light is not of the fixed-focus type, the light must be focused first by an adjusting screw usually provided at the rear of the head light. The adjusting screw should be turned in or out to secure the most concentrated light on the lighting screen.

b. As most automobiles are provided with fixed-focus lamps, all that is necessary when adjusting the light beam is to have the head light properly aimed as shown in the head light aiming chart (fig. 166). The car is placed 25 feet from the screen on a level floor. The upper beams from both head lights should be directed straight ahead. The top of these beams should project to the height of the light centers as marked on the focusing screen. If this is done, the beams from the head lights will always be below the vision of approaching drivers on a level road. The amount of deflection obtained from depressed beams is fixed by the distance between the filaments of the lamp.

134. Depressed Beam

In order to enable the driver to prevent glare in the eyes of approaching drivers, various methods of depressing the head light beam have been introduced.

a. Double Filament Lamps. Double filament lamps are commonly used at the present time to obtain both driving beams from one lamp. The lamp is designed so that when it is mounted in the head lights, one filament will be at the focal point of the reflector, and the other filament will be slightly out of focus so that the rays will be deflected downward. Depressing the beam is accomplished by a foot-operated switch which changes the current from one filament to the other.

b. Tilting Reflectors. Tilting reflectors have been used for obtaining the depressed beam. The reflectors are mounted on a horizontal pivot so that by manipulating a lever on the steering column, the head light reflectors may be tilted forward to lower the light beams, thus reducing glare. This method differs from the other methods in that it merely redirects the light rays and does not reduce either the light intensity of the current consumption of the lighting system for driving on lighted highways and city streets.

c. Separate Head Lamps. Separate head lamps have been used to obtain the two driving beams, each head lamp having one filament at the focal point. Four head lamps are provided, two being directed for the upper beam and two for the depressed beam.

135. Switches

a. Head Light. (1) Two head light controls are usually provided, one switch being mounted on the instrument panel and another switch on the toe board near the clutch pedal position. A light control switch for instrument panel mounting is usually of the plunger type with three positions. In the first position, with the plunger knob pushed all the way in, head lights, parking lights, tail lights, and instrument lamps are all off; that is, the switch is open. In the second or middle position, the parking lights, tail lights, and instrument lamps are turned on. In the third position, with the plunger knob pulled all the way out, head lights, tail lights, and instrument lamps are on. With the plunger knob in this position, it is possible to change the head lights for either upper or depressed beam by pressing the foot dimmer switch on the toe board. Thus it is possible for the driver to shift from the driving beam to the passing beam without removing his hands from the steering wheel. This is highly desirable at high speeds. Usually a small indicating lamp is provided on the instrument panel, which will light when the upper driving beam is on, giving the driver an indication of which beam is being used.

(2) Some manufacturers provide four positions on the instrument panel light switch. Two positions are then provided for the selection of the proper light beam. When the instrument panel switch is in the third or depressed beam position, the foot dimmer switch is inoperative; thus, the driver can maintain the depressed beam when there is difficulty in distinguishing which beam is in use. The foot dimmer switch is operative for the selection of the proper beam when the knob is in the fourth position or all the way out.

(3) The foot dimmer switch is located either to the left of the clutch pedal or between the clutch and brake pedals so that the left foot can be used to operate the switch. The switch is operated by depressing the button to the full depth, which rotates a contactor cam, breaking one contact and making the other. Depressing the button a second time restores the switch to its original position. The switch is designed so that the contacts overlap; that is, one contact is made before the other is broken, so that both beams will not be off at the same time. This eliminates any possibility of head lamps being out while changing beams.

b. Stop Light. (1) As the function of the stop light, mounted at the rear of the vehicle, is to warn any following vehicle that the driver intends to stop, or slow down, the stop light should be so mounted and its brilliance such that it may be readily noticed either day or night. For reason of safety, operation of the stop light should also be automatic so that special attention is not required by the driver. Thus, the stop light is expected to go on whenever the brakes are applied to slow down or stop the vehicle.

(2) Two types of stop light switches have been universally adopted, one for use with mechanical brake systems, and the other for use with hydraulic or air-operated brake systems.

(3) The operation of the stop light switch must be coincidental with

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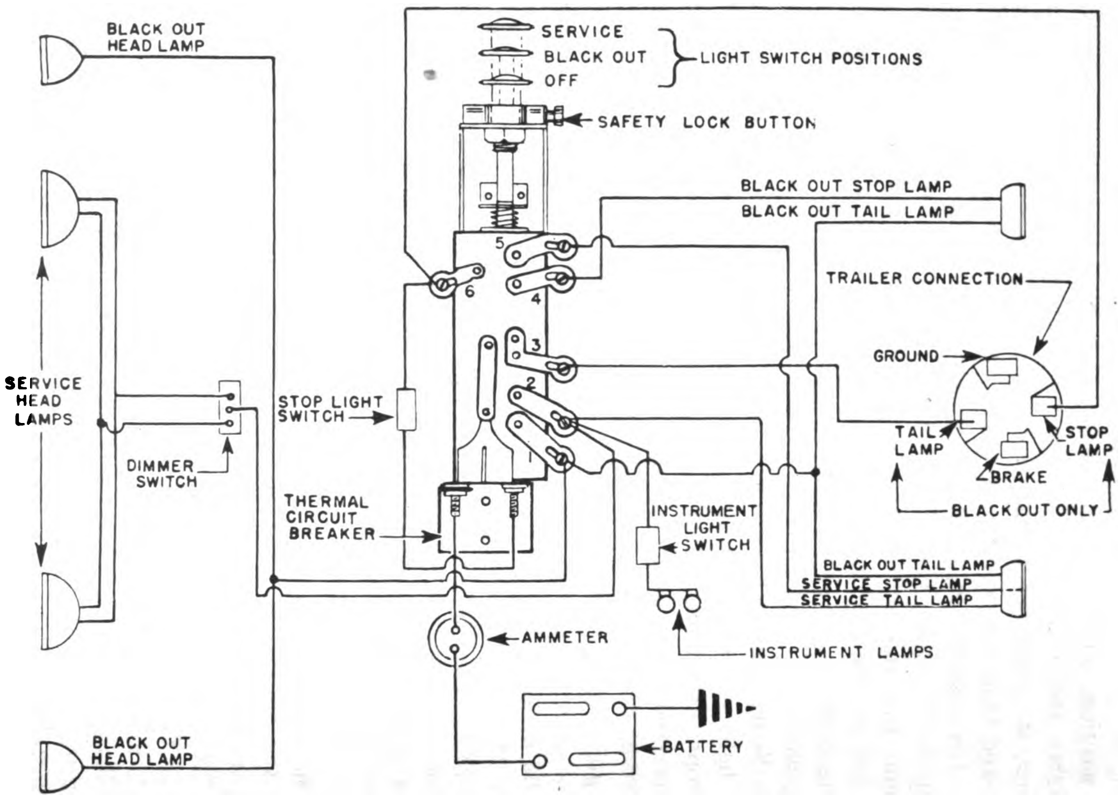

Figure 167. Blackout Light Switch and Connections.

the operation of the brake pedal. In the mechanical switch, the contacts are closed by a linkage connection to the brake pedal. The hydraulic switch unit is connected directly to the master cylinder so that when the brakes are applied the fluid pressure will operate the switch. The stop light switch on air break systems is operated from the air pressure of the system.

c. BLACKOUT LIGHT. Vehicles provided with blackout lights have a special blackout light switch which incorporates the operation of the service lights and blackout lights in one unit. This switch is shown in figure 167, with its connections to the various units in the lighting system. The plunger knob has three positions: off, blackout lights, and service lights. In its second or middle position, the switch turns the blackout lights on, keeping all other lights off. The plunger knob cannot be pulled out to its third position until the safety lock button is pushed in. This is a safety feature to prevent any lights visible from above being accidentally turned on during a blackout. In the third position, with the plunger knob pulled all the way out, the service lamps are on and operate normally as described in *a* above. A trailer connection is provided to operate lamps on the rear of the trailer. Trailers are provided with blackout lights only. These are lit when the switch is in both the second and third positions.

136. Other Lamps

a. INSTRUMENT LIGHTS. Ordinarily, indirect lighting is used for the instrument lamps, which light whenever the lighting switch is in any of the "on" positions. Many cars are equipped with an instrument panel lamp switch so that the instrument panel lamps can be turned off when desired.

b. DOME LIGHTS. Practically all closed automobiles make use of dome or tonneau lights. These are ordinarily controlled by means of a switch on a body post near the right-hand door.

c. PARKING LIGHTS. (1) The smaller lights used for parking are sometimes located immediately above or below the main head lights. The parking light housing is then usually constructed as a part of the main head light housing.

(2) Side lights sometimes serve as parking lights in which case a separate housing is used.

(3) A smaller lamp located within the main head light and above the main head light lamp has been frequently used to provide a parking light. A 4- or 6-candlepower lamp, or smaller, is used for a parking light.

d. TAIL AND STOP LIGHTS. Tail and stop lights are ordinarily combined, with two lamps contained in a single housing with a red lens. A larger lamp (about 15 candlepower) is used for the stop light and a smaller lamp (about 3 candlepower) for the tail light. Tail and stop lights are sometimes enclosed in a single lamp having a double filament. Tail lights light whenever the lighting switch is in any of the "on" positions.

e. BACKING LIGHTS. Occasionally a backing light is used, mounted so as to direct light to the rear of the vehicle. It is arranged and wired so that a switch turns on the lamp when the gear shift lever is put into reverse position.

f. SPOT LIGHTS. These lights are similar in construction to the head lights. They are designed to project a beam for a great distance ahead and are constructed so that the light can be aimed by the vehicle operator. They are valuable for detecting pedestrians at a safe distance, for observing the condition of the roadway to the sides, and for reading road marking signs.

g. AUXILIARY DRIVING LIGHTS. In order to improve the lighting of the roadway without throwing glaring light rays into the eyes of approaching drivers and pedestrians, auxiliary driving lights are sometimes used. They are designed to be mounted on the front of the car on the head light tie rod, on the fender, or on the horns of the car frame. Spot lights may be used for this purpose and mounted similarly.

h. INDICATING LIGHTS. Buses and trucks are usually provided with lights to indicate their width or length. These lights are provided with red, yellow, or green lenses to attract the attention of approaching drivers. The lights are required by the Interstate Commerce Commission and should be arranged and operated in accordance with their instructions.

i. BLACKOUT LIGHTS. (1) It is a difficult problem to provide a lighting system for night driving that will illuminate the roadway sufficiently to drive at reasonable speeds with a fair degree of safety and at the same time prevent effective observation by the enemy. Intensive study is being given to luminous markers placed on roadsides and on vehicles combined with special driving lights, which illuminate the markers and at the same time are not visible at a distance. The problem of proper night lighting and the use of marking devices depend largely on the selection of drivers. Two men who see equally well in daylight may have quite different relative vision at night. Tests must be made for the selection of men who have acute vision at night. At the present time, small blackout lights are used. Further research will probably bring other developments.

(2) Blackout lights are used to enable a convoy to move at night without being observed from the air. These lights provide sufficient illumination to enable units in a convoy to keep in line while progressing at slow speeds. Two blackout head lights, two blackout tail lights, and a blackout stop light are provided for this illumination. All other lights in the car are off when the blackout lights are lit.

(3) Small housings, somewhat similar to passenger car parking light housings, are used with small lamps that produce subdued lighting. A shutter somewhat like a venetian blind is placed in front of the lens to prevent any light from being projected upward.

CHAPTER 11

OVERLOAD BREAKERS, INSTRUMENTS AND GAGES

Section I. OVERLOAD BREAKERS

137. Overload Breakers

Besides limiting the current by current regulation, the battery and wiring should be protected against excessive loads which might occur due to shorts or grounds in the wiring system. Such protection may be secured by a current limiting circuit breaker or a single fuse. The location of an overload breaker in the electrical system is shown in figure 168.

a. CIRCUIT BREAKER. (1) The circuit breaker is a protective device designed to open the circuit when a current in excess of what it is intended to carry passes through its winding. All current for lights and accessories pass through it. It is similar in construction to the cut-out, but opens the circuit rather than closes it. If there is a ground or other trouble in the circuit, the rush of current will start the circuit breaker vibrating and in this way it indicates that there is something wrong in the system. The device breaks the circuit at about 25 amperes but after opening, allows only about 5 amperes to pass through, which keeps it vibrating. Thus the circuit breaker protects the battery from rapid discharge when trouble develops. The circuit breaker will continue to vibrate until the trouble is found and corrected.

(2) In all types of circuit breakers, the short circuit must be removed before the breaker can be reset. The short circuit can be easily located by disconnecting each circuit separately until the circuit breaker stops vibrating.

(3) Some automatic breakers do not vibrate but have a "telltale" light placed across the contacts. This light, generally placed where it is visible by the operator, is protected by a resistance. When the circuit breaker contacts are opened by excessive current, the light flashes on. There is generally sufficient current flowing through the relay coil with the lamp in series to hold the contact arm of the circuit breaker down until the short is removed. After removing the short, it may be necessary to turn off all lights for an instant to permit the relay to reset itself and extinguish the "telltale" light.

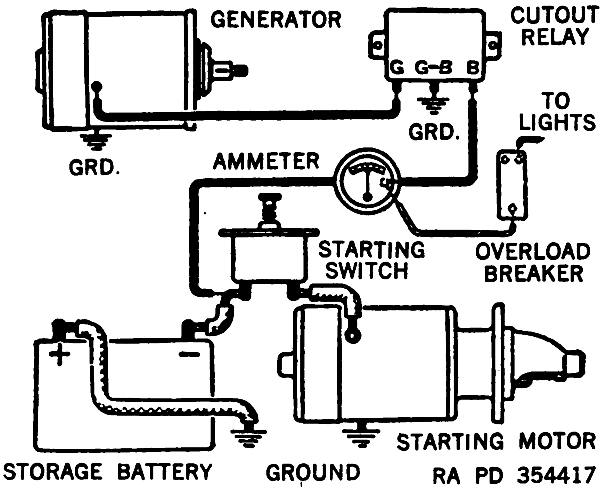

Figure 168. Simplified Wiring Diagram Showing Location of Overload Breaker (Circuit Breaker or Fuse) in Electrical System.

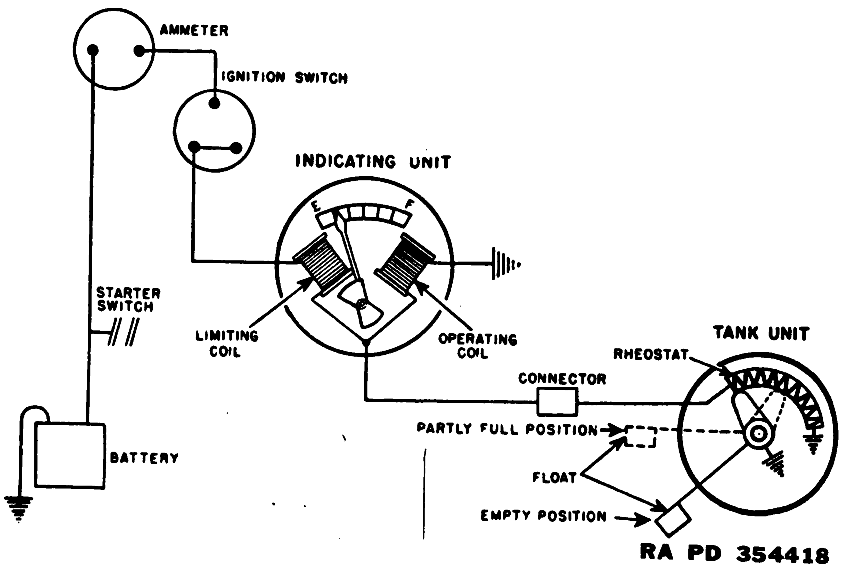

Figure 169. Coil Type Fuel Gage Circuit.

b. FUSE. A more common method of protection is to use a fuse in the lighting circuit. Whenever there is an excessive current through the lighting circuit, the fuse will burn out and open the circuit. The short circuit should be removed before the fuse is replaced. The disadvantages of using a fuse are that the circuit must be traced to locate the trouble and that a burned-out fuse must be replaced. However, it provides much cheaper protection to the system.

Section II. INSTRUMENTS AND GAGES

138. Instrument Panel

The instrument panel is usually placed so that the instruments may be easily read by the driver. They inform the driver of the approximate speed, engine temperature, oil pressure, rate of charge or discharge of the battery, amount of gasoline in the supply tank, distance traveled, and the time. Certain controls are frequently mounted on the instrument board such as throttle, spark, choke, starter, heater, windshield wiper, and other controls.

139. Ammeter

a. The ammeter is used to indicate the amount of current flowing to and from the battery. It does not give an indication of total generator output because other units in the electrical system besides the battery are supplied by the generator. If it shows a 10-ampere discharge it indicates that a 100 ampere-hour battery would be discharged in 10 hours; that is, 10 amperes flowing for 10 hours.

b. Current flowing from the storage battery to the starting motor is never sent through the ammeter, since the great quantities used (200 to 600 amperes) cannot be measured on an instrument of such limited capacity. In the usual type of ammeter, all the current flowing to and from the battery, except for starting, is actually sent through a coil to produce a magnetic effect which deflects the ammeter needle in proportion to the amount of current. Thirty amperes is about the maximum capacity for this coil.

140. Fuel Gage

Most fuel gages are electrically operated and composed of two units; the indicating unit which is mounted on the instrument panel, and the tank unit which is mounted on the gasoline fuel tank. The ignition switch is included in the fuel gage circuit so that the electrical fuel gage operates only when the ignition switch is "on." Operation of the electrical gage depends on either coil action or thermostatic action.

a. COIL TYPE. (1) The electrical circuit for a fuel gage is shown in figure 169 in which the coil type indicating unit is illustrated. Indication of the fuel level is accomplished by the variation in magnetic effect of two coils on a pointer caused by a change of resistance in the tank unit. The rising or falling float in the fuel tank moves the arm of a rheostat or variable resistance.

(2) Current from the battery passes through the limiting coil to the common connection between the two coils, which is the lower terminal on the indicating unit. At this point, the current is offered two paths, one through the operating coil of the indicating unit and the other over the wire to the tank unit. When the gasoline tank is empty, the grounded rheostat arm on the rheostat cuts out all the resistance in the tank unit. Most of the current will pass through the tank unit circuit because of the low resistance and only a very small portion through the operating coil of the indicating unit. As a result, this coil is not sufficiently magnetized to move the indicating pointer in the indicating unit which is held at the empty position by the limiting coil. If the gasoline tank is partly full, the float of the tank unit rises on the surface of the gasoline and moves the rheostat arm over the resistance, putting resistance into the tank unit circuit as indicated by the broken lines in figure 169. More current will then pass through the operating coil to give a magnetic pull on the pointer, which overcomes some of the pull of the limiting

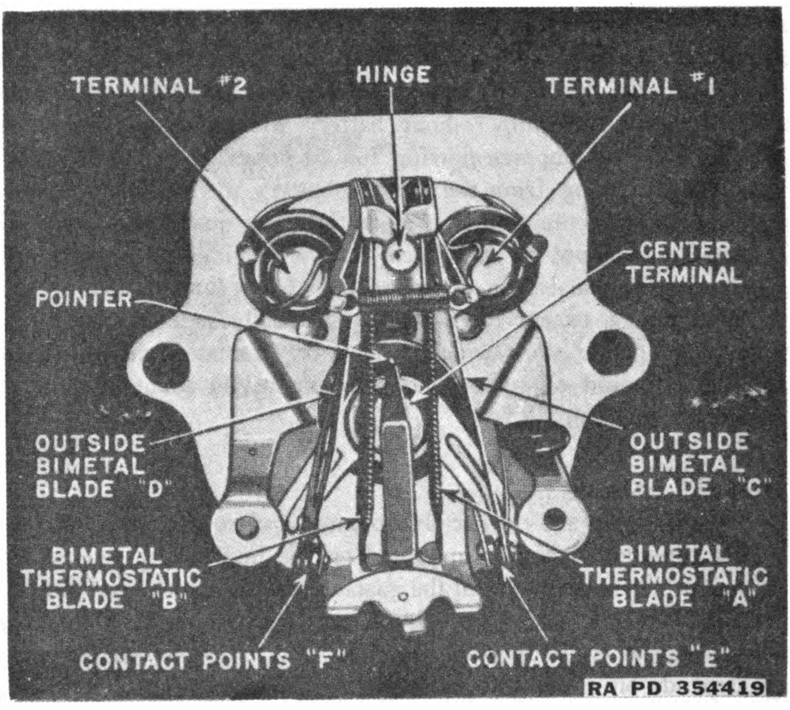

Figure 170. Instrument Panel Indicating Unit of Bi-metal Thermostatic. Fuel Gage (Dial Removed).

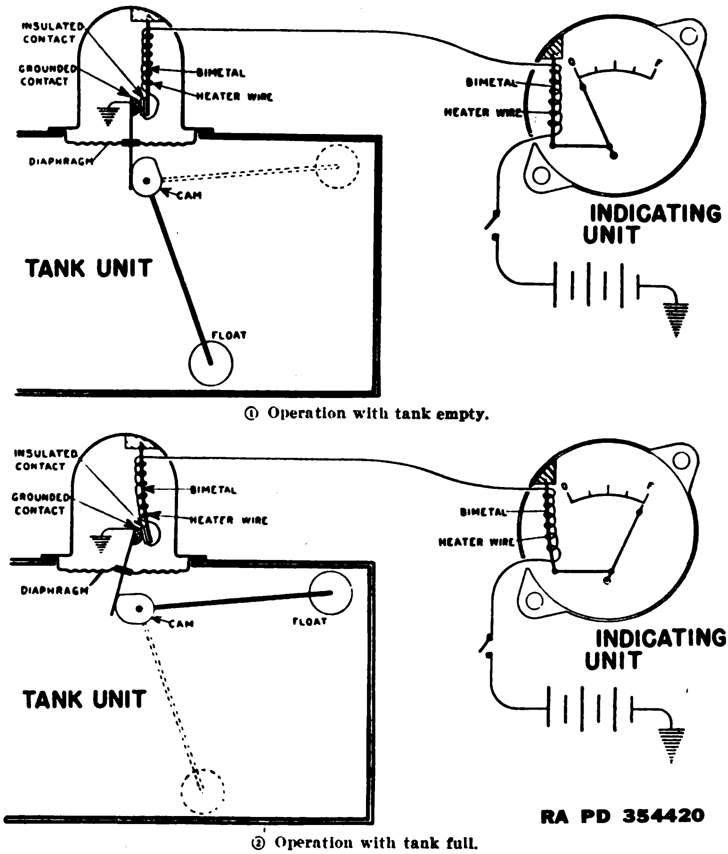

Figure 171. Fuel Gage in Which Both Indicating and Tank Units are Thermostatically Operated.

coil. When the tank is full, the tank unit circuit contains its maximum resistance to the flow of current. The operating coil will then receive its maximum current and exert a maximum pull on the pointer to give a full tank reading. As the tank empties, the operating coil loses some of its magnetic pull while the limiting coil still has approximately the same pull so that the pointer is pulled toward a lower reading.

(3) This type of gage consumes very little current, about ⅛ ampere. Since the operation of this gage depends on the difference in the magnetic effect between two coils, variations in the battery voltage will not cause an error in the gage reading.

b. Thermostatic Indicating Unit. (1) The indicating unit, with the dial removed, of one type of thermostatically operated electric fuel gage is shown in figure 170. This gage operates by the electrical heating of bimetal thermostat blades. The blades A and B are heated by the insulated resistance wire wound around them. Current enters the fuel gage at the center terminal on the back of the gage. From there it passes through the contact points E, then up the blade C, and down the blades A and B to a point near the end of each blade where the resistance heater wire is welded to them. It then passes up through the resistance wire on each blade to the terminals marked Nos. 1 and 2. These terminals are both connected by separate wires to each end of a rheostat in the tank unit.

(2) When the tank unit float is all the way down, all of the rheostat resistance (25 ohms) is in terminal No. 2 circuit and none is in terminal No. 1 circuit. Most of the current will flow through terminal No. 1 circuit and the bimetal blade A. This current through the resistance wire on blade A will heat the blade making it deflect clockwise and push the indicator pointer to empty.

(3) When the tank unit float is raised all the way up, the rheostat resistance is zero in terminal No. 2 circuit and 25 ohms in terminal No. 1 circuit. The resistance wire around the bimetal blade B will then receive most of the current and become heated. Blade B deflects counterclockwise when heated so that it pushes the indicator pointer toward full.

(4) The outside bimetal blades C and D compensate for the effect of outside air temperature on blades A and B and also compensate for the variation in battery voltage. The combined deflection of the blades, due to the temperature reached when 5 volts is across the gage, opens the contact points E. Below 5 volts, the contact points do not open. Above 5 volts, they open and close intermittently to maintain constant input to the gage. The insulated contact points F merely act as an anchor for the entire operating mechanism for the purpose of temperature compensation.

c. THERMOSTATIC INDICATING UNIT AND TANK UNIT TYPE. (1) Another type of thermostatic electric fuel gage has bimetal blades in both indicating and tank units. This type gage may also be used as a temperature or oil pressure gage by using changes in pressure or temperature to operate the movable grounded contact in the tank or sender unit.

(2) When the tank is empty and the float is down (fig. 171 (1)), the two contacts in the tank unit are just touching. Current flows through the resistance heater wires of both indicating and tank units causing the bimetal blades to bend. Bending of the bimetal blade in the tank unit separates the contacts to break the circuit. The heater wire cools when the current stops flowing and the bimetal blades return to their original position. Contact is again made and the cycle of operation is repeated approximately every second. Opening and closing of the contacts gives an intermittent flow of current which does not heat the indicating unit blade sufficiently to bend it. The blade then holds the pointer at the empty reading.

(3) When the tank is full, the action of the float and cam (fig. 171 (2)), pushes the grounded contact against the insulated bimetal contact, bending the bimetal blade in the tank unit. Since the bimetal is then

under a strain, the current must flow longer to bend it sufficiently to open the contacts. The longer flow of current will then cause a bending of the bimetal blade in the indicating unit and push the pointer over to the full position.

(4) The contacts open and close fast enough to give a steady reading by the pointer. The maximum current requirement for a full reading is less than ¼ ampere. This type of gage is not affected by variations of battery voltage and is compensated for outside air temperature variations.

d. Hydrostatic Gasoline Gage. The hydrostatic gasoline gage consists of a dash unit and a tank unit connected by an air tube. In operating condition the air tube and air chamber of the tank unit and the air tube connecting the tank unit with the dash unit are filled with air. The gasoline tries to rise to the same level in the tank unit as it is in the tank, but this is impossible because of the air trapped between the bottom of the tank unit and the liquid in the dash unit. The pressure is thus transmitted by means of the air column in the air tube to the dash unit, where it forces the liquid of the dash unit down in the brass tube and up in the glass indicating tube. The cup and the air-delivery tube mounted in the tank take no part in the reading of the gage, but act only as a means of supplying air to the air chamber to keep it full of air.

141. Speedometer

a. General. A speedometer (fig. 172) is used to indicate vehicle speed in miles per hour, and to record distance traveled by means of an odometer. A speedometer is driven through a flexible shaft connected to a set of gears in the vehicle transmission (fig. 173). These gears are

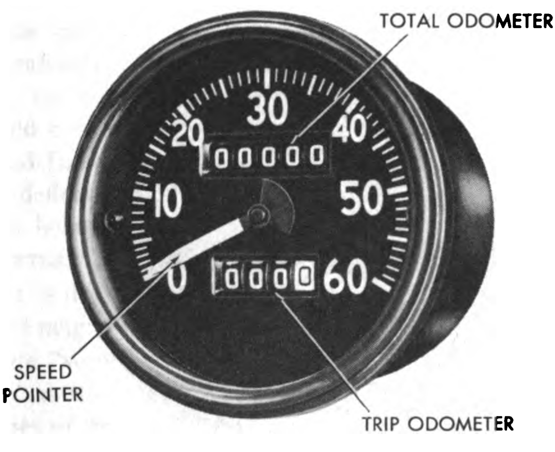

Figure 172. Speedometer

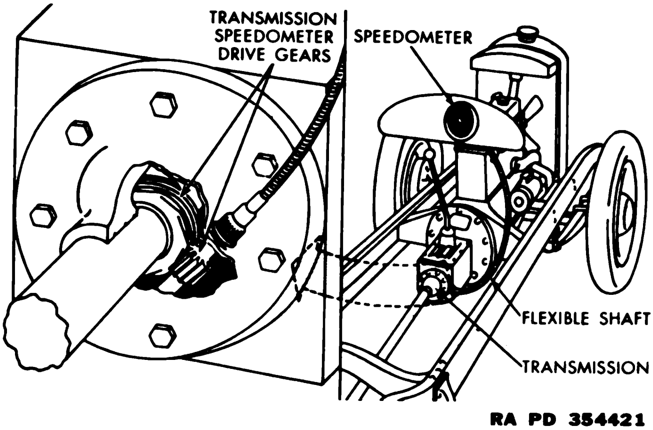

Figure 173. Speedometer Installation.

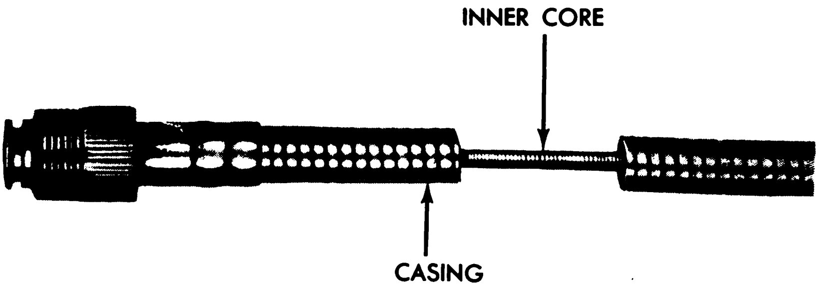

Figure 174. Speedometer and Tachometer Flexible Drive Shaft.

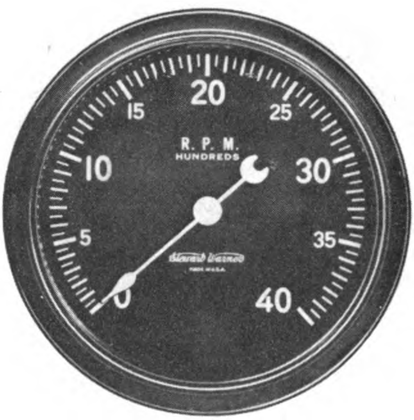

Figure 175. Tachometer.

designed for the particular vehicle model and take into consideration the tire size and rear axle ratio. The flexible shaft, which connects the transmission driven gear to the speedometer, consists of an outer casing and the inner drive core (fig. 174).

b. TACHOMETER. A magnetic-type tachometer (fig. 175) is similar to a speedometer, except that the face dial indicates in revolutions per minute instead of miles per hour. It is ordinarily used to indicate vehicle engine speed. A tachometer is driven through a flexible shaft which is usually connected to the vehicle generator shaft, camshaft, or distributor shaft by means of a drive joint or adapter. An odometer is often incorporated in a tachometer to record total revolutions.

c. OPERATION OF SPEEDOMETER AND TACHOMETER. Even though the internal parts of various magnetic-type instruments vary in construction and appearance, they all incorporate the same basic components and operate on the same principles.

(1) SPEED INDICATION (fig. 176). The speed-indicating portion of a speedometer or tachometer of the magnetic type operates on the magnetic principle, and includes a revolving permanent magnet (driven by the flexible shaft). Around this revolving permanent magnet is a stationary field plate. (Some instruments have a revolving field plate.) Between the magnet and field plate is a movable speed cup, with the indicating pointer attached to the end of the speed cup staff. As the magnet revolves within the speed cup, it sets up a rotating magnetic field which exerts a pull or magnetic drag on the speed cup, making it revolve in the same direction. The movement of the speed cup is retarded and held steady by a hair spring attached to the speed cup staff. The speed cup comes to rest at a point where the magnetic drag is just balanced by the retarding force created by the hair spring. An additional function of the hair spring is to pull the pointer back to zero when the vehicle or engine stops. There is no mechanical connection between the revolving magnet and the speed cup. As the speed of the magnet increases due to vehicle acceleration or (as in the case of a tachometer) increase in the engine speed, the magnetic drag on the speed cup also increases and pulls the speed cup further around, thus registering a faster speed by the pointer and face dial. The magnetic field is constant, and the amount of speed cup deflection is at all times proportional to the speed at which the magnet is being revolved.

(2) ODOMETER OPERATION. (*a*) TOTAL ODOMETER (fig. 177). The total odometer is driven through a series of gears originating at a spiral gear cut on the magnet shaft. This gear, known as the "first gear", drives an intermediate "second gear" and "third gear" which is connected to a "fourth gear" at the odometer. The "fourth gear" turns the odometer through a series of "star pinion" gears inside the odometer dials or figure wheels. The total odometer usually has five figure wheels or dials, and is so constructed and geared that as any one wheel finishes a complete revolu-

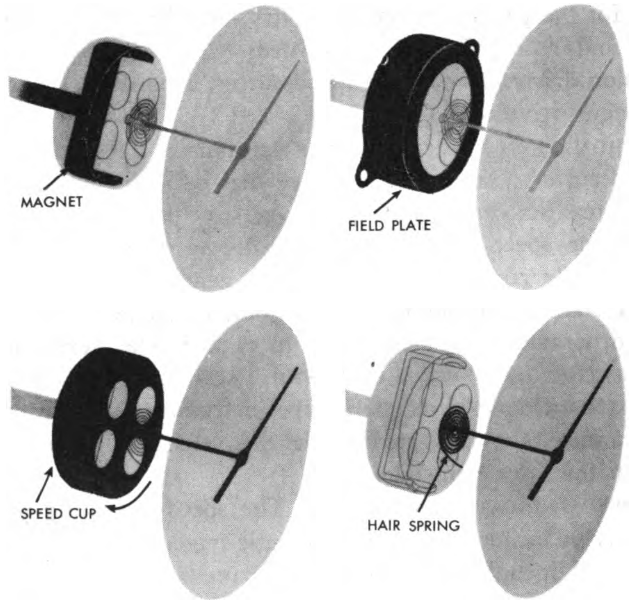

Figure 176. Phantom View of Basic Components of Speed—Indicating Portion of Speedometer.

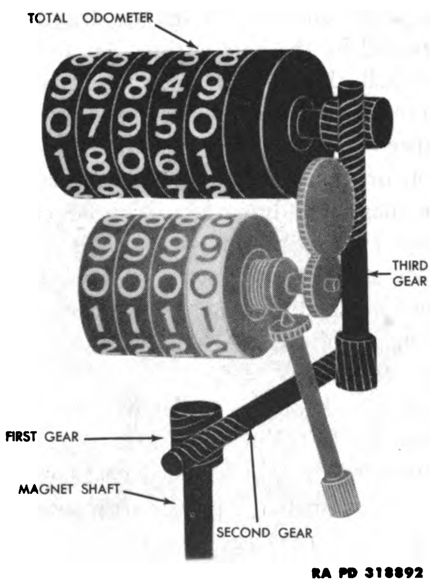

Figure 177. Schematic View of Total Odometer.

tion it turns the next figure wheel to the left $\frac{1}{10}$ of a revolution. Most models record to 99,999 miles, then automatically "zero" themselves.

(*b*) Trip Odometer (fig. 178). The trip odometer is also driven by the "third gear", through the trip odometer drive gear, and another gear at the trip odometer. The trip odometer usually has four figure wheels, and is so constructed that as any one figure wheel finishes a complete revolution, it turns the next figure wheel to the left $\frac{1}{10}$ of a revolution. The figure wheel on the extreme right registers in tenths of a mile. Most models record to 999.9 miles, then automatically "zero" themselves; also they are usually equipped with a reset mechanism so that the mileage on the trip odometer can be reset as desired.

142. Oil Pressure Gage

a. Location and Function. An oil pressure gage indicates the oil pressure in the system. Usually, such gages are mounted on the instrument board and are calibrated to read in pounds per square inch.

b. Operation. Most gages are actuated by the pressure of air trapped above the oil in a very small copper tube connected from the gage to the lubricating system. Air pressure in the connecting tube is maintained by the oil pressure in the system. The operation of the gage itself is based on the use of the Bourdon tube. A Bourdon tube is a semicircular metal tube, elliptically shaped in cross section, having one sealed end and one

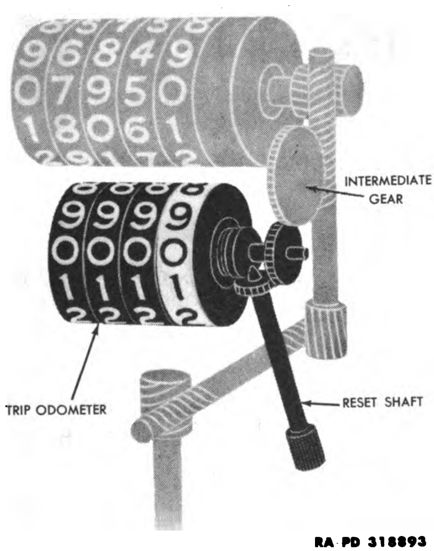

Figure 178. Schematic View of Trip Odometer.

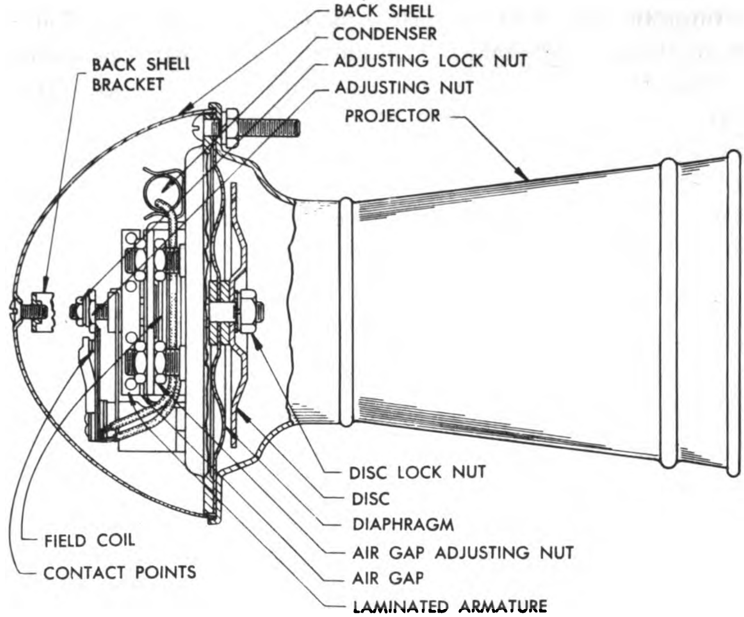

Figure 179a. Electric Horn (Vibrator Type) Cross Section.

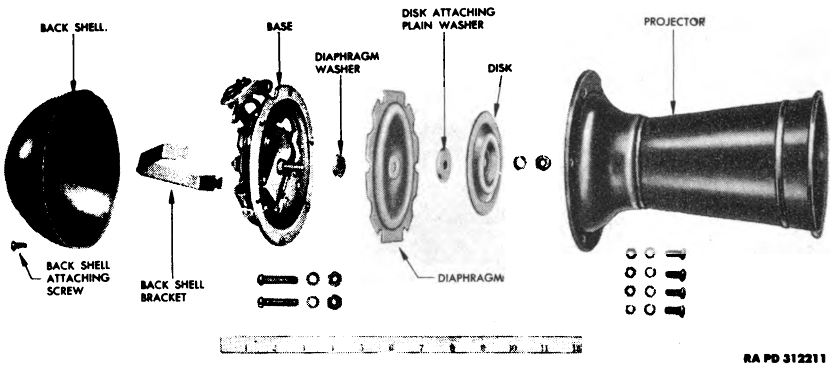

Figure 179b. Electric Horn (Vibrator Type) Disassembled.

open end. The open end is connected to the pressure system, and if the pressure of gas or liquid within the tube increases, the tube will tend to straighten itself. As the pressure decreases, the tube will resume its normal semicircular shape. By fixing the open end and allowing the sealed end to move freely, the "straightening" movement of the tube can be used to move a needle across a dial. A simple spring, gear, and lever arrangement serves to return the needle as the pressure is reduced and the tube resumes its shape.

143. Temperature Gage

A temperature gage, mounted on the dash board, indicates the temperature of the coolant in the water jacket and may operate either electrically or on the principle of the Bourdon tube.

a. BOURDON TUBE. When the principle of operation is the Bourdon tube, described in paragraph 142*b*, it is actuated by pressure conducted to it from a bulb which is screwed into the water jacket of the engine. The heat of the water affects the liquid in the bulb. This liquid vaporizes at a very low temperature and the gas flows through the capillary, a very small tube connecting the bulb to the gage. The greater the heat, the more vapor given off and the greater the pressure; thus the higher temperature is indicated on the gage.

b. ELECTRIC THERMO GAGE. The electric thermo gage functions on much the same principle as the coil-type fuel gage described in paragraph 140*d*. As in the fuel gage, the dash unit of the thermo gage consists of 2 coils at right angles to each other with an armature at the intersection of the coil axis. Connected to the armature is a pointer. Essentially, the engine unit is a resistor whose resistance varies inversely with the temperature of the engine. When the engine temperature is high, the resistance is low; when the temperature is low, the resistance is high. On the low temperature side of the dash unit, the coil is connected directly across the battery. Thus, there exists a constant magnetic strength in that coil which attracts the armature and pointer to the low temperature side. However, the coil on the high temperature side is connected in series with the resistance of the engine unit and across the battery. Since the resistance varies with the temperature, the coil's magnetic strength varies. More current flows when the resistance is low (high engine temperature) and so a stronger magnetic field is created. As the engine temperature increases, the greater magnetic strength of the high temperature coil attracts the armature and pointer to a point of balance between the two sides. The scale is calibrated to the pointer movement.

144. Horns

a. DESCRIPTION. The most common type of horn is the vibrator type in which the general principle of operation is the same as that of a vibrating coil. A vibrating diaphragm is operated by the coil which also operates the contacts that break the circuit. Magnetism from the coil pulls the diaphragm toward it when the contacts are closed. The contacts are then pulled open by the coil, reducing the magnetism and allowing the diaphragm to return to its normal position. When the contacts are closed again, a new surge of current induces magnetism in the coil and starts a second movement of the diaphragm. This cycle is repeated rapidly. The vibrations of the diaphragm within an air column produce the note of the horn. Typical horn construction is shown in figure 179.

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b. ADJUSTMENT. Tone and volume adjustments are made by loosening the adjusting lock nut and turning the adjusting nut. This very sensitive adjustment controls the current consumed by the horn. Increasing the current increases the volume. However, too much current will make the horn sputter and may lock the diaphragm.

c. DUAL HORNS. In dual horns, one horn with a low pitch is blended with another horn with a high pitch. These horns, although operated electrically, produce a sound closely resembling that of an air horn. The sound frequency of the low pitch horn is controlled by a long air column and that of the high pitch horn by a short air column. The air column is formed by the projector and by a spiral passage cast into the base of the horn. Inasmuch as the total current required by a horn is approximately 12 amperes, dual horns are operated by a relay switch and controlled by the horn button. The relay, when adjusted properly, should close at 4 volts; therefore, when the voltage available is less than 4 volts, the horns will not operate.

145. Accessories

a. Accessories such as electric windshield wipers, heaters, and fans depend upon small electric motors for their operation. These motors use about 45 watts. They should be connected to the ammeter so that any battery discharge required to run them is registered on the ammeter.

b. The electric windshield wiper has suitable gearing placed on the motor shaft to provide the reciprocating motion required to operate the wipers. Heaters and fans have fan blades mounted on the motor shafts to circulate air within the car. The heater fan forces air through a heating element, similar to a radiator, which on most heaters is heated by the engine cooling water.

CHAPTER 12

RADIO INTERFERENCE SUPPRESSION

Section I. INTERFERENCE

146. Automotive Radio

While the supply and maintenance of radio equipment is properly a responsibility of the Signal Corps, its use by motor vehicle units for coordinating convoy movements in isolated areas must often be considered. Transmitting and receiving equipment of this type depends upon the electrical system of the vehicle in which it is installed for its source of power.

a. INSTALLATION. Installation of these units varies in different types and makes of equipment. In general, units of radio equipment should be mounted on brackets, panels, or metal members that are securely attached to the body or frame by welding or riveting. All paints, lacquers, or primers should be removed from all mounting surfaces coming in direct contact with the equipment and the surfaces tinned in order to insure the best possible ground. The units should be located so that all switches or controls are within easy access of the operator. All flexible control cables should be free of sharp bends. So far as possible, installation or removal of this type of equipment should be done by specialists of the Signal Corps trained in this type of work.

b. POWER REQUIREMENTS. Radio units require from 4 to 5 amperes for receivers and 12 to 16 amperes for large units and transmitters. In many instances, it will be found necessary to equip the vehicle with a larger generator with a regulator device to supply the additional current. All power leads from the vehicle electrical system should be of sufficient size to meet the current requirements and should be equipped with fuzes or other overload protective devices. All leads should be as short as possible. High voltage direct current is sometimes necessary, in which case a motor generator is required.

147. Interference

Any spark created by the operation of electrical equipment, such as spark plugs, circuit breakers, coils, generators, regulators, magnetos, or distributor assemblies, by loose or dirty connections, or chafing of metal to metal, may cause interference with radio reception of nearby radio

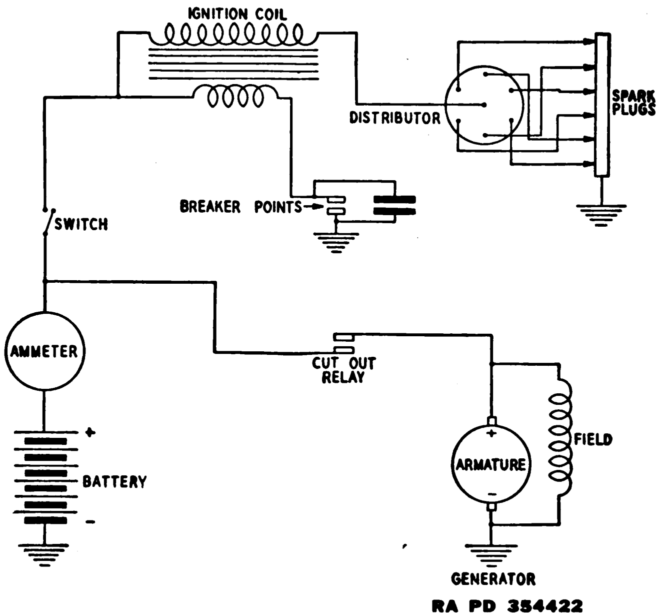

Figure 180. Typical Battery Ignition System.

receivers. Since the units of the electrical equipment are connected by a wire or a series of wires, as in an automotive ignition system, the wiring acts as an antenna to transmit the interference created by the spark into the air. The capacitive effect of the wires and the spark-producing unit causes the radiated energy to affect a wide band of frequencies on a radio receiver with pronounced effects on certain frequencies.

148. Ignition Noises

a. CAUSE. When distributor breaker points are opened and closed by operation of engine, the ignition coil produces a high voltage current which flows across the gap in the spark plug to cause ignition. The sparks at the plugs and those at the breaker points cause violent surges of current to flow in all wires of the circuit (fig. 180). Around each wire, a magnetic field builds up and collapses with each make and break of the circuit. The rapidity of these changes in the magnetic field is governed by the engine speed.

b. RECOGNITION. The resultant noise in the receiver from breaker points, distributors, or spark plugs is recognized by clicking sounds which vary in rapidity and intensity with the speed of the engine.

149. Generator Noises

a. CAUSES. With the generator in operation, there is some sparking between the brushes and commutator segments. Generators in good mechanical condition may exhibit some sparking which usually is not severe enough to cause radio interference. This type sparking is increased by any of the following mechanical defects:

(1) Brushes do not fit commutator.
(2) Brushes worn more than one-half original length.
(3) Incorrect brush spring tension.
(4) Collection of oil or carbon particles around commutator.
(5) Commutator worn out-of-round.
(6) Generator loaded in excess of rated capacity.
(7) Commutator segments burned or grooved.
(8) High insulation between segments of commutator.

b. RECOGNITION. Sparking between the brushes and commutator segments, may cause interference in nearby radio sets. This type of interference can be recognized by a roaring or whining noise which varies in pitch with the speed of the engine.

150. Body Noises

a. CAUSES. Body noises are produced by loose screws and bolts which allow various parts of the body to chafe against each other. This chafing produces static discharges which are a source of interference to radio receivers. Static charges caused by friction, and induced charges from wiring on the vehicles are collected by the vehicle body. These charges are retained by poorly grounded sections of the body until they build up to a sufficient value to jump to any well-grounded part of the vehicle. Each discharge causes a spark of sufficient intensity to create interference in a radio receiver. This type of disturbance is intermittent, varies in value, and can be detected by a frying or snapping sound. These effects are produced only when the vehicle is in motion, or for a very short period after the vehicle is stopped.

b. RECOGNITION. Looseness in the hood, brackets, and bolts can cause considerable noise in a receiver. This type of disturbance can be detected only when the vehicle is in motion, or by moving the loose parts. It can be recognized by a scratching sound in a receiver.

Section II. SUPPRESSION

151. Description of Suppression Methods

a. GENERAL. There are various methods used to suppress radio interference caused by a vehicle. They are as follows:

(1) Resistor-suppressors.
(2) Condensers.
(3) Filters.
(4) Bonding.
(5) Shielding.

Application of one of the above methods is sufficient usually to adequately suppress the interference from any one source. In some instances it may be necessary to use a combination of the above methods to obtain the desired amount of suppression.

b. RESISTOR-SUPPRESSORS. A resistor-suppressor consists of a short carbon rod of high resistance, protected by a plastic cover. Resistor-suppressors are connected in the high-tension wires at the spark plugs and distributor to reduce the intensity of surges and thus eliminate interference from these sources. The resistance of the suppressors is high enough to control the surges but not high enough to effect the operation of the engine in any way.

c. CONDENSERS. These are units of metal foils separated by paper insulation and protected by a metal case. The case is filled with an impregnating compound to keep the moisture out. A wire connected to one side of the condenser is provided for connection to a circuit. The other side of the condenser is connected internally to the case. Surges created in the wiring by sparks at the generator brushes, regulator, and gage contacts are not as strong as those produced by the high-tension ignition circuit because the voltage is low, but they are strong enough to cause interference in a radio set. Resistor-suppressors cannot be used in these circuits because their resistance would reduce the low-voltage current too much. However, condensers, because of their inherent capacity, may be used to dissipate these surges. They are attached to the circuit as near as possible to the point at which the spark occurs. The case of the condenser is mounted on the metal frame of the unit causing interference, and the condenser wire is connected to the terminal. A condenser allows the interfering voltage to pass freely to ground (frame and body of vehicle), and at the same time prevents any loss of the useful direct current. Thus the surges are conducted away from the wiring and cannot cause interference.

d. FILTERS. An assembly made of a closely wound coil of heavy wire and one or more condensers mounted in a metal container is called a filter (fig. 181). The condensers act in the same manner described previously, and the coil of wire acts to block the interfering voltage from getting further in the circuit. Filters are used in some generator, regulator, and low-tension ignition circuits.

e. BONDING. This term is applied to the method of electrically connecting individual metal sections to each other and to the frame or hull of the vehicle. Such bonding is necessary to provide an easy path for grounding static charges. Bonding is accomplished by internal-external toothed lock washers, and by bond straps. The better the connection between metal parts, the greater is the effect in preventing interfering waves from being thrown off to affect radio reception.

f. SHIELDING. This term is applied to the method of covering all wiring carrying interfering voltages or surges with a metal shield. Woven

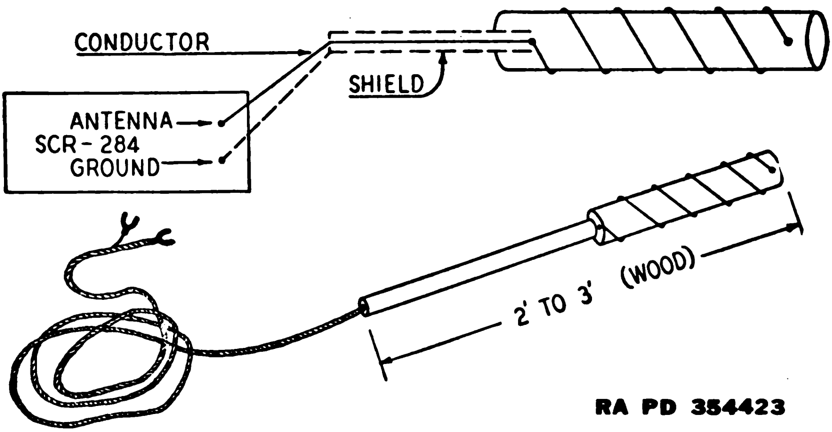

Figure 181. Typical Filters in Battery Ignition System.

metal conduit is used where flexibility is required, while solid conduit is used elsewhere. Units causing interference, such as spark plugs, ignition coil, distributor, and regulator, are inclosed in metal boxes. This shielding does not reduce the intensity of the interfering surges, but prevents their radiation. While such shielding is effective in preventing the radiation of interfering waves, filters and condensers are necessary to eliminate any interfering surges that would otherwise travel on the wires and affect the radio set through the power supply. Such filters and condensers are inclosed in metal shielding boxes provided with means of attachment to the conduit and shielding containing the connecting wires.

152. Typical Applications of Suppression Systems to Vehicles

a. TRANSPORT VEHICLES—ORDINARY SUPPRESSION SYSTEM. The system found on most vehicles consists of the following items:

(1) Resistor-suppressors are used in each high-tension lead from distributor to spark plugs. The suppressors are usually of a type that will slip over the terminal of the plug. The lead is screwed directly into the suppressor, thus locating the suppressor as close as possible to the spark gap in the plug.

(2) A resistor-suppressor is used in the high-tension lead from distributor to coil. This suppressor is placed in the lead as close as possible to the distributor. Usually it will be found about an inch or two away from the distributor.

(3) A filter is placed in the lead from the ignition coil to the ignition switch. This filter is mounted on the firewall where the lead goes through to the switch. Thus, the exposed lead between the filter and firewall is as short as possible. In later production vehicles, this filter is replaced

by a condenser which is usually mounted on or near the coil, with its lead connected to the switch side of the ignition coil primary circuit.

(4) Filters are used in regulator circuits. One is usually connected between the battery terminal of the regulator and the ammeter, one is connected in the generator armature lead, and one is sometimes connected in the field lead between the generator and regulator. These filters are mounted on the firewall in such a position that the exposed leads leaving the filter are as short as possible. On certain vehicles, condensers (usually 0.1 mfd capacity) may be found at these points, mounted on the firewall, with the leads connected to the battery and generator armature terminals. A 0.01 microfarad condenser is sometimes applied with its lead connected to the field terminal of the regulator.

(5) A condenser is mounted on the generator with its lead connected to the output terminal. Condensers are used on certain lighting circuits, either mounted on the firewall or close to any junction point. The lead is connected to the circuit that may be carrying radio interference.

(6) Bonding straps will usually be found at the following places (there may be others):

(*a*) From hood to firewall.

(*b*) From hood top panel to hood side panel.

(*c*) From overhead valve covers to firewall.

(*d*) From engine block to frame.

(*e*) From fenders and fender skirt to frame.

(*f*) From radiator brush guard to frame.

(7) Bonding by means of internal-external toothed lock washers will usually be found at the following places:

(*a*) Under head of side panel mounting screws.

(*b*) Hood hold-down locks or latches.

(*c*) At gage sending unit.

(*d*) Under head of radiator grille mounting screws.

(*e*) Under head of fender mounting screws.

(*f*) Under head of any bolt or screw securing a separate section of metal that will help to form a shield in the vicinity of the engine compartment.

b. Transport Vehicles—Completely Shielded Suppression System. A few vehicles have a completely shielded system of suppressing, and, in such cases, usually only one filter is used. It is mounted in a metal box close to the regulator (it may be on the cab side of the firewall). A condenser will be found mounted on the generator, in a round metal shielding case. In most cases the only bond is between the engine and the frame.

c. Tanks and Armored Cars. The resistor-suppressor system used on tanks with in-line engines and most armored cars is basically the same as that used on transport vehicles described in *a* above. Usually there will be fewer bonds and toothed lock washers and more condensers.

Less bonds and washers are needed because of the heavy, bolted, or welded construction of the hull or body. Resistor-suppressors, filters and condensers are used in the same circuits as in the transport vehicles. More condensers will be used to bypass the interfering surges from such accessories as auto-pulse fuel pump, electric gages, windshield wipers, traversing motors, auxiliary generators, and similar items. The condensers are always mounted close to the device causing interference with the lead connected to the "hot" side of the supply line. The complete shielding system is used on most tanks having radial engines and on some armored cars.

(1) In tanks, all wiring is inclosed in flexible metal conduit or solid metal conduit. Very little bonding is necessary with this system. In most cases only the engine is bonded to the support or hull. Control devices consisting of metal rods or tubing extending from crew compartment to engine compartment may be bonded at the point they enter the crew compartment.

(*a*) Usually one filter is used, inclosed in a shielding box. It is always mounted close to the regulator and the battery.

(*b*) Condensers are used on the electrical devices in the turret. They will be found at the brushes of the traversing motor, generator, and in the circuits of the stabilizer control switch box.

(2) In those armored scout cars and gun motor carriages which have the completely shielded system, all high tension, primary ignition, and charging circuit wiring is shielded with flexible metal conduit which is grounded every 2 feet with clips and internal-external toothed washers. The distributor, ignition coil, and regulator are shielded.

(*a*) Filters may or may not be used. If one is used, it will be mounted close to the regulator on the firewall.

(*b*) A condenser is mounted on the generator.

(*c*) Usually the only bond is that from engine to frame. Both sides of the engine are generally bonded.

PART FOUR

POWER TRAINS

CHAPTER 13

INTRODUCTION TO POWER TRAINS

153. Purpose

The purpose of the power train is to transmit the power of the engine to the wheels and accessory equipment such as winches. In a simple situation, a set of gears or a chain could perform this task, but automotive vehicles are not usually designed for such simple operating conditions; they are designed to have great pulling power, to move at high speeds, to travel in reverse as well as forward, and to operate on rough ground as well as on smooth roads. To meet these widely varying demands, a number of units have been added. These include clutches, transmissions, auxiliary transmissions, transfer cases, propeller shafts, universal joints, final drives, differentials, live axles, devices for resisting drive torques and thrust, and the bearings used therein.

154. Basic Power Trains—Wheel Vehicles

The common elements of the power transmission system assembled in a standard type vehicle are shown in figure 182. Reading from the engine to the wheels, the following are the main units of the power train.

a. CLUTCH. By means of this device, the operator can disconnect the engine from the remainder of the power train. This is essential for starting the engine, for allowing the vehicle to stand motionless while the engine is running, for gradual engagements of the engine to the power train, and for allowing gear ratios to be changed to meet varying road conditions.

b. TRANSMISSION. An internal-external engine cannot develop appreciable torque at low speeds, and it develops maximum torque only at one speed. The crankshaft of an engine must always rotate in the same direction. For these reasons, the transmission is included in automotive vehicles. The transmission provides the mechanical advantage which enables the engine to propel the vehicle under adverse conditions of load. It also provides the driver with a selection of vehicle speeds while the engine is held at speeds within the effective torque range, and it allows disengaging and reversing the flow of power from the engine to the wheels.

c. Transfer Assembly. This is an auxiliary gear train on all-wheel-drive vehicles. It provides a means of lowering or displacing the power train sufficiently to permit the forward propeller shaft to clear the crankcase of the engine. It also permits the power to be divided and transferred to both forward and rear propeller shafts, and to the propeller shaft on amphibious vehicles.

d. Universal Joints. It is necessary to provide flexibility in the power train if springs are to be used on the vehicle. As load is increased or decreased, and as the vehicle travels over uneven surfaces, the angle between the engine crankshaft axis and a line to the axle will change. This flexibility is provided by the use of universal joints which permit transfer of torque at an angle.

e. Slip Joints. As the load is changed, and as the vehicle travels over uneven ground, the distance from unit to unit in the power train varies. Slip joints provide for this variation.

f. Propeller Shaft. This device carries the torque from one place to another; from the transfer case to the differential, for example.

g. Final Drive. This device transmits the power flow from the propeller shaft to the differential, and at the same time provides a further gear reduction.

h. Differential. When a vehicle is driven around a curve, the outer wheels travel faster, as well as farther, than the inner wheels. The differential permits this difference in rotational speed of the axles.

155. Basic Power Trains—Tracklaying Vehicles

a. General. The power trains in tracklaying vehicles perform the same function as in wheel vehicles. They are designed for operating under more rugged conditions, however, and therefore are of more sturdy construction and in general, provide for greater gear reduction.

b. Differences Due to Steering Arrangements. Full-track vehicles are steered by varying the speed of one track in relation to the other, and this leads to the most important differences between wheel and tracklaying vehicles.

(1) In some full-track vehicles, clutches are used in the final drive to each sprocket. By engaging and disengaging the clutches, the relative speed of the tracks can be controlled by the driver. This system is satisfactory for slow-speed vehicles.

(2) In modern high-speed vehicles, steering is accomplished by means of a controlled differential. This differential employs a system of planetary gear trains, allowing power to be applied to both tracks at all times and still permitting the operator to regulate their relative speeds. This is illustrated in figure 183.

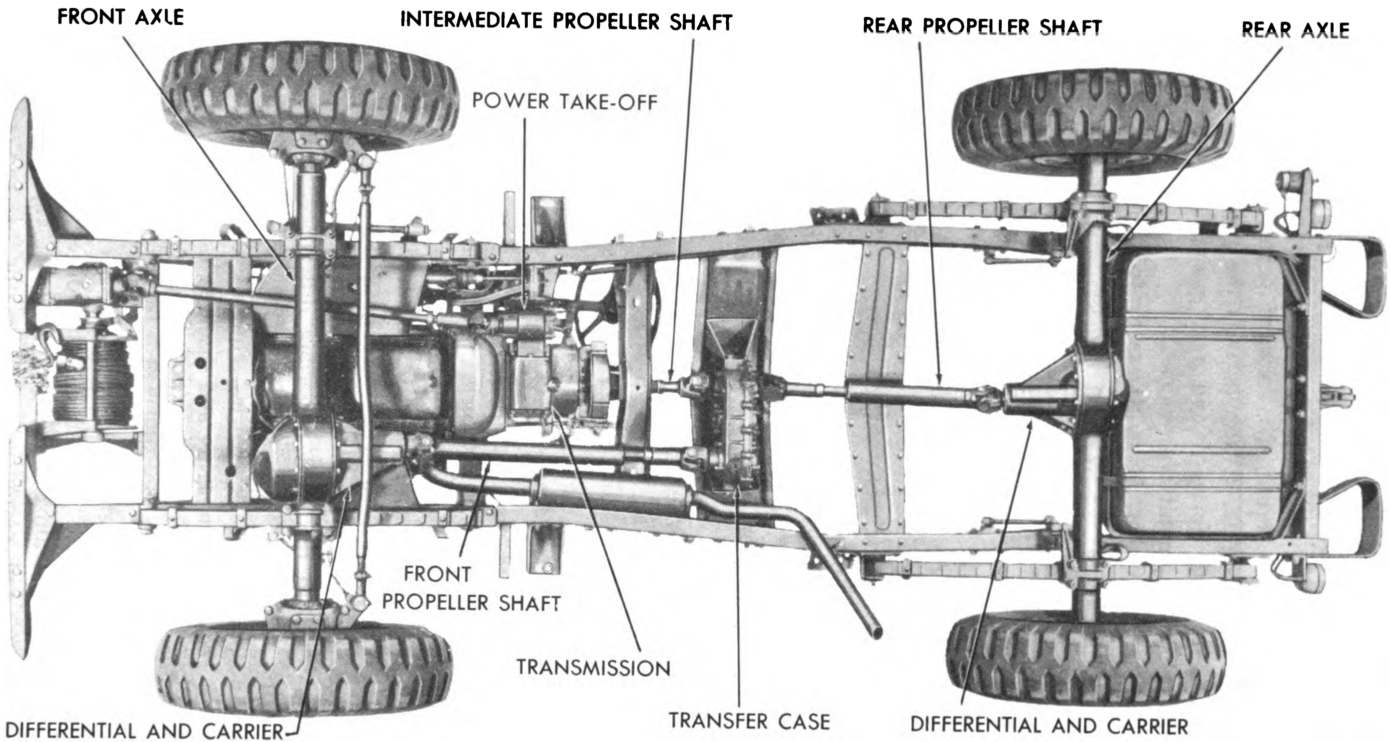

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Figure 182a. Power Transmission System in 4 x 4 Wheeled Vehicle.

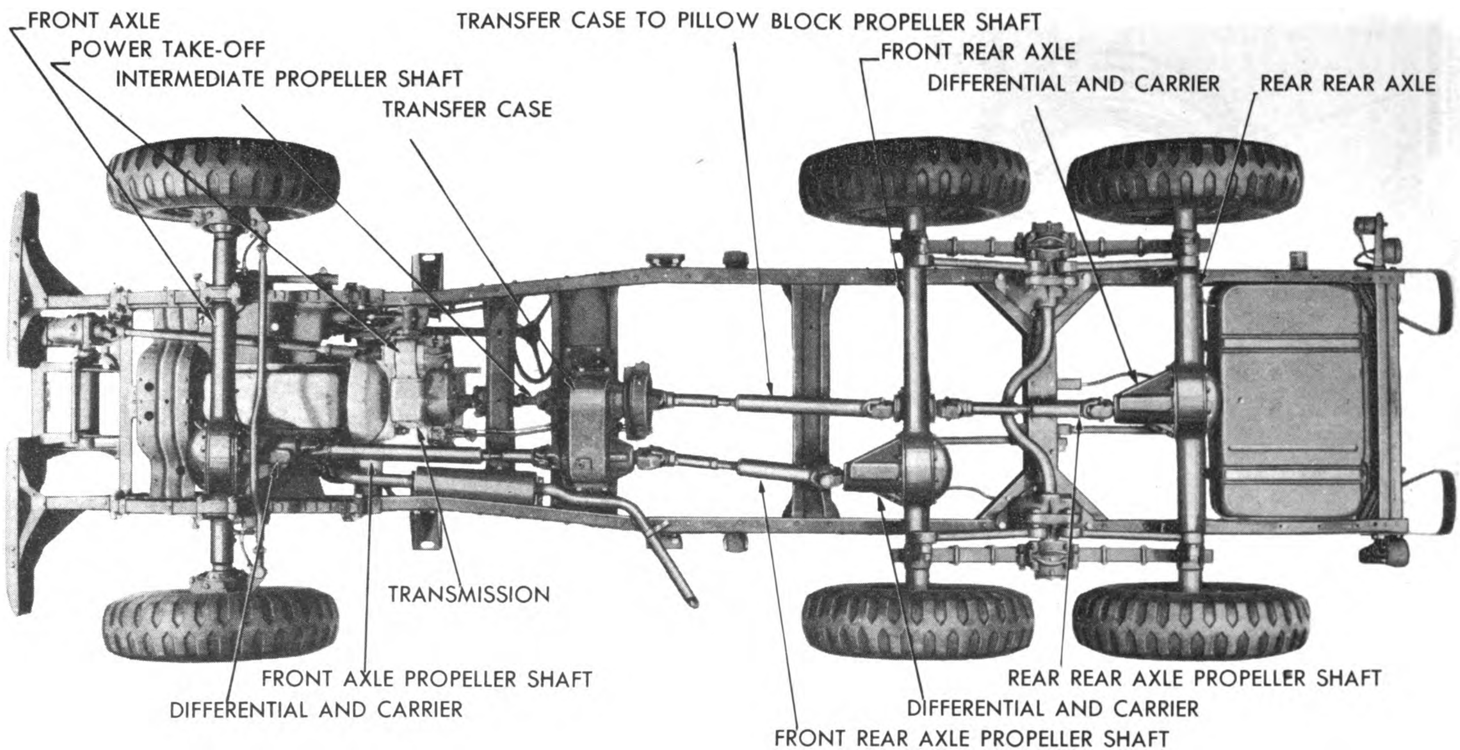

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Figure 182b. Power Transmission System in 6 x 6 Wheeled Vehicle.

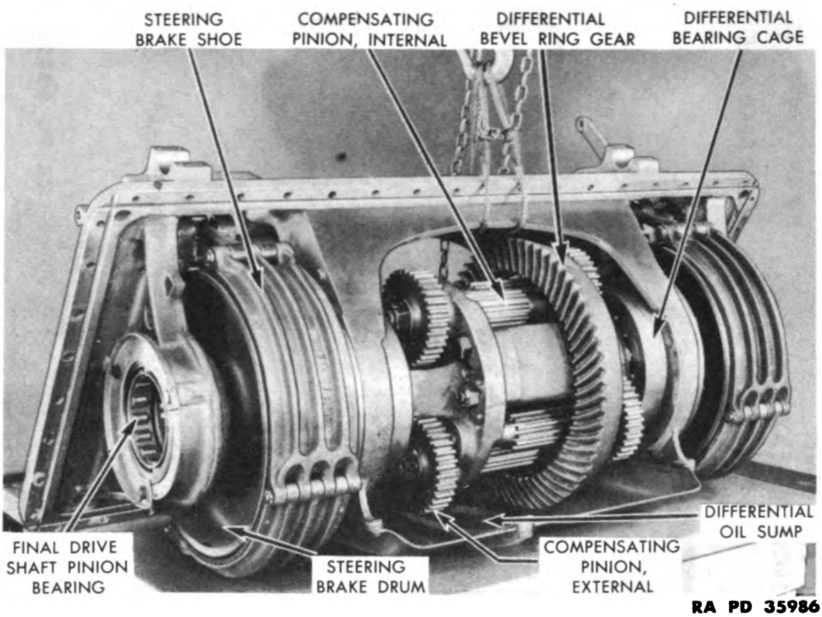

Figure 183a. Controlled Differential with Planetary Gear Trains.

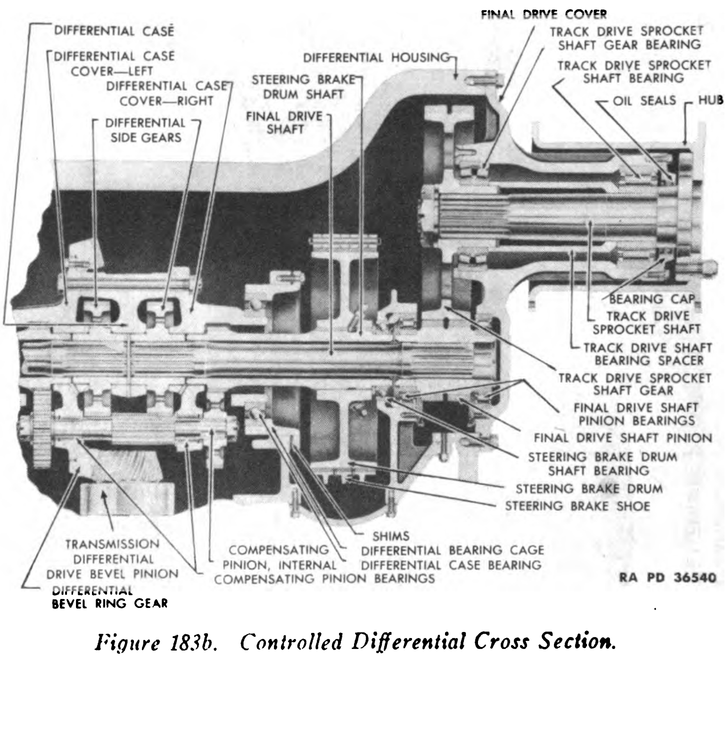

Figure 183b. Controlled Differential Cross Section.

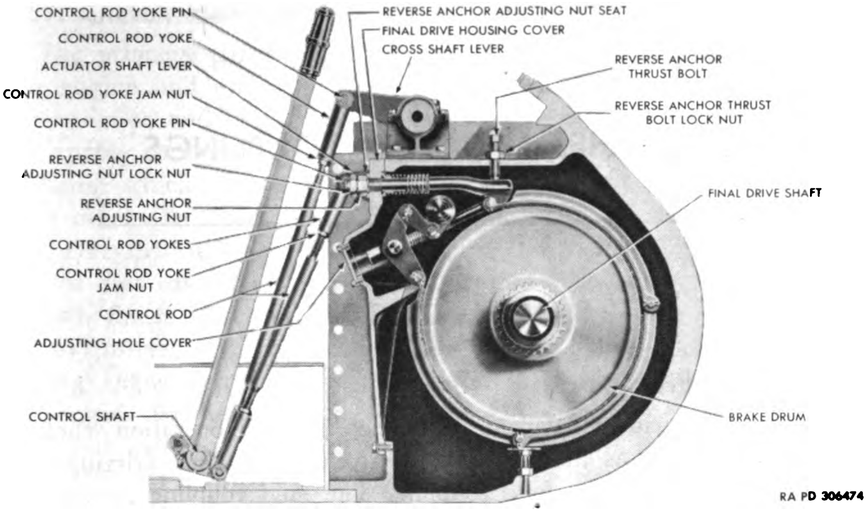

Figure 183c. Controlled Differential Cross Section.

CHAPTER 14

CLUTCHES AND FLUID COUPLINGS

Section I. CLUTCHES

156. Clutch Principles

a. Automotive clutches depend on friction for their operation whether it be solid friction as in the conventional clutch, or fluid friction and inertia as utilized in the fluid coupling. The fluid coupling serves the same purpose as the conventional clutch, but the difference in the principle of operation makes it necessary to discuss the two mechanisms separately. Therefore, the first part of this chapter will be concerned with conventional clutches, and fluid couplings will be discussed in the last paragraph.

b. A clutch in an automotive vehicle provides a means of connecting and disconnecting the engine from the power transmission system. Since the internal combustion engine does not develop a high starting torque, it must be disconnected from the power train and allowed to operate without load until it develops enough torque to overcome the inertia of the vehicle when starting from rest. The application of the engine power to the load must be gradual to provide smooth engagement and to lessen the shock on the driving parts. After engagement the clutch must transmit all of the engine power to the transmission without slipping. Further, it is desirable to disconnect the engine from the power train during the time the gears in the transmission are being shifted from one gear ratio to another.

c. The transmission of power through the clutch is accomplished by bringing one or more rotating driving members secured to the crankshaft into gradual contact with one or more driven members secured to the unit being driven. These members are either stationary, or rotating at different speeds. Contact is established and maintained by strong spring pressure controlled by the driver through the clutch pedal and suitable linkage. As spring pressure increases, the friction increases; therefore, when the pressure is light, the comparatively small amount of friction between the members permits a great deal of slippage. As the spring pressure increases, less slippage occurs until, when the full spring pressure is applied, the speed of the driving and driven members is the same. All slipping has stopped, and there is, in effect, a direct connection between the driving and driven parts.

157. Clutch Elements

The principal parts of a clutch are: the driving members, attached to the engine and turning with it; the driven members attached to the transmission and turning with it; the operating members which include the spring or springs and the linkage required to apply and release the pressure which holds the driving and driven members in contact with each other (fig. 184).

a. DRIVING MEMBERS. The driving members of a clutch usually consist of two cast-iron plates or flat surfaces machined and ground to a smooth finish. Cast iron is desirable because it contains enough graphite to provide some lubrication when the driving member is slipping during engagement. One of these surfaces is usually the rear face of the engine flywheel, and the other is a comparatively heavy flat ring with one side machined and surfaced. This part is known as the pressure plate. It is fitted into a steel cover, which also contains some of the operating members, and is bolted to the flywheel.

b. DRIVEN MEMBERS.

(1) The driven member is a disk with a splined hub which is free to slide lengthwise along the splines of the clutch shaft, but which drives the shaft through these same splines. (The driven member is sometimes referred to as the clutch plate, but in this text the word "disk" will be used to denote the driven member and thus differentiate between this part and the clutch pressure plate.) The clutch disk is usually made of spring steel in the shape of a single flat disk of a number of flat segments. Suitable frictional facings are attached to each side of the disk by means of copper rivets. These facings must be heat resistant since friction produces heat. The most commonly used facings are made of cotton and asbestos fibers woven or molded together and impregnated with resins or similar binding agents. Very

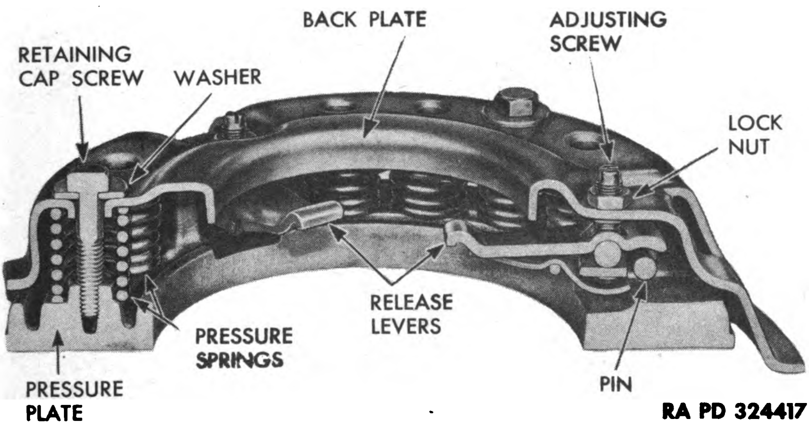

Figure 184. Helical Pressure Spring Disk Type Clutch.

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often copper wires are woven or pressed into the material to give it additional strength.

(2) In order to make clutch engagement as smooth as possible and eliminate "chatter", several methods have been used to give a little flexibility to the driven disk. One type of disk is "dished", so that the inner and outer edges of the friction facing make contact with the driving members first, and the rest of the facing makes contact gradually as the spring pressure increases and the disk is flattened out. In another type the steel segments attached to the splined hub are slightly twisted which also causes the facings to make gradual contact as the disk flattens out.

(3) The driven members in many clutches are provided with flexible centers (fig. 185) to absorb the torsional vibration of the crankshaft which would be transmitted to the power train unless it were eliminated. These flexible centers usually take the form of steel compression springs placed between the hub and the steel disk. The springs permit the disk to rotate slightly with relation to its hub until, under extreme conditions, the springs are fully compressed and relative motion stops. Then the disk can rotate slightly backward as the springs decompress. This slight backward and forward rotation permitted by the springs allows the clutch shaft to rotate at a more uniform rate than the crankshaft, thereby eliminating some of the torsional vibration from the crankshaft and preventing the vibration from being carried back through the transmission.

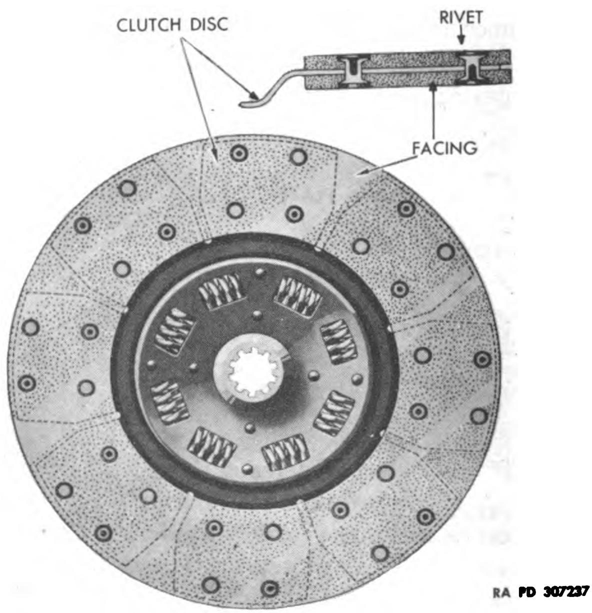


Figure 185. Clutch Driven Plate with Flexible Center.

c. Operating Members. As previously stated, the driving and driven members are held in contact by spring pressure. This pressure may be exerted by a single large coil spring as shown in figure 186, a number of small helical springs located circumferentially around the outer portion of the pressure plate (fig. 184), or a one-piece conical or diaphragm spring as shown in figure 187. In the helical-spring clutches, a system of levers pivoted on the cover forces the pressure plate away from the driven disk and against the pressure of the springs whenever

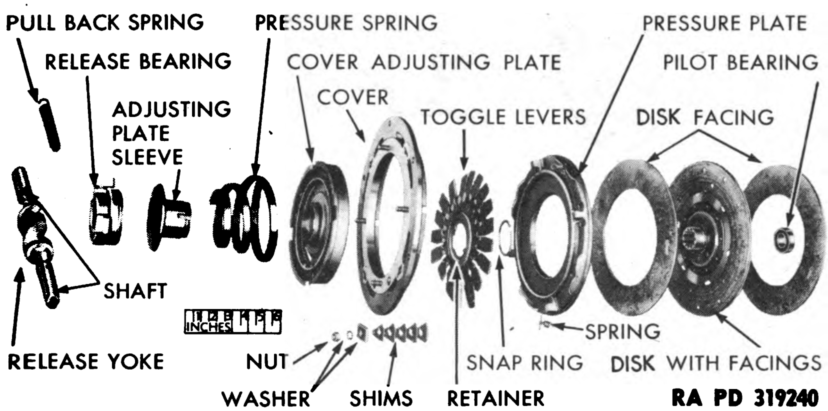


Figure 186a. Single Large Coil Pressure Spring Type Clutch.

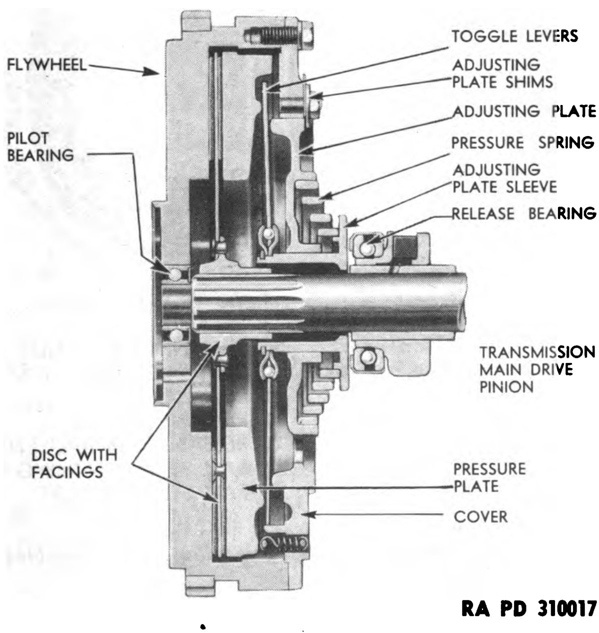


Figure 186b. Single Large Coil Pressure Spring Type Clutch.

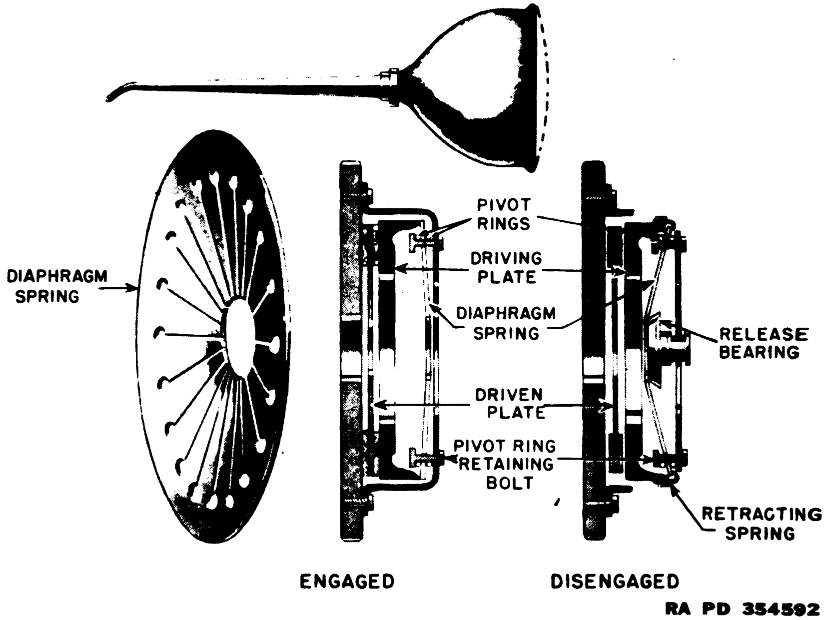
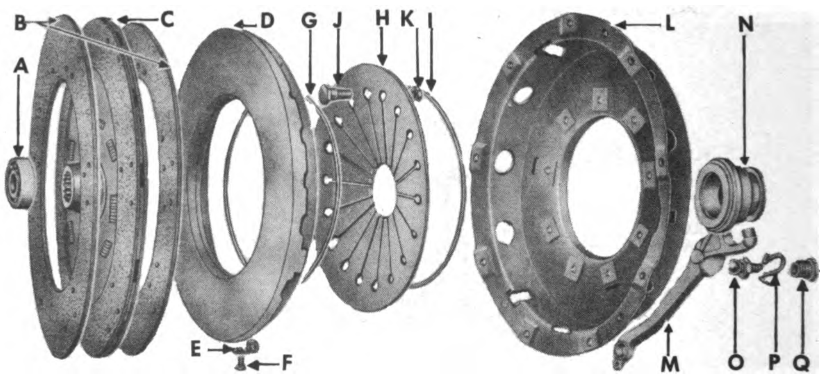


Figure 187a. Diaphragm Spring Type Clutch Operation.



A	PILOT BEARING	**I**	OUTER PIVOT RING
B	FACING	**J**	RETAINING BOLT
C	DRIVEN PLATE AND HUB	**K**	RETAINING BOLT NUT
D	PRESSURE PLATE	**L**	CLUTCH COVER
E	RETRACTING SPRING	**M**	RELEASE FORK
F	RETRACTING SPRING CAP SCREW	**N**	RELEASE BEARING
G	INNER PIVOT RING	**O**	RELEASE FORK BALL STUD
H	DIAPHRAGM SPRING	**P**	BALL STUD RETAINING SPRING
		Q	BALL STUD SUPPORT

RA PD 303204

Figure 187b. Diaphragm Spring Type Clutch Disassembled.

the clutch release bearing moves forward against the inner ends of the levers. In single-spring clutches, the large coil spring holds the plates in contact. In diaphragm clutches, the dish-shaped diaphragm performs the same function. The clutch release (or throwout) bearing is a ball-thrust bearing contained in the clutch release bearing housing or collar mounted on a sleeve attached to the front of the transmission case. The release bearing is connected through linkage to the clutch, and is moved by the release yoke to engage the release levers and move the pressure plate to the rear, thus separating the clutch driving members from the driven member when the clutch pedal is depressed by the driver.

158. Clutch Operation

a. The operation of the clutch, shown in figure 188, is as follows: when the clutch is fully engaged, the driven disk is firmly clamped between the flywheel and the pressure plate by the pressure of the springs. When the driver disengages the clutch by depressing the pedal, the release yoke is moved on its pivot, and pressure is applied to the release collar containing the release bearing. The rotating race of the release bearing presses against the clutch release levers and moves them on their pivots. The outer ends of the release levers, being fastened to the cover move the pressure plate to the rear, compressing the clutch springs and allowing the driving members to rotate independently of the driven member. The release yoke moves only on its pivot which is fastened to the flywheel housing by means of a bracket or a transverse shaft. All parts of the clutch except the release bearing and collar rotate with the flywheel when the clutch is engaged. When the clutch is disengaged, the release bearing rotates with the flywheel, but the driven disk and the clutch shaft come to rest.

b. In some clutches a diaphragm is used instead of coil springs. It is a conical piece of spring steel punched as shown in figure 187 to give it greater flexibility. The diaphragm is positioned between the cover and the pressure plate so that the diaphragm spring is nearly flat when the clutch is in the engaged position. The action of this type of spring is similar to that of the bottom of an ordinary oil can. The pressure of the outer rim of the spring on the pressure plate increases until it reaches the flat position and decreases as this position is passed. The outer rim of the diaphragm is secured to the pressure plate and is pivoted on rings approximately one inch in from the outer edge so that the application of pressure at the inner section will cause the outer rim to move away from the flywheel and draw the pressure plate away from the clutch disk, thus releasing or disengaging the clutch. When the pressure is released from the inner section, the oil-can action of the diaphragm causes the inner section to move out, and the movement of the outer rim forces the pressure plate against the clutch disk thus engaging the clutch.

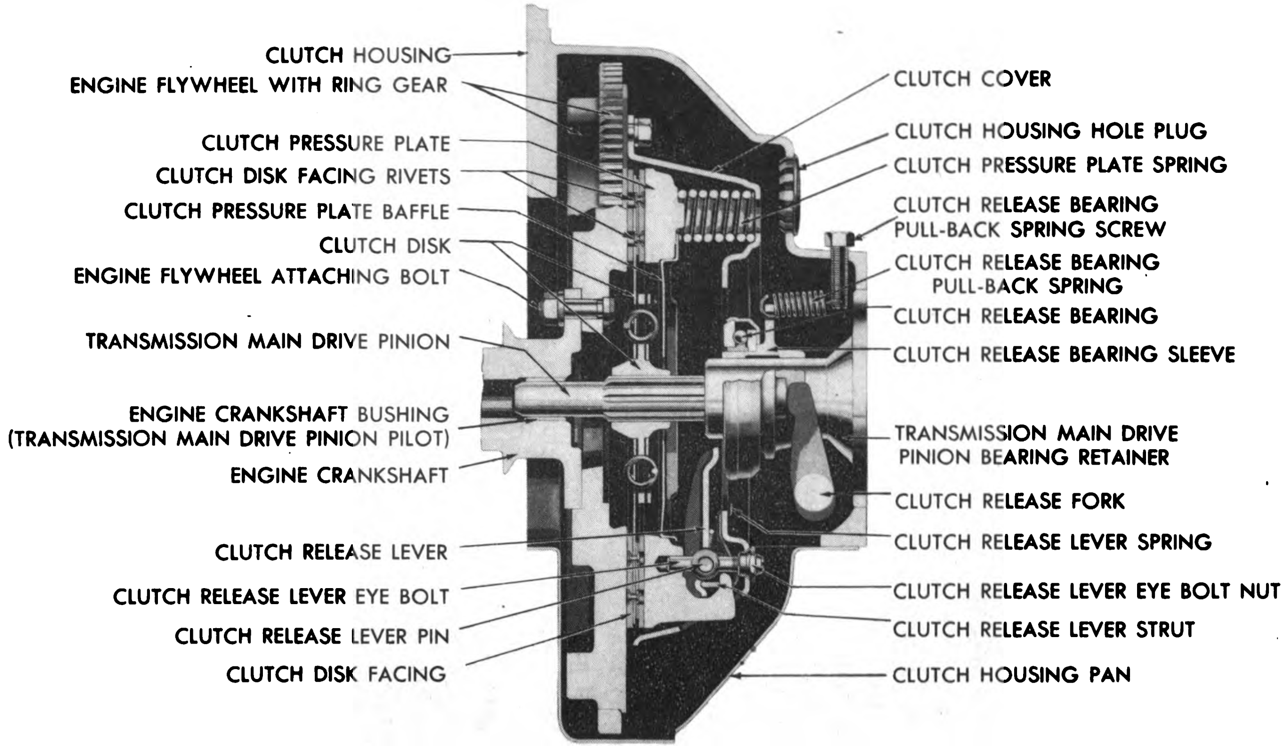


Figure 188. Plate Type Clutch Cross-section.

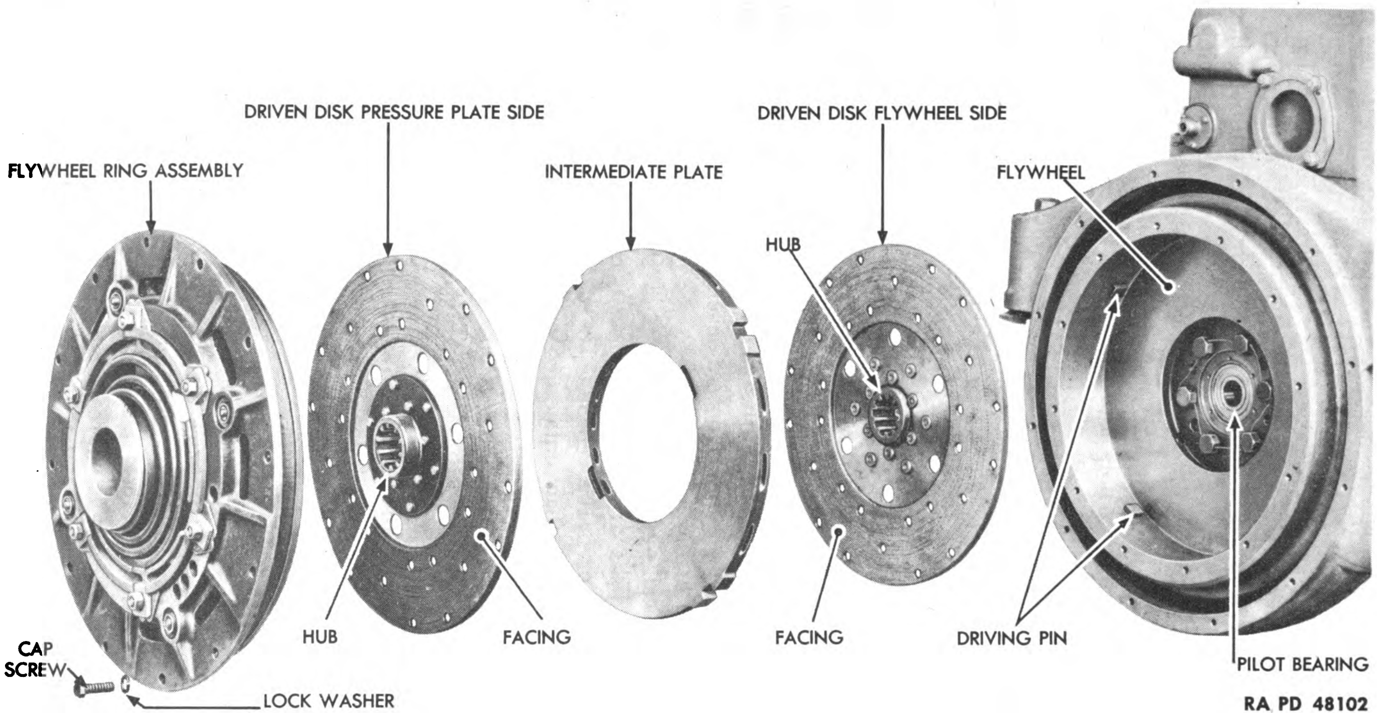


Figure 189. Disk Clutch with Two Driven Disks Disassembled.

159. Types of Clutches

a. Automotive clutches may be classified according to the number of plates or disks used. The single plate clutch contains one driven disk operating between the flywheel and the pressure plate (fig. 188). The flywheel is not considered to be a plate even though it acts as one of the driving surfaces. A double plate clutch is substantially the same except that another driven disk and an intermediate driving plate are added (fig. 189). A clutch having more than three driven disks is referred to as a multiple disk clutch (fig. 190). A further classification based on whether or not oil is supplied to the friction surfaces provides a positive method of identifying the many types and clutches in use; if oil is supplied, the clutch is known as the wet type and if oil is not supplied, the clutch is the dry type. Difference in the action of the clutches is largely a difference in the time of operation, the time required to engage the clutch depending on the number of plates and the condition of the surfaces. A plate clutch will engage the load and start it in motion sooner than will a multiple disk clutch. A dry clutch will be quicker to act than a wet clutch in which the oil must be squeezed out from between the driven and driving members before engagement is accomplished. Plate clutches are generally used on light and medium weight vehicles and the multidisk clutch on heavier vehicles, in which the sudden action of the other type would impose a severe shock on the engine and power train when starting a heavy load.

b. A typical multiple disk clutch is shown in figure 190. A large number of disks are used, often as many as eleven driving and ten driven disks for heavy vehicles. The driving disks have lugs similar to gear teeth around their outside edges that mesh with internal splines in the clutch case which is bolted to and rotates with the flywheel. The driven disks are carried on parallel pins which are solidly set in the clutch spider. This construction permits movement of all the disks and the pressure plate in order to provide clearance between them. When the clutch is engaged, the spring moves the pressure plate forward, holding all the disks firmly together. This causes the clutch spider to revolve and turn the clutch shaft to which it is keyed. In multiple disk clutches the facings are usually attached to the driving disks. This reduces the weight of the driven disks and, consequently, their tendency to continue spinning after the clutch is released. Because of the considerable number of disks involved, the pressure plate has to move farther to separate the disks completely than it does in clutches having fewer driving and driven members. There is, therefore, less mechanical advantage on the clutch pedal and a greater foot pressure is required to depress it.

c. In a "wet" type clutch the disks and the entire internal assembly run in an oil bath. The operation of this type of clutch is similar to that of the dry type except that the friction surfaces are made of different materials and the gradual engagement between the driving and driven

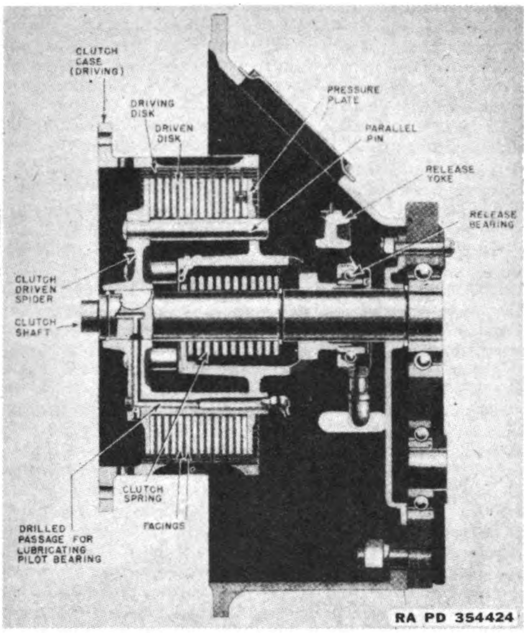


Figure 190. Multiple Disk Clutch.

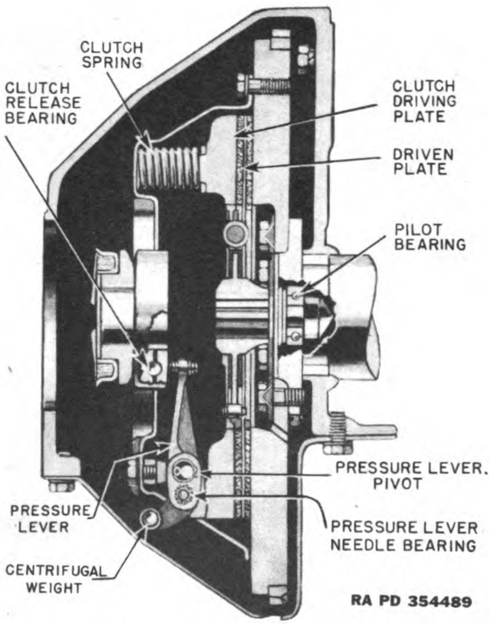


Figure 191. Semicentrifugal Clutch Cross Section.

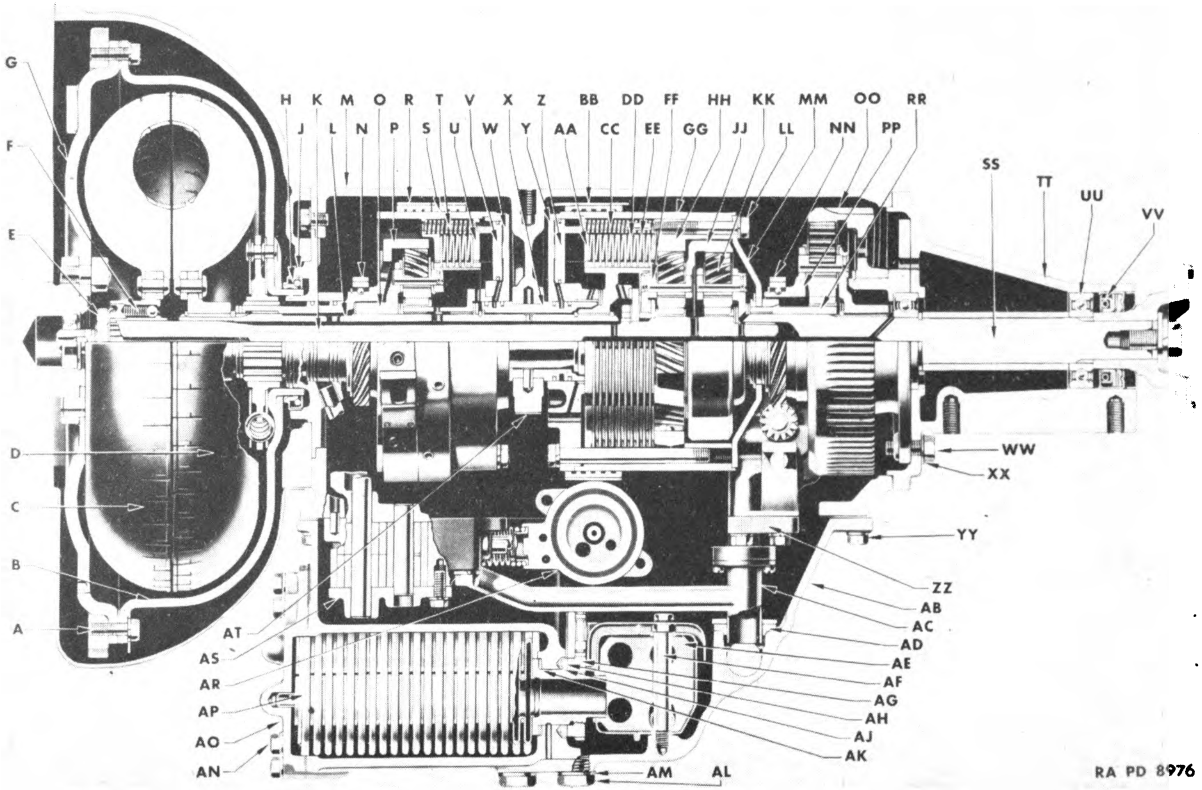


Figure 192a. Fluid Coupling and Hydramatic Transmission (Including Reverse Speed) Cross Section.

A — SCREW
B — COVER, ASSEMBLY
C — TORUS, ASSEMBLY
D — TORUS, ASSEMBLY
E — NUT
F — SPRING
G — FLYWHEEL, ASSEMBLY
H — SEAL, ASSEMBLY
J — COVER, ASSEMBLY
K — SHAFT, ASSEMBLY
L — SHAFT, ASSEMBLY
M — CASE, ASSEMBLY
N — GEAR
O — CARRIER, ASSEMBLY
P — GEAR, ASSEMBLY
R — BAND, ASSEMBLY
S — DRUM, ASSEMBLY
T — SPRING
U — PLATE
V — PISTON
W — DRUM, ASSEMBLY
X — SLEEVE, ASSEMBLY
Y — DRUM, ASSEMBLY
Z — PISTON
AA — PLATE
BB — BAND, ASSEMBLY
CC — SPRING
DD — PLATE
EE — PLATE
FF — PIN
GG — DRUM, ASSEMBLY
HH — GEAR, ASSEMBLY
JJ — CARRIER, ASSEMBLY
KK — PINION
LL — SCREW
MM — FLANGE
NN — GEAR
OO — GEAR
PP — CARRIER, ASSEMBLY
RR — GEAR, ASSEMBLY
SS — SHAFT, ASSEMBLY
TT — RETAINER
UU — BEARING, ASSEMBLY
VV — SEAL, ASSEMBLY
WW — SCREW
XX — WASHER
YY — SCREW
ZZ — PUMP, ASSEMBLY
AB — PAN
AC — PIPE, ASSEMBLY
AD — SEAL
AE — SCREEN, ASSEMBLY
AF — BOLT
AG — NUT
AH — RING
AJ — SEAL
AK — GASKET
AL — PLUG
AM — GASKET
AN — SCREW
AO — COVER
AP — COOLER, ASSEMBLY
AR — SERVO, ASSEMBLY
AS — SERVO AND OIL PUMP ASSEMBLY
AT — CAP, ASSEMBLY

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Figure 192b. Legend for Fluid Coupling and Hydramatic Transmission (Including Reverse Speed) Cross Section.

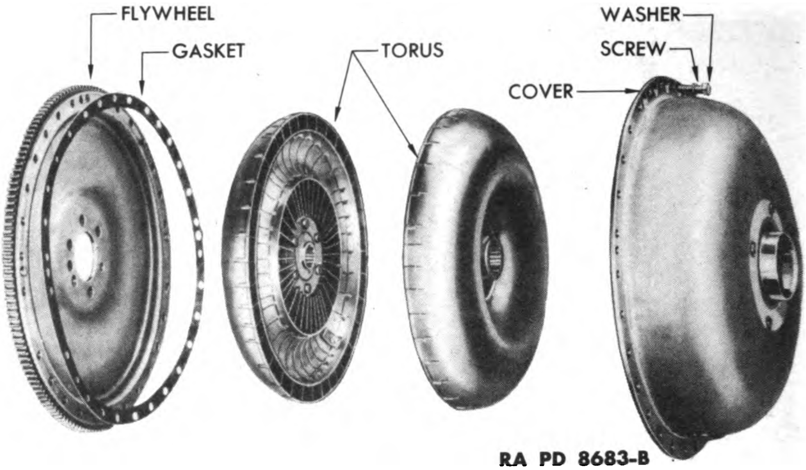

Figure 193a. Fluid Coupling Disassembled.

members is partly effected by pressing the oil from between the disks. As the oil is eliminated, the friction increases.

d. Many passenger-car clutches are of the semicentrifugal type shown in figure 191, in which the pressure between the plates is increased as the speed of the clutch increases. This is accomplished by means of centrifugal weights built into the outer ends of the release levers so that the outward pull of centrifugal force is translated into pressure on the plate. This construction permits the use of relatively light clutch springs, thus facilitating the depression of the clutch pedal for gear shifting.

Section II. FLUID COUPLINGS

160. Principles

a. The fluid coupling is used either with a convention clutch and transmission, or as a part of an automatic transmission in which case it replaces the clutch (fig. 192). The principle of this type of drive is illustrated by the action of two electric fans, facing each other, one with the power connected and the other with the power disconnected. As the speed of the power-driven fan is increased, power is transmitted to the motionless fan and it begins to rotate. The free-running fan gains speed until it is rotating almost as rapidly as the power-driven fan. The same action takes place in the fluid coupling except that oil instead of air transmits the power.

b. The fluid coupling consists of a centrifugal pump or impeller driven by the engine and a runner or turbine mounted on the driven shaft. These parts are shown in figure 193. There is no metallic connection between them. The entire assembly is mounted on the engine crankshaft in place of the conventional flywheel and the starter is attached to the impeller or driving member. An oiltight joint unites the case and the impeller so that the runner or driving member is inclosed between them. The driven shaft is made oiltight by a spring-loaded bronze sealing ring attached to the center of the case. The assembly is kept filled with oil under control of a relief valve by means of high capacity pumps. When the crankshaft and impeller rotate, the oil is thrown by centrifugal force from the center to the outside edge of the impeller between the vanes. This increases the velocity of the oil and increases its energy. The oil then enters the runner vanes at the outside and flows toward the center, imparting a rotating motion to the runner. The oil circulates as long as the impeller and the runner rotate at different speeds. When the two members are rotating at the same speed, the oil stops circulating. Both members of the drive are the same so that when the vehicle is coasting in gear the wheels drive the engine. In this case, the oil circulates in a reverse direction.

c. When the engine is idling the energy imparted to the oil is insufficient to rotate the runner. As the amount of slip is determined by the torque required by the driven member, the slip is 100 percent with the vehicle stationary but drops quickly as the vehicle gathers speed. In some arrangements it is less than 1 percent during normal operation above 30 m. p. h. The main advantage of the fluid coupling is that it eliminates torsional vibration and provides a smooth, jerkless acceleration because of the cushioning of the fluid medium between the two members.

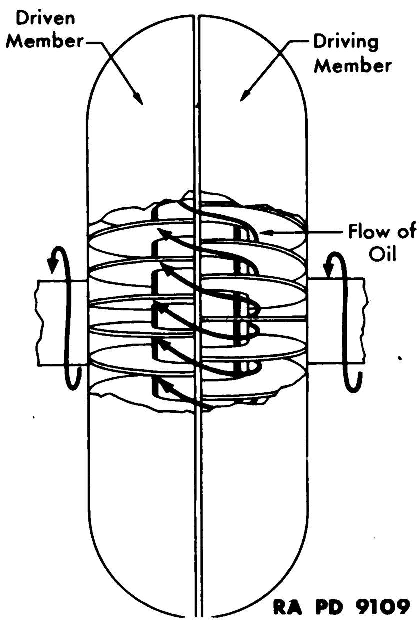

Figure 193b. Fluid Coupling, Schematic View.

CHAPTER 15

TRANSMISSIONS AND TRANSFER ASSEMBLIES

Section I. CONVENTIONAL TRANSMISSIONS AND TRANSFER ASSEMBLIES

161. Function

As explained in Chapter 13, the purpose of the transmission is to provide the operator with a selection of gear ratios between engine and wheels so that the vehicles can operate at best efficiency under a variety of driving conditions and loads.

162. Types

a. Basic Types. There are three basic types: the sliding gear, the planetary, and the friction-disk. The friction-disk is no longer used; the planetary is no longer used although it is incorporated in the hydramatic type in overdrives, and in some dual-ratio rear axles; the sliding-gear type is now known as the conventional transmission. There are two types of sliding-gear transmissions. One is the progressive in which the arrangement is such that it is necessary to pass one gear through another in definite order. Thus, in a three-speed progressive transmission, it is impossible to shift from "low" to "high" without going through "second." The use of this system is limited almost entirely to motorcycles. The other sliding-gear type is known as selective. In this system, the operator can select any ratio without going through intermediate stages. Its construction and operation will be explained later in this chapter.

b. Special Types. (1) In modern passenger cars, the disadvantages of sliding-gear types are overcome by use of constant-mesh transmissions. These eliminate the noise and clashing common to spur-gear trains. A more complete discussion will be found later in the chapter.

(2) Synchromesh transmissions are a type of constant-mesh. Their construction and operation will be discussed later in the chapter.

163. Construction and Operation

a. General. Conventional transmissions have certain fundamental components. These are the case, which houses the gears and shafts; the control cover, which houses the shifter mechanism; and the various shafts and gears. Three-speed selective transmissions have three shafts.

They are, in the order of the flow of power, the clutch shaft, the countershaft, and the mainshaft. The function of the three shafts together with the gears which connect them will be discussed in detail.

b. PARTS. The parts are shown in their correct relative positions but disassembled in the case. The names and functions of the parts follow:

(1) *Shafts.* The clutch shaft and transmission main drive gear (fig. 194) are one piece and rotate with the clutch driven plate or disks; that is, they rotate all the time the clutch is engaged. The transmission main drive gear is in constant mesh with the countershaft drive gear (fig. 194). Since all the gears in the countershaft cluster are either made integral or keyed on, they also rotate at the time the clutch is engaged. The transmission mainshaft (fig. 194) is held in line with the clutch shaft by a pilot bearing at its front end, which allows it to rotate or come to rest independently of the clutch shaft.

(2) *Gears.* The transmission second-and-high and low-and-reverse mainshaft gears (fig. 194) have grooved hub extensions into which fit the shift forks which slide them back and forth on the mainshaft spline. Thus, the second-and-high mainshaft gear can be shifted rearward to mesh with the countershaft second-speed gear. The second-and-high mainshaft gear also has internal teeth which mesh with the external teeth on the rear of the transmission main drive gear when the gear is shifted forward into the direct-drive position. The low-and-reverse mainshaft gear can be shifted forward to mesh with the countershaft low-speed gear or rearward to mesh with the reverse idler gear. The countershaft reverse gear is usually in constant mesh with the reverse idler gear (fig. 194). In some transmissions, the reverse idler gear is shifted to mesh with the countershaft reverse gear at the same time that the low-and-reverse mainshaft gear is shifted to mesh with the reverse idler gear.

(3) *Other parts.* The main, counter, and clutch shafts with their respective gears, are mounted on antifriction bearings in the transmission case. Shift rails and forks are provided to move the gears when the control lever is moved by the driver to change speeds. The countershaft is generally placed below the mainshaft. This permits a deep, narrow case, which allows a considerable quantity of oil in the case without danger of leakage since the oil level is maintained below the oil seals where the clutch shaft enters the case and the mainshaft leaves it.

c. TRANSMISSION POSITIONS. (1) *Neutral.* In figure 195, the gears are shown in the neutral position. The clutch shaft drives the countershaft through the main drive gear and countershaft drive gear. None of the countershaft gears are in mesh with the mainshaft sliding gears, however, so the mainshaft is not driven. Therefore, when the gears are in this position, there is no connection between the engine and the driving wheels so the vehicle remains stationary while the engine is running. In the transmission shown in figure 195, the gear ratio between the transmission main drive gear and the countershaft drive gear is about 1.5 to 1.

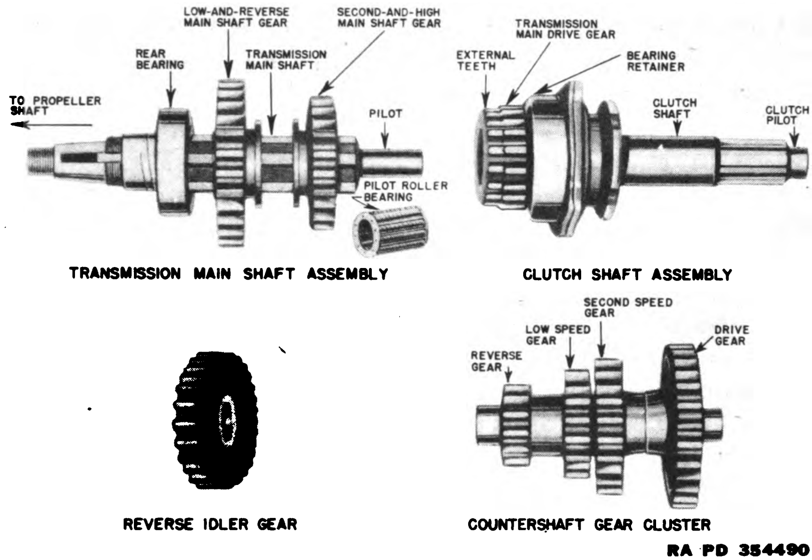

Figure 194. Principal Gear Groups of a Three-Speed Selective System.

Therefore the countershaft rotates at approximately 0.7 times the speed of the clutch shaft or crankshaft. The path of transmitted power is shown by arrows.

(2) *Low speed.* When the gears are in low-speed position, the low-and-reverse mainshaft gear is shifted forward to mesh with and be driven by the countershaft low-speed gear. The countershaft rotates at about half crankshaft speed. There is a further speed reduction between the countershaft low-speed gear (driving) and the low-and-reverse main-shaft gear (driven) of about 1.5. Therefore the crankshaft rotates 1.5x1.5=2.25 times for each turn of the propeller shaft.

(3) *Second speed.* The second-speed position is shown in figure 196. In passing from low speed to second speed, both sliding gears have been shifted rearward; the low-and-reverse mainshaft gear has been shifted out of engagement into the neutral position and the second-and-high mainshaft gear has been shifted into mesh with the countershaft second-speed gear. The clutch shaft and the main drive gear are now driving the countershaft through the countershaft drive gear (as is the case in all speeds) and the countershaft is driving the mainshaft through the countershaft second-speed gear and the second-and-high mainshaft gear as shown by the arrows. Since the countershaft second-speed gear and the second-and-high mainshaft gear are the same size, their gear ratio is 1 to 1. This means that the transmission mainshaft rotates at the same speed as the countershaft; that is, the engine crankshaft makes about 1.5 revolutions to one of the propeller shaft.

(4) *High speed.* The high-speed, or direct-drive, position of the gears

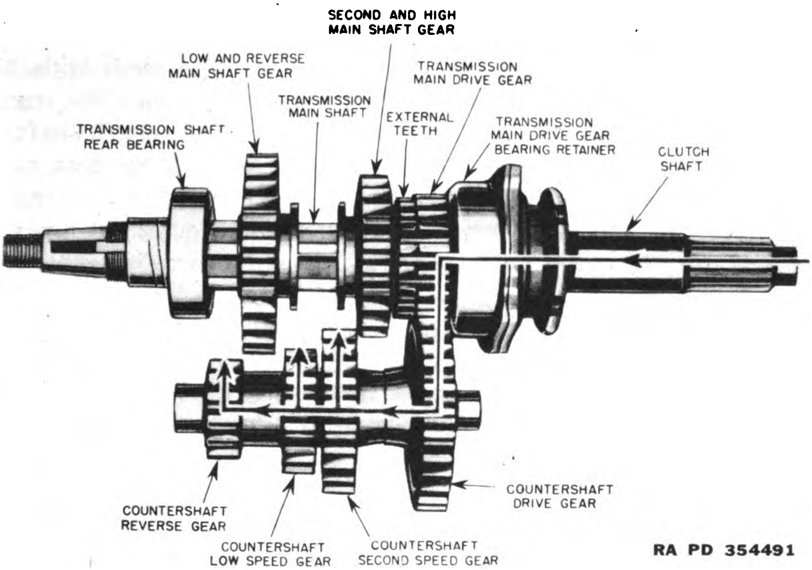

Figure 195. Transmission Gears in Neutral Position.

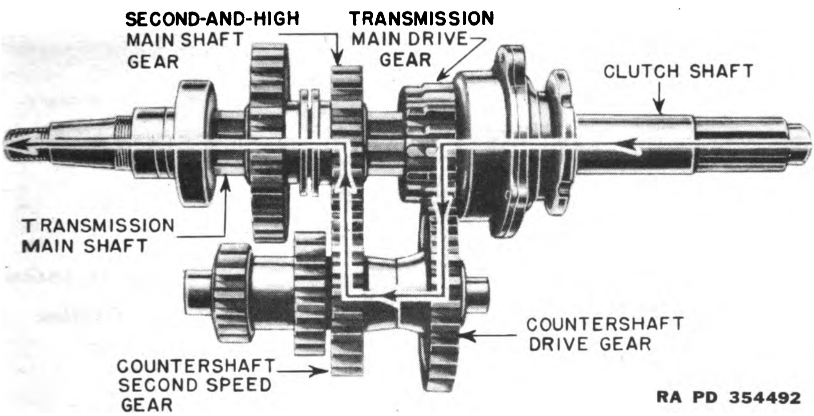

Figure 196. Transmission Gears in Second Speed Position.

is shown in figure 197. In passing from second speed to high speed, the second-and-high mainshaft gear has been shifted forward, causing the internal teeth in this gear to engage the external teeth on the main drive gear. This is an application of the dog clutch. It makes a direct connection between the clutch shaft and transmission mainshaft as shown by the arrows. The propeller shaft therefore rotates at crankshaft speed.

(5) *Reverse.* The reverse position of the gears is shown in figure 198. In order better to illustrate the reverse idler gear, the parts have been turned end for end and are shown from the opposite side from

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previous illustrations. In passing from neutral to reverse, the low-and-reverse mainshaft gear has been shifted rearward to mesh with the reverse idler gear. The sole function of this gear is to make the transmission mainshaft rotate in the opposite direction to the clutch shaft as shown by the short, heavy arrows; it does not influence the gear ratio between the countershaft reverse gear and the low-and-reverse mainshaft gear. The gear ratio between these gears is about 2. In reverse, therefore, the crankshaft rotates 1.5x2=3 times for every revolution of the propeller shaft.

d. Helical Gears. For the purpose of simplicity, the transmission described above is of the spur-gear type. In modern practice, however, helical gears are widely used because they run more quietly than spur gears. There is a side thrust on a helical gear, due to the angularity of the teeth, which tends to slide the gears out of mesh. This difficulty is avoided in constant-mesh transmissions because the gears do not slide

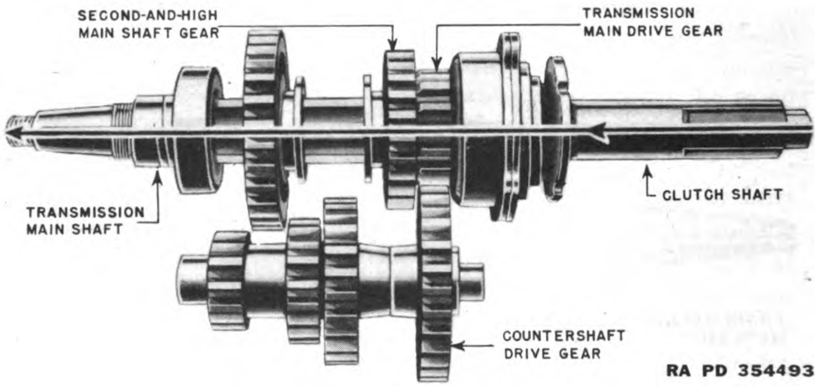

Figure 197. Transmission Gears in High Speed or Direct Drive Position.

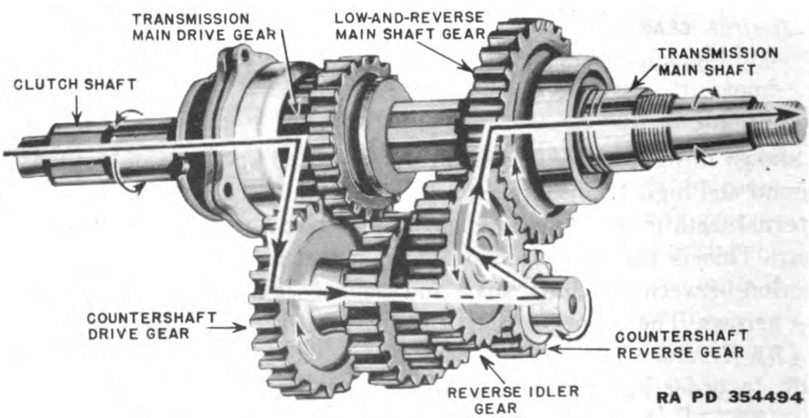

Figure 198. Transmission Gears in Reverse Speed Position.

on the shaft. When sliding helical gears are employed in a transmission, the splines on which they slide are also cut helically to the same angle as the teeth; this offsets the side thrust.

e. TRANSMISSION CONTROLS. (1) The three-speed selective transmission described above is operated by a control lever assembled to, and extending from the transmission cover as shown in figure 199. The lever has a ball fulcrum fitting into a socket in the cover. It is kept from rotating by a set screw entering a slot in the side of the ball fulcrum but is free to move backward, forward, and sidewise. The end of the lever below the ball fulcrum engages both slots, but there is an interlock device (usually a ball or pin engaging notches in each rail) that permits one rail to move at a time, but not both. This prevents two speeds being engaged at once. When the control lever handle is pressed to the left, the slot in the low-and-reverse shift rail is engaged and the fork can be moved backward or forward. After the low-and-reverse shift rail has been returned to the neutral position, the control lever can be pressed to the right and the second-and-high shift rail and fork can be moved forward or backward. The shift rails are held in the different speeds and the neutral position by spring loaded balls, or poppets engaging notches in the shift rails.

(2) Since 1939 the transmission control levers on the steering column have come into general use. These are generally used with the synchromesh type transmission and are described in paragraph 164c.

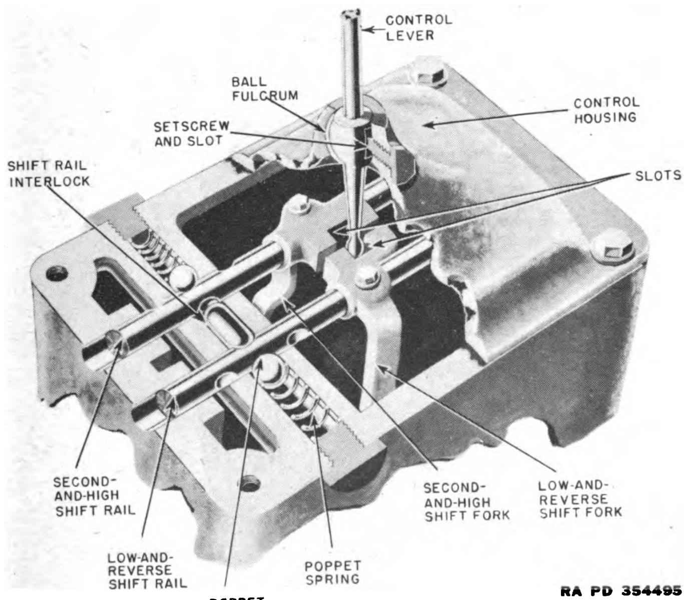

Figure 199. Transmission Shifting Mechanism and Control Lever.

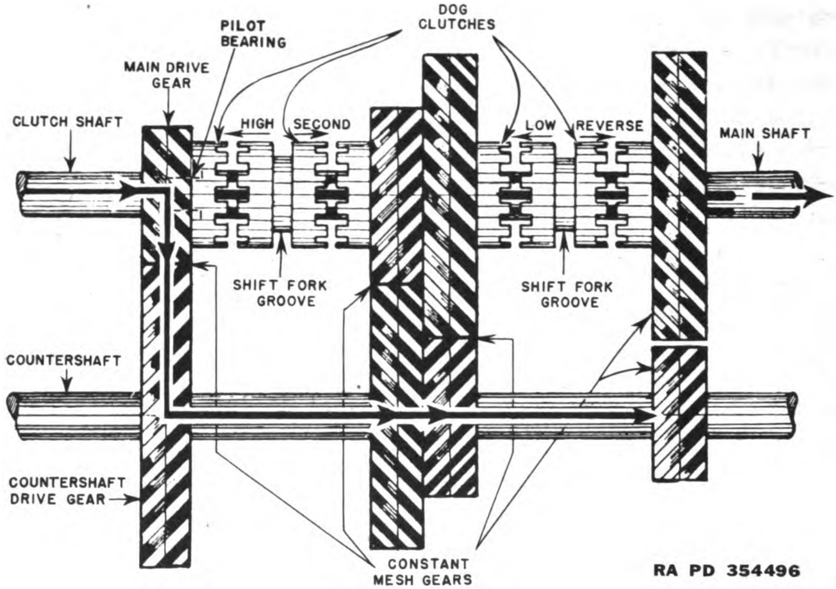

Figure 200. Principles of Constant Mesh Transmission.

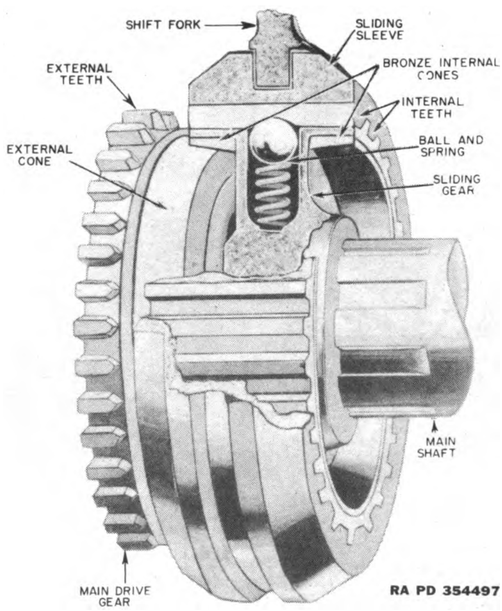

Figure 201. Synchromesh Clutch Disengaged.

164. Constant-mesh and Synchromesh Transmissions

a. PURPOSE. Sliding-gear transmissions use stub-tooth gears for easy engagement; consequently, the transmission is usually noisy when operating in the intermediate speeds. In recent years, the conventional sliding-gear transmission has been superseded, particularly on passenger vehicles, by systems in which the gears are always in mesh with their mates, and selection is made by sliding other components into and out of connection. Two of the most common of these systems are the constant-mesh type and the synchromesh, which has an additional feature to prevent clashing of gears.

b. CONSTANT-MESH TRANSMISSIONS. The gears of the constant-mesh speeds are nearly always of the helical type and give quiet operation in the intermediate speeds. In transmissions of this type, all the countershaft gears and the transmission main drive gears are fixed to their shafts; the low-and-reverse and second-and-high mainshaft gears rotate on the mainshaft. All the mainshaft and mating countershaft gears are constantly meshed as shown in figure 200. A speed change is made by sliding the driving member of a dog clutch along the splined mainshaft until it meshes with a driven member integral with the required gear, causing it to rotate with the mainshaft. Constant-mesh gears are seldom used for all speeds. Common practice is to employ constant-mesh helical gears for second speed, or for low and second speed, and a sliding helical or spur gear for low and reverse, or for reverse only.

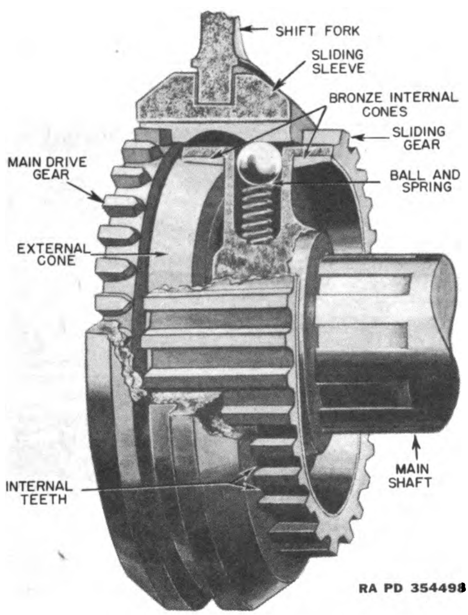

Figure 202. Synchromesh Clutch Engaged.

c. SYNCHROMESH TRANSMISSIONS. (1) The synchromesh transmission is a type of constant-mesh transmission that permits gears to be selected without clashing by synchronizing the speeds of mating parts before they engage. It employs a combination metal-to-metal friction cone clutch and a dog or gear positive clutch to engage the main drive gear and second-speed mainshaft gear with the transmission mainshaft. The friction cone clutch engages first, bringing the driving and driven members to the same speed, after which the dog clutch engages easily without clashing. This process is accomplished in one continuous operation when the driver declutches and moves the control lever in the usual manner. The construction of synchromesh transmissions varies somewhat with different manufacturers but the principle is the same in all.

(2) The construction of a popular synchromesh clutch is shown in figure 201. The driving member consists of a sliding gear splined to the transmission mainshaft with bronze internal cones on each side. It is surrounded by a sliding sleeve having internal teeth which are meshed with the external teeth of the sliding gear. The sliding sleeve is grooved around the outside to receive the shift fork. Six spring-loaded balls in radial drilled holes in the gear fit into an internal groove in the sliding sleeve and prevent it from moving endwise relative to the gear until the latter has reached the end of its travel. The driven members are the main drive gear and second-speed mainshaft gear, each of which has external cones and external teeth machined on its sides to engage the internal cones of the sliding gear and the internal teeth of the sliding sleeve. The synchromesh clutch is shown disengaged in figure 201 and engaged in figure 202.

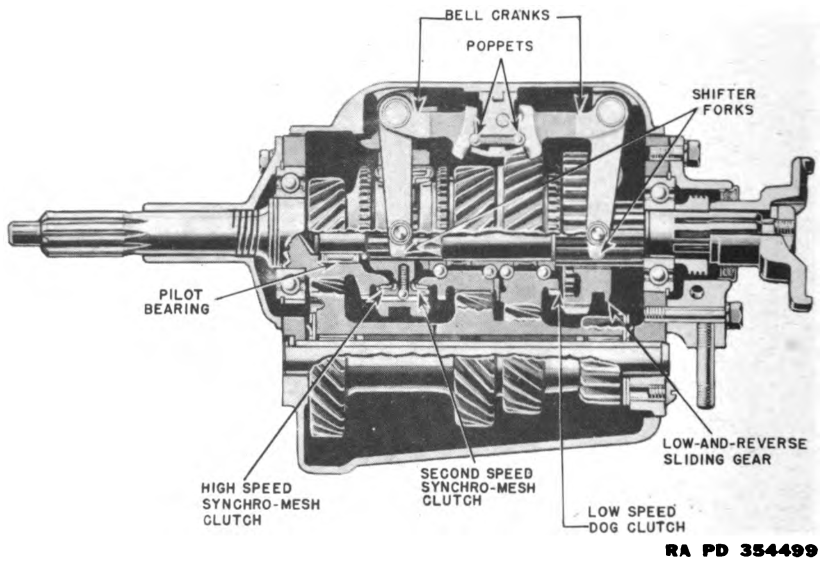

Figure 203. Synchromesh Transmission Arranged for Steering Column Control.

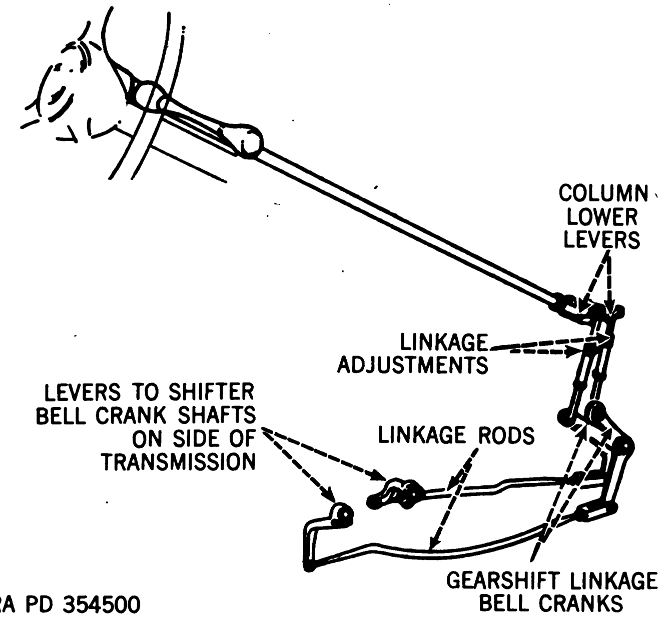

Figure 204. Steering Column Transmission Control Linkage.

(3) The synchromesh clutch operates as follows: when the transmission control lever is moved by the driver to the high speed or direct drive position, the shift fork moves the sliding gear and sliding sleeve forward as a unit until the internal cone on the sliding gear engages the external cone on the main drive gear. This action brings the two gears to the same speed and stops endwise travel of the sliding gear. The sliding sleeve then slides over the balls and silently engages the external teeth on the main drive gear, locking the main drive gear and transmission mainshaft together as shown in figure 202. When the transmission control lever is shifted to the second-speed position, the sliding gear and sleeve move rearward and the same action takes place, locking the transmission mainshaft to the second-speed mainshaft gear. The synchromesh clutch is not applied to low speed or reverse. Low speed is engaged by an ordinary dog clutch when constant mesh is employed, or by a sliding gear; reverse is always engaged by means of a sliding gear. Figure 203 shows a synchromesh transmission in cross section which uses contant-mesh helical gears for the three forward speeds and a sliding spur gear for reverse.

(4) This transmission is controlled by a steering column control lever (fig. 204). The positions for the various speeds are the same as those for the vertical control lever except that the lever is horizontal. The shifter forks are pivoted on bell cranks which are turned by a steering column control lever through the linkage shown. The poppets shown in

figure 203 engage notches at the inner end of each bell crank. Other types of synchromesh transmissions controlled by steering column levers have shift rails and forks moved by a linkage similar to those used with a vertical control lever.

(5) Transmissions of heavy duty trucks are not equipped with synchromesh gears. To assure engagement without clashing, "double clutching" is usually employed by the driver.

Section II. AUTOMATIC TRANSMISSIONS

165. Hydramatic Transmission

a. General. The hydramatic transmission (figs. 192 and 205) consists of a fluid coupling (par. 160) and an automatic transmission having four speeds forward and one reverse. In some vehicles no reverse gearing is incorporated in the transmission, as this is provided in the transfer assembly. Slippage in the fluid coupling at engine idling speeds provides the cushioning action of a clutch. Gear changes are made automatically by hydraulic pressure and are governed by the speed of the vehicle and the extent to which the driver depresses the accelerator.

b. Power Transmitting Units. The hydramatic transmission consists of the following power transmitting units, listed in the order in

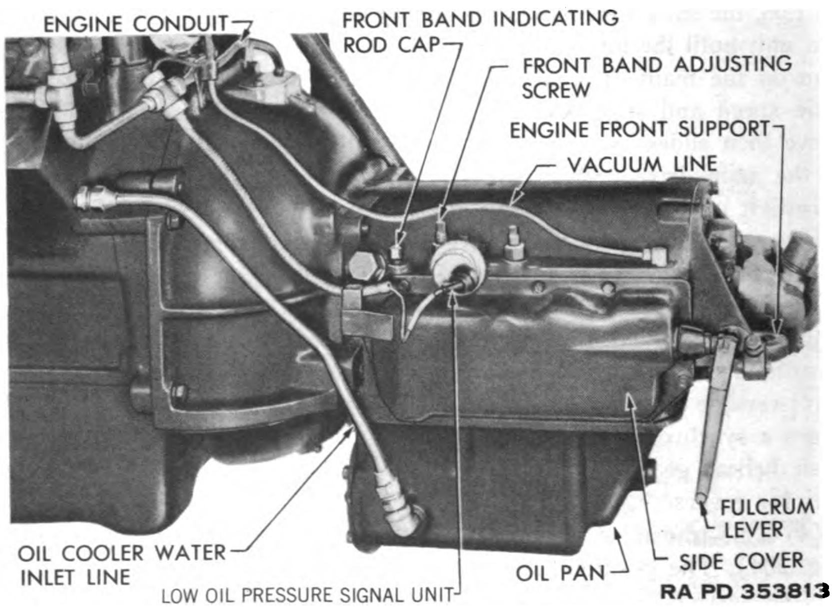

Figure 205. Hydramatic Transmission (Without Reverse Speed).

which they transmit the power: the flywheel cover, the front planetary unit, consisting of single reduction planetary gears; the fluid coupling or torus members, and the rear planetary unit, also consisting of single reduction planetary gears. The output shaft is connected to the rear planet carrier.

c. Planetary Units. The planetary units consist of planet gears (four in the front unit and six in the rear unit), which encircle and are meshed with the center or sun gear. These gears are in turn surrounded by a gear having internal teeth. One member of this planetary unit can be kept from rotating by a band wrapped around an integral drum. The band is applied or released by a servo mechanism which is merely a double-acting piston and cylinder operated by spring and oil pressure. Each unit also includes a multiple disk clutch which is applied by oil pressure and released by spring pressure. When the clutch is released and the band applied, the planet gears are forced by the driving gear to "walk around" the stationary gear; consequently the output shaft, which is connected to the planet gears, is driven at reduced speed and the unit is in reduction (fig. 206). When the band is released and the clutch applied, the entire unit is locked together and rotates as a unit, providing direct drive (fig. 207). Each planetary unit is a complete two-speed transmission in itself, as it can operate either in reduction or direct drive. The transmission contains two of these planetary units.

d. Hydraulic Control Units. The hydraulic control units include two oil pumps, two servos that operate the bands, a governor assembly, and a master control valve assembly that controls the hydraulic oil pressure to the various control units. The speeds at which the gear changes occur are controlled by oil pressure to the control valve mechanism. Briefly, this mechanism consists of balanced shift valves against which oil pressure is exerted at one end in proportion to engine vacuum, and at the other end by pressure from the centrifugal governor which is in direct proportion to the speed of the vehicle. When the vehicle reaches a certain point in relation to governor pressure and engine vacuum, the transmission upshifts to a higher speed. When the vehicle speed decreases due to brake action or ascending a hill, a point is reached when the various pressures cause the transmission to shift to a lower gear. As engine vacuum follows engine torque very closely, it controls the shift valve positioning in accordance with the demands for power made by the driver.

e. Gear Ratio. The four transmission speed ranges are secured as follows: in first speed, both planetary units are in reduction for a total ratio of 3.92:1; in second speed, the front unit is in direct drive and the rear unit in reduction for a ratio of 2.53:1; in third speed, the front unit is in reduction and the rear unit direct drive for a ratio of 1.55:1; in fourth speed, both units are in direct drive.

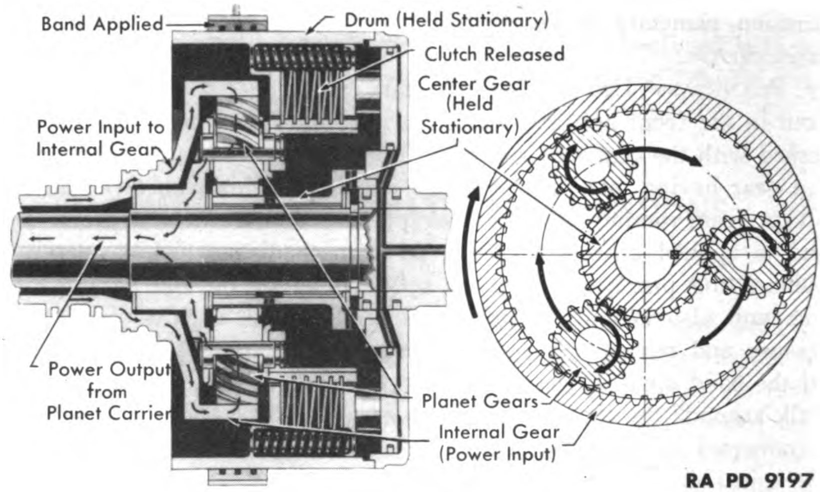

Figure 206. Planetary Unit in Reduction.

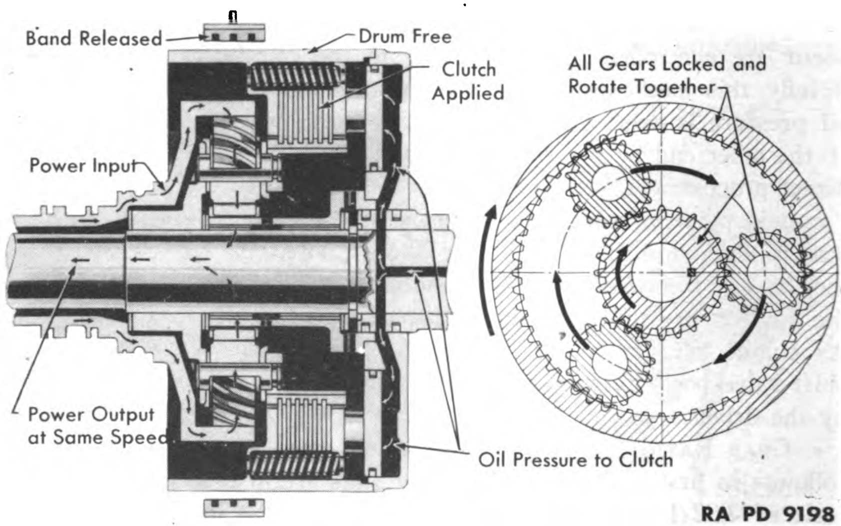

Figure 207a. Planetary Unit in Direct Drive.

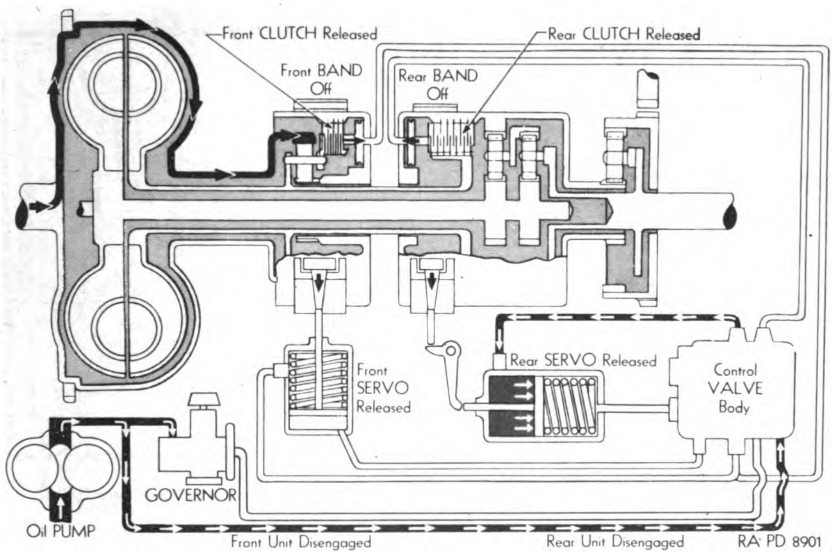

Figure 207b. Hydramatic Transmission (Including Reverse Speed) in Neutral.

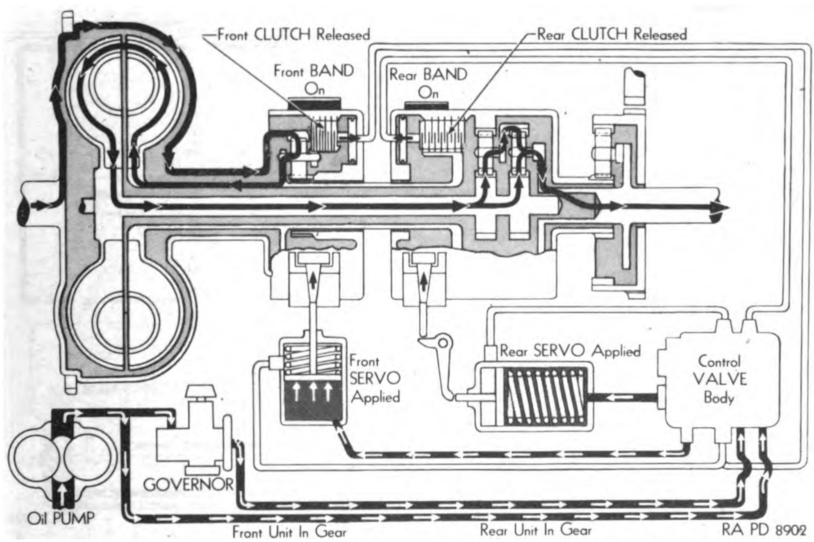

Figure 207c. Hydramatic Transmission (Including Reverse Speed) in First Speed.

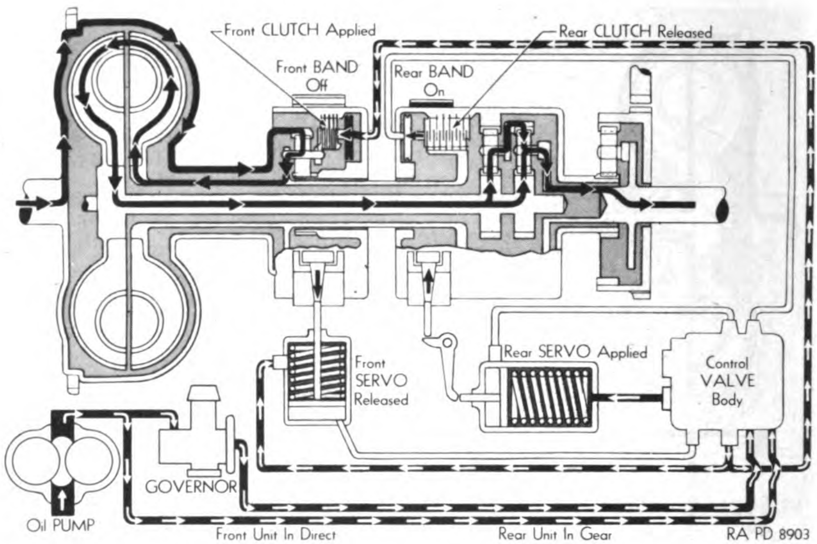

Figure 207d. Hydramatic Transmission (Including Reverse Speed) in Second Speed.

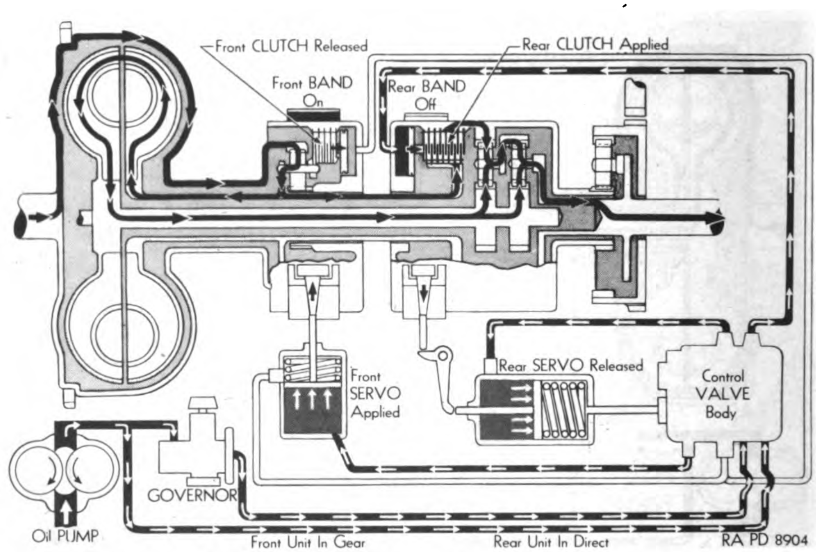

Figure 207e. Hydramatic Transmission (Including Reverse Speed) in Third Speed.

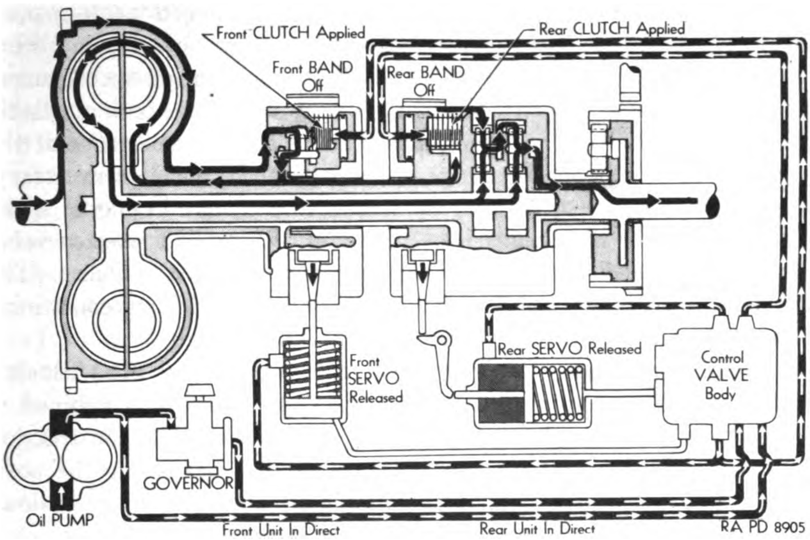

Figure 207f. Hydramatic Transmission (Including Reverse Speed) in Fourth Speed.

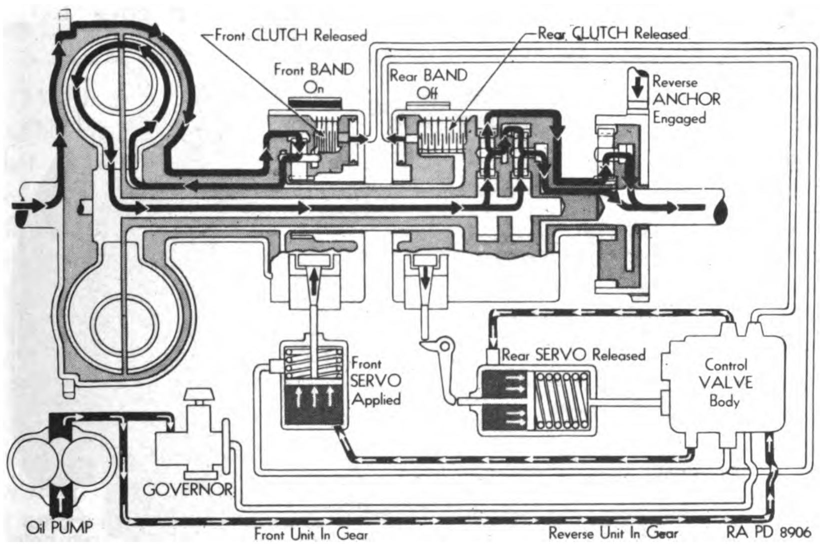

Figure 207g. Hydramatic Transmission (Including Reverse Speed) in Reverse.

166. Torqmatic Transmission

a. General. The torqmatic transmission is especially adapted for heavy duty vehicles, allowing easy mobility and rugged performance. Its four speed ranges include three forward and one reverse, and there is an over-all torque ratio coverage of 20:1. Inasmuch as all speed ranges consist of frictionally applied planetary drives, each range is immediately obtainable under all driving conditions. Due to the characteristics of the converter, the shift from one range to another can be made, if necessary, with full torque applied, without any substantial change in engine speed or severe shock to the final drive. A manually controlled selector valve engages hydraulically actuated brake bands or friction clutches. The selection of the proper range, which is determined by driving conditions, is the only function necessary for the driver to perform.

b. Construction. (1) The torqmatic transmission (fig. 208) consists basically of two major units: a hydraulic torque converter combined in series with a three-speed planetary gear transmission. The construction also includes the transfer assembly. Terms used in describing the position of the various parts of the transmission are explained in the following: the "front" end of the transmission is defined as the torque converter or power imput end which is connected with the engine. The "rear" end is defined as the output end which is connected through the final drive gear to the driving axle of the vehicle.

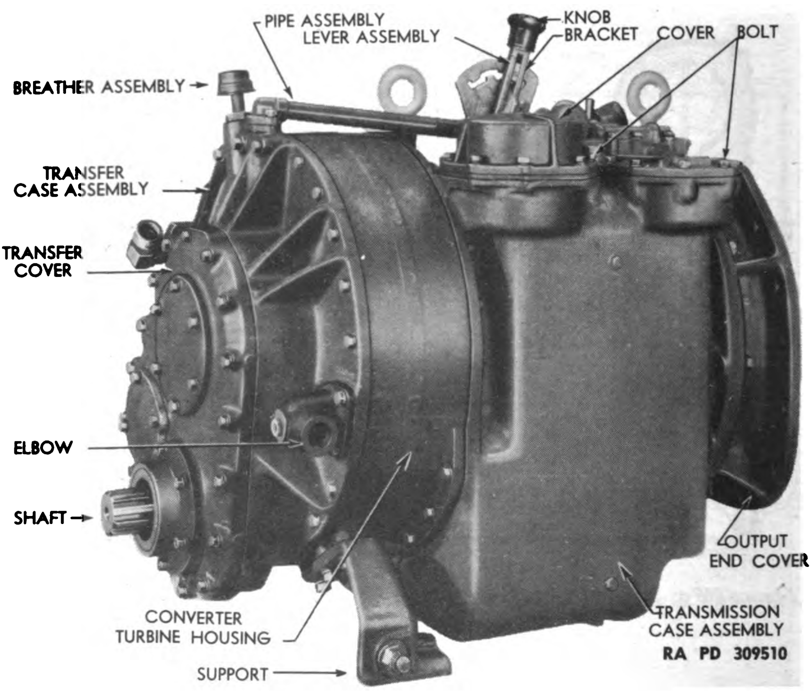

Figure 208a. Torqmatic Transmission Assembly.

(2) The power from the engine enters the transmission by way of the transfer assembly and hydraulic torque converter. The gear train in this case locates the input shaft below the centerline of the transmission in order to obtain a low position for the propeller shaft in the vehicle. This application provides a reduction of 1.20:1 in this transfer assembly to balance the capacity of the power output of the engine selected. This ratio may be altered to suit the characteristics of various types of engine installations.

(3) The hydraulic torque converter (par. 167) is located between the transfer assembly and the main transmission case. The front pump, which is a hydraulic pressure pump of the internal-external gear type, is assembled in the transfer unit around the torque converter input shaft.

(4) In back of the converter, the gear train in the transmission consists of two planetary gear sets. The two friction clutches and two brake bands, also located in the transmission case, are alternatively engaged (see below) to obtain three speeds.

Band and clutch application

	Brake bands		Clutches	
	Front	Rear	Inner	Outer
Reverse	On	Off	Off	On.
Neutral	Off	Off	On	Off.
Low	Off	Off	On	On.
Intermediate	Off	On	On	Off.
High	On	Off	On	Off.

(5) All gears of the planetary sets are in constant mesh making it possible under all conditions to shift instantly from one range to another without interrupting the power flow. Individual bands or clutches are applied hydraulically by means of pistons in the brake application cylinders or annular pistons in the clutch drums. Speed selection is obtained by means of a control lever mounted next to the driver. The control valves are so arranged and coordinated that a practically instantaneous shift is obtained from one speed range to the next. This permits shifting either upward or downward under full power; also any possibility of wear and scoring due to overlapping application is eliminated.

(6) A spline on the output shaft in the rear of the transmission is provided for the mounting of the pinion which transmits the power to the final drive gearing. Also driven from this output shaft is the rear oil pump which supplies oil under pressure for actuation of bands and clutches, and for lubrication.

c. Operation. The manual lever is the only control employed by the driver for shifting of the torqmatic transmission. The five positions provided are arranged in the following order: reverse, neutral, low range, intermediate range, and high range. A button latch on the manual lever serves as a detent to prevent shifting more than one step at a time. When ready to start, the lever is shifted to the position required for the anticipated driving conditions and the vehicle is put into motion by stepping on the accelerator.

(1) *Low range.* Low range provides an emergency range for extreme conditions. This range is used when maximum pulling power is needed at speeds below 16 m. p. h.

(2) *Intermediate range.* Intermediate range is used for starting on soft ground and on inclines. This range provides the greatest tractive effort for operation at speeds between 12 and 34 m. p. h.

(3) *High range.* High range is used for driving on good roads or firm, level ground. Under favorable conditions the vehicle can be started in high range and can be left in this range for all normal driving and on grades up to about 10 percent.

167. Torque Converter

a. General. The purpose of the torque converter is to act as both a clutch and transmission and apply the engine horsepower to the drive members smoothly and in variable torque-speed ratio. The desired ratio is automatically determined at any moment solely by the load imposed upon the output shaft. The torque converter is physically limited to a torque output of from one to about five times the input torque, and the normal working speed of the output shaft is from zero to almost two-thirds input speed. Any increase in torque or input speed above the normal operating range (½ to ⅔ maximum engine speed) of the converter is usually obtained by a gear box between it and the final drive members.

b. Construction. The torque converter itself (fig. 208) consists of four major parts: a centrifugal pump that is driven by the engine; a coaxial three-stage turbine (or rotor) attached to the output shaft of the engine; a hydraulic chamber; and reactor blades attached to the inside of the chamber.

c. Operation. (1) In operation, the pump is driven by the engine. Due to the centrifugal forces, the fluid is thrown out toward the pump periphery, absorbing kinetic energy at the same time and thereby imposing the corresponding load on the engine or driving member (fig. 208). As the fluid strikes the turbine blades it attempts to rotate the output shaft. If the load on the output shaft is great, little or no rotation will result and the fluid will rebound from these blades, reversing its direction of flow. In this operation only part of the energy of the fluid is spent. This action could be likened to the throwing of a rubber ball against a wall. The ball strikes the wall with a great force and rebounds because the wall did not move. The stationary wall causes the ball to reverse its direction of flight and at the same time a push is exerted against the wall as rebound takes place; the energy stored in the ball is only partially spent. Similarly, as only a part of the energy has been expended in passing through the first set of turbine blades, it would seem to be good practice to make provision for utilizing the remainder. Due to the shape of the hydraulic chamber, however, the fluid is forced to flow through a set of reactor blades which are securely attached to the inner wall of the chamber, and to reverse its motion back to the original direction. Again the fluid can be likened to the rubber ball which, when rebounding, is traveling in a direction away from the wall, the remaining energy wasted unless the rebound direction is reversed. This can be done by having the ball rebound from a parallel wall, travel toward the first wall in the original direction, and exert a second push against it. The first set of reactor blades causes the fluid to rebound

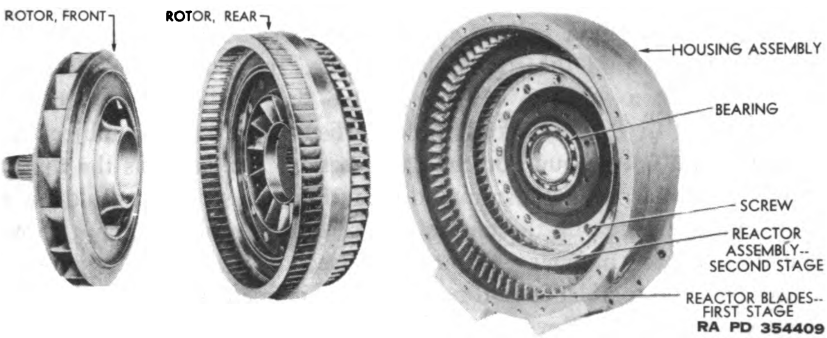

Figure 208b. Torqmatic Transmission Torque Converter Rotors, Housing and Reactor.

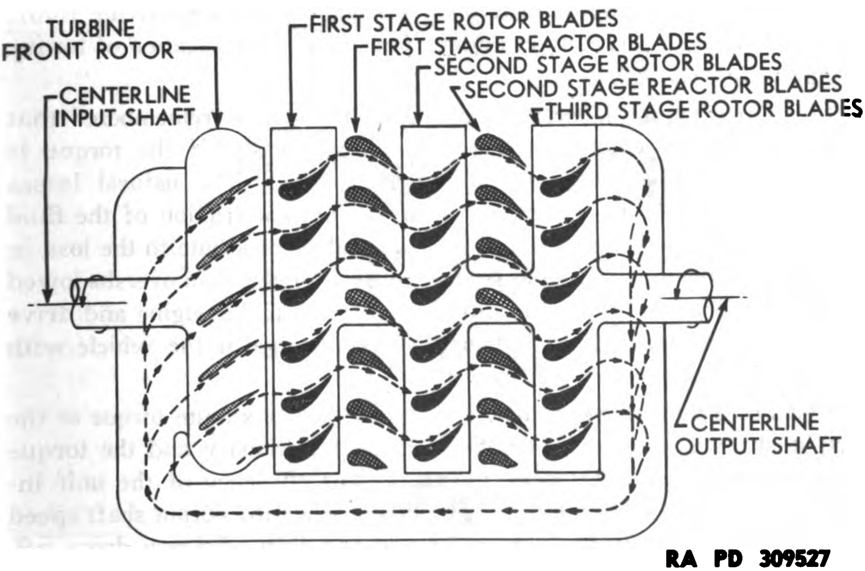

Figure 208c. Oil Flow and Turbine Action in Torque Converter.

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again, but this time instead of being forced outward, it is forced downward through a second set of turbine blades where it again attempts to rotate the output shaft in the same direction that the input shaft is turning. After passing through the second set of turbine blades, more of the energy has been utilized and the direction is again reversed. More of the energy is spent, so that the fluid is forced inward toward the center of the chamber through a second set of reactor blades and finally to the third and last set of turbine blades on the output shaft. Here the remaining energy in the fluid is spent and is conducted by this third set of turbine blades in toward the center of the centrifugal pump where the fluid started its cycle.

(2) On the other hand, however, if the load on the output shaft is not very great the blades will be rotated easily and the greater part of the energy in the fluid will be spent at the first set of blades, with no reversal of the fluid direction taking place. It would simulate a ball thrown against a movable object. As the ball strikes the object, the energy stored in the ball would be absorbed in moving the object and the ball would not rebound or change direction. Similarly, as the fluid is forced to flow through the remainder of the blades, there would be no further push exerted on the output shaft. Multiplication of input torque depends upon the number of times the direction of oil flow is reversed by the driven rotor blades before its energy is spent and upon the completeness of reversal. Reversal of flow is complete only when the turbine or rotor blades are stationary. If the rotor blades move with the oil, the torque decreases accordingly. Therefore, the multiplication of torque is at its maximum when the driven rotor is stationary, or when starting a motionless vehicle. It is at a minimum when the rotating speed of the driven shaft is approximately the same as that of the driving rotor, or when the vehicle is fully in motion. Maximum multiplication of torque is approximately 4.8:1.

(3) Throughout the cycle of operation it must be remembered that power or energy cannot be increased. Consequently, if the torque is increased, the speed is correspondingly reduced. The natural losses incurred in circulating the fluid due to the internal friction of the fluid itself and the friction of the reactor blades also contribute to the loss in efficiency of the unit. These losses are, however, more than overshadowed by the fact that an automatic torque ratio between the engine and drive members is maintained throughout the speed range of the vehicle with the engine at a constant throttle setting.

(4) From the foregoing, it will be noted that maximum torque at the output shaft is obtained when the vehicle is stationary and the torque decreases as the vehicle speed increases. The efficiency of the unit increases to a point of slightly over 80 percent when the output shaft speed reaches a point of ½ to ⅔ engine speed and then efficiency drops off, so that if vehicle speeds of greater ranges are desired, a selective trans-

mission must be incorporated, or a sacrifice of efficiency and overheating will result. Even during normal operation, a means for cooling the fluid as well as an expansion tank to accommodate its volumetric increase due to expansion must be provided.

(5) Heat generated within the converter is directly proportional to its loss in efficiency; since it is operated normally above 70 percent efficiency, cooling radiators capable of dissipating 30 percent of the maximum engine horsepower must be provided. Circulation of fluid through the radiator is obtained by utilizing the pressure differential across the converter pump. This unit does not operate well when cold, because the thickened fluid does not circulate readily. For this reason a very thin fluid is used ranging from an SAE 10 engine oil to a straight Diesel fuel. Engine oil must be used when the fluid in the converter is also circulated through a gear box for lubricating purposes.

Section III. AUXILIARY EQUIPMENT

168. Transfer Assemblies

a. PURPOSE. With the addition of front wheels as driving members of a vehicle to supply more traction, the need for a transfer assembly became imperative. The transfer assembly, an auxiliary gear train on all-wheel-drive vehicles (fig. 209), enables the power to be divided or transferred to both forward and rear propeller shafts and provides a

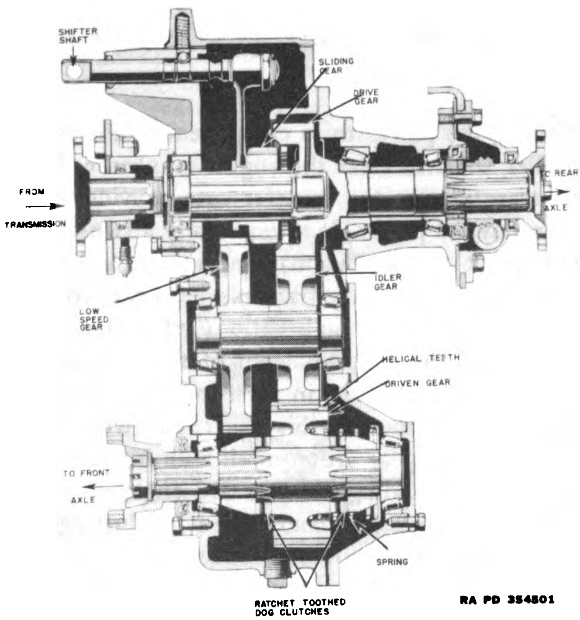
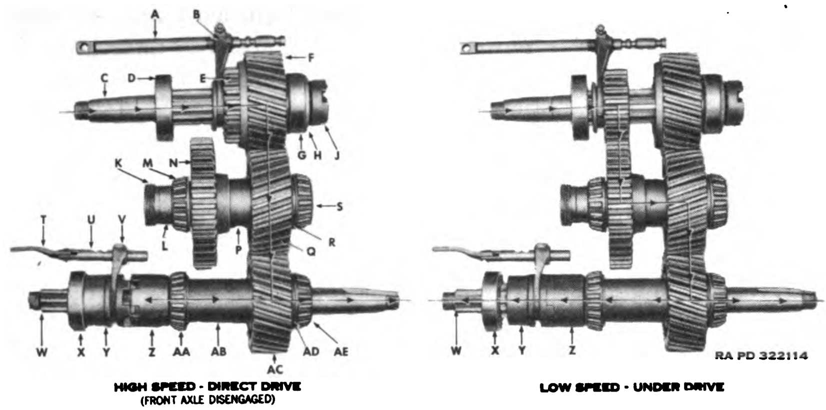


Figure 209a. Transfer Assembly Cross Section.



A—GEARSHIFT SHAFT
B—GEARSHIFT FORK
C—MAIN SHAFT
D—MAIN SHAFT FRONT BEARING
E—MAIN SHAFT LOW-SPEED SLIDING GEAR
F—MAIN DRIVE GEAR
G—MAIN SHAFT REAR BEARING
H—MAIN SHAFT REAR BEARING WASHER
J—MAIN SHAFT POWER TAKE-OFF CLUTCH
K—SPEEDOMETER DRIVE GEAR
L—SPEEDOMETER DRIVE GEAR SPACER
M—IDLER SHAFT FRONT BEARING CONE
N—LOW-SPEED GEAR
P—IDLER SHAFT
Q—IDLER GEAR
R—IDLER SHAFT WASHER
S—IDLER SHAFT REAR BEARING CONE
T—SHIFT CONTROL LINK
U—SHIFTING SHAFT
V—SHIFT FORK
W—DECLUTCH SHAFT
X—DECLUTCH SHAFT BEARING
Y—DECLUTCH SLIDING CLUTCH
Z—DECLUTCH DRIVING CLUTCH
AA—DRIVEN SHAFT FRONT BEARING CONE
AB—DRIVEN SHAFT
AC—DRIVEN GEAR
AD—DRIVEN SHAFT WASHER
AE—DRIVEN SHAFT REAR BEARING CONE

Figure 209b. Transfer Assembly Power Flow.

means of lowering the power train components sufficiently to permit the forward propeller shaft to clear the engine crankcase. In systems utilizing automatic transmission the transfer case provides for reversing the direction of the flow of power. It is essentially a two-speed transmission unit (low and direct drive), but may include an additional gear reduction. It is similar to the auxiliary transmission (par. 169) in mounting.

b. Operation. (1) In the high ratio (1:1) when driving both the front and rear axles, the external teeth of the sliding gear (splined to the transmission mainshaft) are in mesh with the internal teeth of the constant mesh gear mounted on this shaft. Likewise the external teeth of the front axle sliding gear are in mesh with internal teeth on the constant mesh gear or the sliding clutches are engaged. Disengagement of the drive to the front axle is accomplished by shifting the sliding gear on the front axle mainshaft out of mesh with the constant mesh gear, permitting the latter to roll free on the shaft, or sliding the clutches out of mesh.

(2) When using the low ratio in the transfer assembly, the sliding gear on the transmission mainshaft is disengaged from the constant mesh gear and engaged with the idler gear on the idler shaft. This reduces the speed by having the sliding gear mesh with the larger idler gear. The shifting linkage on some vehicles is so arranged that shifting into the low range is possible only when the drive to the front axle is engaged. This prevents the driver from applying maximum torque to the rear drive only, which might cause damage.

c. Power Take-Off Units. These are discussed in chapter 23.

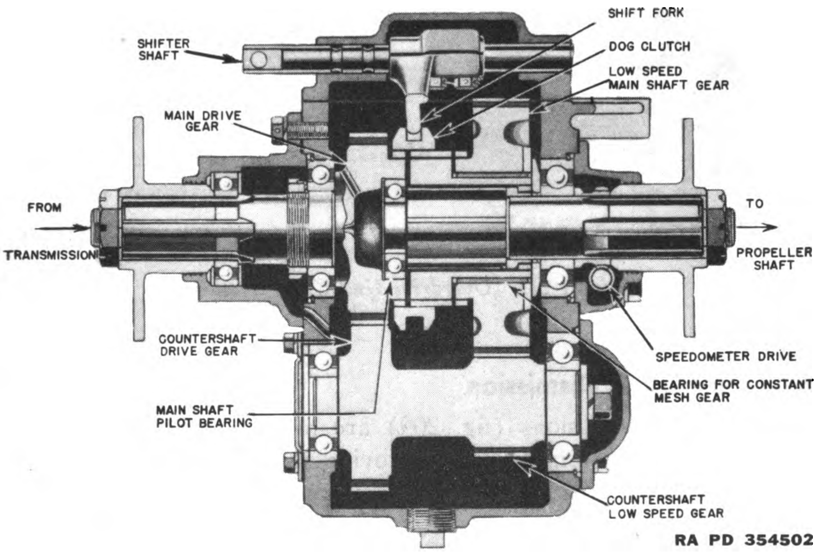


Figure 209c. Sectional View of Auxiliary Transmission.

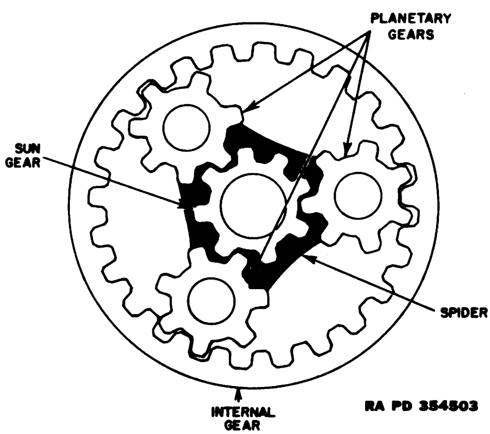


Figure 210. Planetary Gear Train.

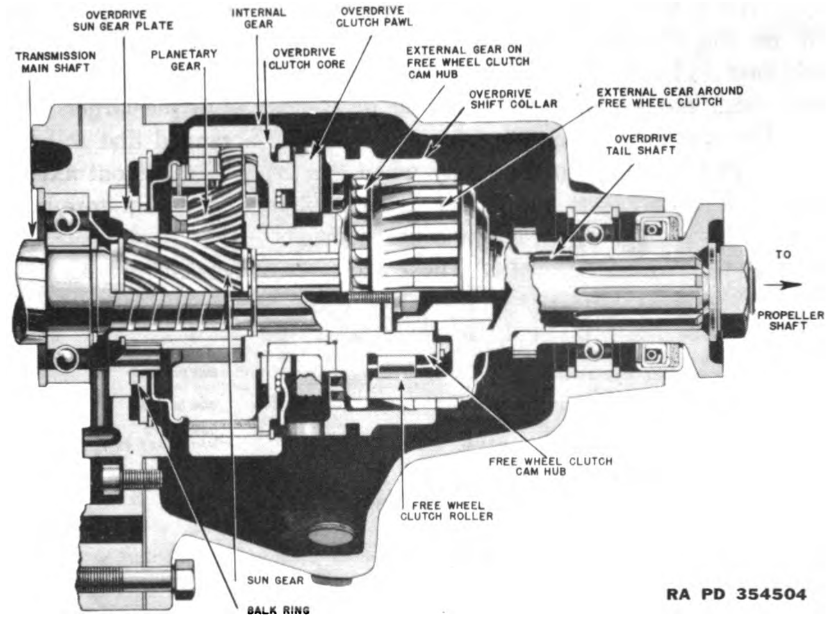


Figure 211. Overdrive Unit Cross Section.

169. Auxiliary Transmission

Auxiliary transmissions (fig. 209) are mechanisms mounted in the ·ear of the regular transmission to provide an increased number of gear ratios. The types most commonly used normally have only a low and a high (direct) range, incorporated into a transfer assembly. The low range provides an extremely low gear ratio on hard pulls. At all other times the high range is used, the power merely passing through the main shaft. Gears are shifted by a separate gearshift lever in the driver's cab.

170. Multiple-speed Subtransmission

Multiple-speed subtransmissions are used only on the heavier trucks. They usually consist of some device, similar to an auxiliary transmission, built into the regular transmission.

171. Overdrives

a. Planetary Gears. A knowledge of planetary gears, a form of gear train ordinarily used to obtain speed reductions, is necessary before the overdrive can be understood. These gears consist of three elements shown diagrammatically in figure 210. The central gear is known as the "sun gear." Three or more gears mounted on a spider (not shown), rotate on their axes and around the sun gear. These are called planetary gears because their motion around the sun gear is the same as the motion of the planets revolving in their orbits around the sun. There is also an internal gear surrounding the planetary gears and in mesh with them. Any one of the three parts of the gear train (sun gear, spider, or internal gear) may be used as the driving member to drive one of the other two members while the third member is held stationary. The methods of determining the various gear ratios obtained through planetary gearing are rather complicated and beyond the scope of this manual.

b. FUNCTION. A transmission overdrive (fig. 211) provides a gear ratio less than 1 to 1. It reduces oil consumption and engine wear by requiring less revolutions of the engine for a given mileage than required if direct drive is used, and reduces gasoline consumption by providing a more suitable gear ratio for high speeds on level roads. When in operation, the overdrive reduces the engine-to-rear-axle gear ratio by approximately 30 percent. A freewheeling device is usually incorporated in the overdrive which also helps to save gasoline. The overdrive is usually a separate unit bolted to the rear of the transmission case. In some transmissions an overdrive is obtained by the gear ratios provided in the transmission.

CHAPTER 16

PROPELLER SHAFTS, SLIP JOINTS, AND UNIVERSAL JOINTS

172. Propeller Shafts and Slip Joints

a. PROPELLER SHAFTS. The power, having been transmitted through an angle by means of a universal joint, is next carried along the power train by a device known as a propeller or drive, shaft (figs. 182 and 212). Propeller shaft is the most commonly used term; however, either may be used. In amphibian vehicles both terms are used: propeller shaft to indicate the device which transmits power to the propeller, and drive shaft to indicate that which transmits power to the wheels. Propeller shafts may be of the solid or tubular type. The torsional stress in a shaft varies from zero at the axis to a maximum at the outside. Since the center of the shaft resists only a small portion of the load, hollow shafts are used wherever practicable. A solid shaft is somewhat stronger than a hollow shaft of the same diameter, but a hollow shaft is much stronger than a solid shaft of the same weight.

b. PROPELLER SHAFT DRIVE IN AMPHIBIAN VEHICLES. On an amphibian truck, the drive for the water propeller is from a water propeller transfer case. This transfer case is connected to the transmission through a short propeller shaft. Transmission speeds used in water operation are transmitted through the water propeller transfer case, then to the water propeller by a drive line consisting of three drive shafts (fig. 212). Front and center drive shafts are of the tubular type, while the rear shaft is of solid construction. The drive shafts are connected by universal joints. A hand crank wheel, used as an auxiliary means for starting the engine, is welded onto the forward end of the front drive shaft tube. A bilge pump drive sprocket is mounted between the water propeller front and center drive shafts. The rear drive shaft is tapered at the end to accommodate the water propeller. Two ball bearing assemblies are used to support the water propeller drive shaft in addition to the babbitted bearing at the strut. A single row ball bearing, mounted in a support bracket, is installed on the forward end of the center drive shaft, and a thrust bearing is installed on the forward end of the rear drive shaft. The driving force of the vehicle is transmitted to the water propeller through the thrust bearing which is mounted in a spherical

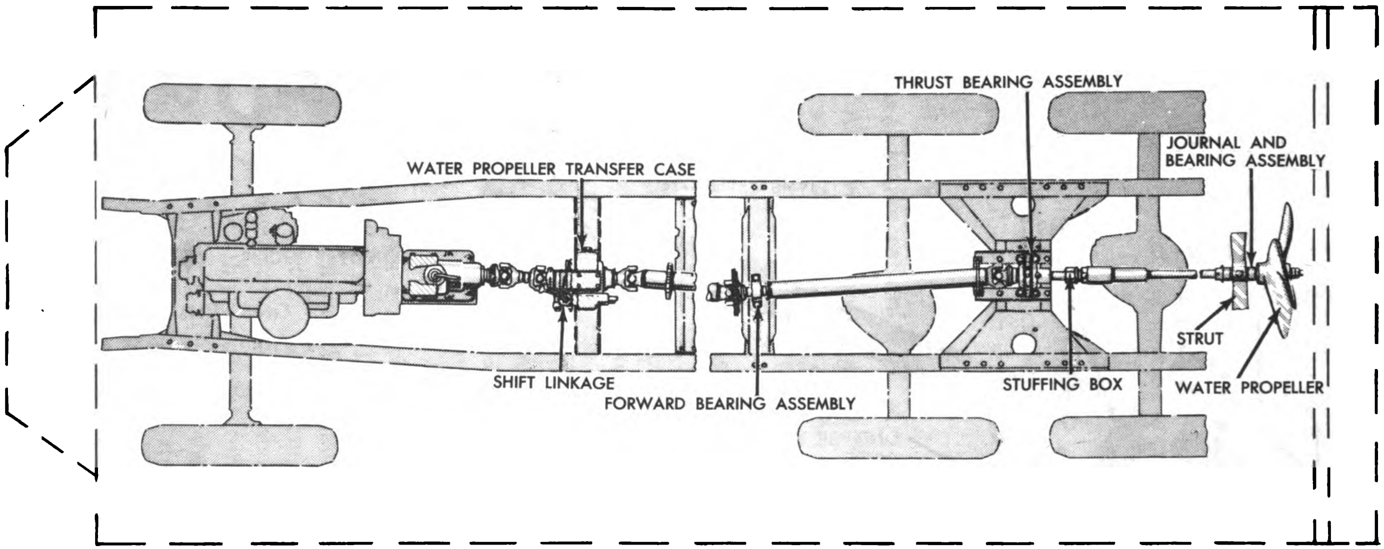


Figure 212a. Propeller Shaft Installations in Amphibian Vehicle.

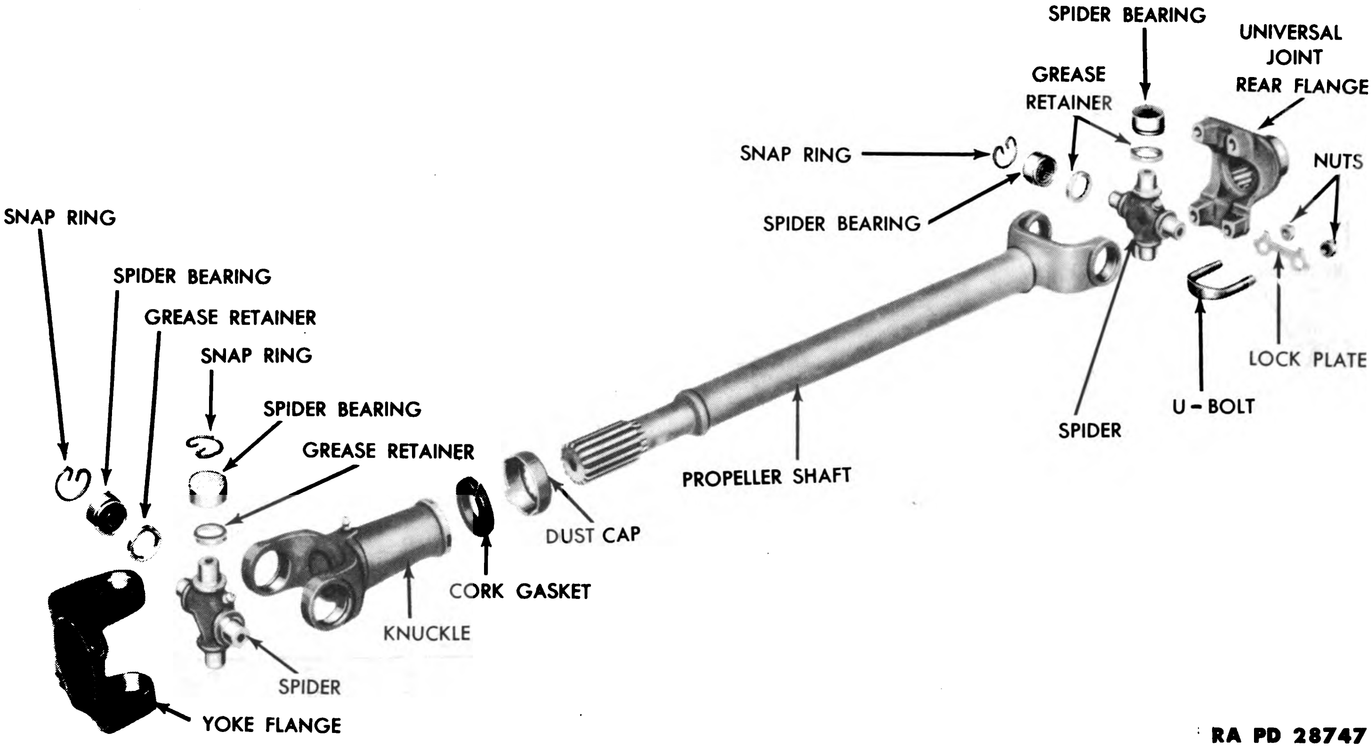


Figure 212b. Propeller Shaft and Universal Joints Disassembled.

shaped chamber in the thrust bearing housing. A stuffing box with a replaceable rawhide packing in an adjustable gland is used at the point where the drive shaft passes through the hull. The stuffing box is attached to the hull tunnel tube by a hose, clamped in position.

c. SLIP JOINTS. Because flexing of the springs causes the axle housing to move forward and backward, it necessarily means that some provision must be made to allow the propeller shaft to contract and expand. A device known as a slip joint provides the necessary telescopic action for the propeller shaft. A slip joint consists of a male and female spline, a grease seal, and a lubrication fitting. The male spline is welded to the propeller shaft and the female portion is fixed to the universal joint directly behind the transmission or transfer case (fig. 212). As the axle housing moves forward and backward, the slip joint gives freedom of movement in a horizontal direction and yet is capable of transmitting rotary motion.

173. Conventional Universal Joint

a. DEFINITION. A universal joint is a flexible coupling between two shafts that permits one shaft to drive another at an angle to it. It is flexible in the sense that it will permit power to be transmitted while the angle between the shafts is being continually varied. A simple universal joint illustrated in figure 213 is composed of three fundamental units—one cross pin and two yokes. The two yokes are set at right angles to each other, and their open ends are joined by the cross pin. This construction permits each yoke to pivot on the axis of the cross pin and also permits the transmission of the rotary motion from one yoke to the other. As a result the universal joint can transmit the power to the engine through the shaft to the rear axle even though the engine is rigidly mounted in the frame at a higher level than the rear axle which is constantly moving up and down in relation to the frame.

b. CHARACTERISTICS OF OPERATION. A peculiarity of the conventional universal joint is that it causes a driven shaft to rotate at a variable speed in respect to the driving shaft. It has been found that there is a cyclic variation in the form of an acceleration and a deceleration of the speed twice during each revolution. The extent of such fluctuation depends on the amount of angularity, roughly about seven percent for an angularity of 15°, and about thirty percent for an angle of 30°. This fact is shown graphically in figure 214 where the variations of the angular velocity during one revolution of a shaft driven through a conventional universal joint are plotted. The driving shaft is running at a constant velocity of 1000 r. p. m., and the angle between the shaft is 30°. Sketches of the universal joint positions at the minimum and maximum velocity fluctuation points are placed above the corresponding portions of the curve to enable the reader to correlate the curve with the action of the yoke and cross the universal joint.

(1) In a quarter of a revolution, the speed of the driven shaft varies from a minimum of 866 r. p. m. to a maximum of 1155 r. p. m. The speed of the driven shaft equals that of the driving shaft at four points during the revolution; that is, 45°, 135°, 225°, and 315°, where the curve intersects the constant velocity (dotted) line. The extent of each fluctuation depends on the size of the angle between the shafts; the greater the angle the greater the variation in the speed of the two shafts.

(2) This variation of velocity cannot be eliminated with a simple universal joint, but its effect can be minimized by using two universal joints (one at each end of the shaft). If only one joint is used between the transmission and the rear axle, the acceleration and deceleration caused by the joint is resisted on one end by the engine and on the other end by the inertia of the vehicle. The combined action of these two forces produces great stress on all parts of the power train and in addition results in a nonuniform force being applied to the wheels. When two universal joints are employed the second joint is used to compensate for the speed fluctuations caused by the first. In order to accomplish this

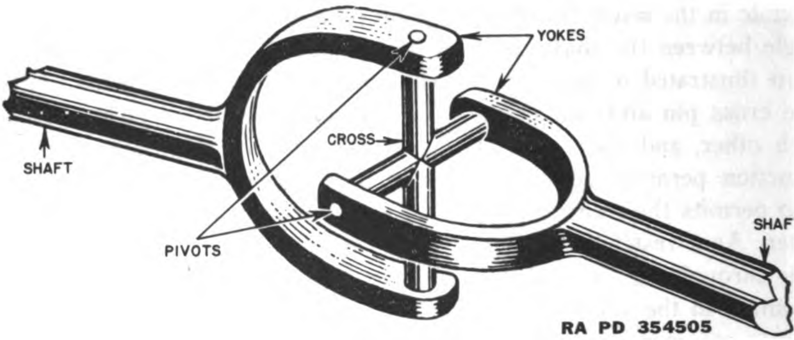


Figure 213. Simple Universal Joint.

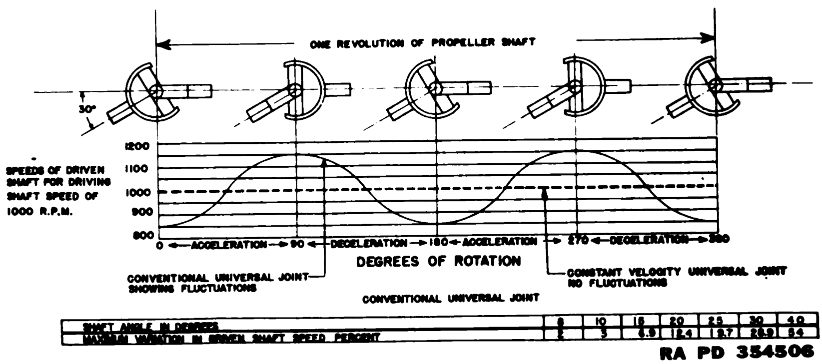


Figure 214. Speed Fluctuations Caused by Conventional Joints.

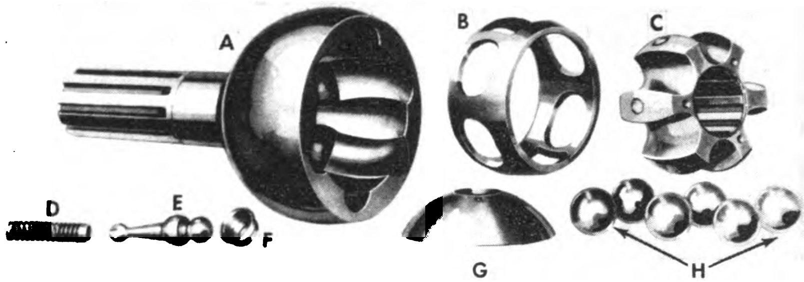
the angle between the transmission shaft and the drive shaft must be the same as the angle between the drive shaft and the final drive of the rear axle. Another requirement is that the two yokes of the universal joint which are attached to the drive shaft are in the same plane. If the yokes of the joints attached to the drive shaft are in the same plane, the driving yoke of the first joint will be at an agle of 90° with the driving yoke of the second. With this arrangement the first joint is producing its maximum fluctuation at the same time the second joint is producing its minimum fluctuation. This results in a non-varying wheel speed for a given engine speed even though the speed of the shaft between the joints is constantly changing.

174. Constant Velocity Universal Joints

a. GENERAL. (1) The speed fluctuations caused by the conventional universal joints just described do not cause much difficulty in automotive drive shafts where they have to drive through only small angles. In front wheel drives where the wheels are cramped up to 30° in steering, velocity fluctuations present a serious problem. Conventional universal joints would cause hard steering, slippage, and tire wear each time the vehicle turned the corner. Constant velocity (C.V.) universal joints, which eliminate the pulsations, are used exclusively today to connect the front axle shaft to the driving wheels.

(2) The conventional universal joint produces velocity fluctuations because the cross pin which connects the two yokes allows no free movement other than a pivoting action. Velocity fluctuations occur because the cross tilts back and forth (wobbles) as the joint rotates. This tilting movement is translated into rotary movement with the result that when the cross tilts toward the output shaft it adds to the speed of the output; and when the cross tilts away from the output shaft it subtracts from the speed, and the output shaft rotates slower than the input shaft. The only time that the speeds of the two shafts are equal is when the cross lies in the plane which bisects the angle between the two shafts. As previously stated this occurs at only four times during each revolution.

(3) From this it can be seen that a universal joint that will transmit constant velocity must be designed so as to permit the point of driving contact between the two halves of the coupling to remain in a plane which bisects the angle between the two shafts. If this is accomplished some arrangements must be made for the points of the driving contact to move laterally as the joint rotates. If this fact is kept in mind it will be easier to understand the principles of C.V. joints which are in universal use today. Four types used in Army vehicles are: Rzeppa, Bendix-Weiss, Tracta and Panhard. These types will be discussed separately to show that, in all, a plane passed through the points of the driving engagement will at all times bisect the angle between the driving and the driven shaft.



A UNIVERSAL JOINT BELL
B BALL CAGE
C INNER RACE
D PLUNGER AND SPRINGS
E PILOT PIN
F PILOT PIN SEAT
G PILOT
H BALLS

Figure 215. Rzeppa Constant Velocity Universal Joint Disassembled.

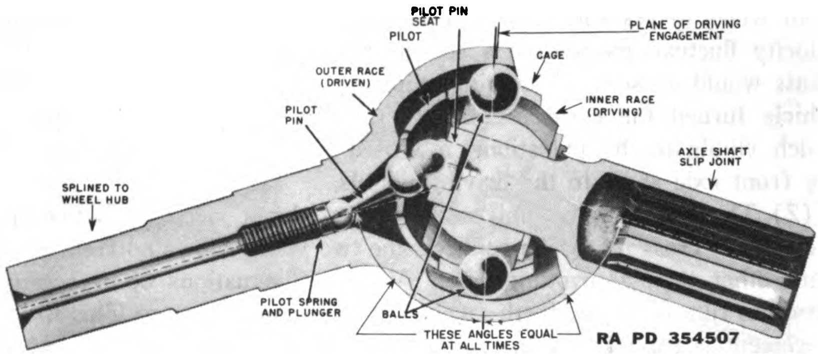


Figure 216. Rzeppa Constant Velocity Universal Joint Cross Section.

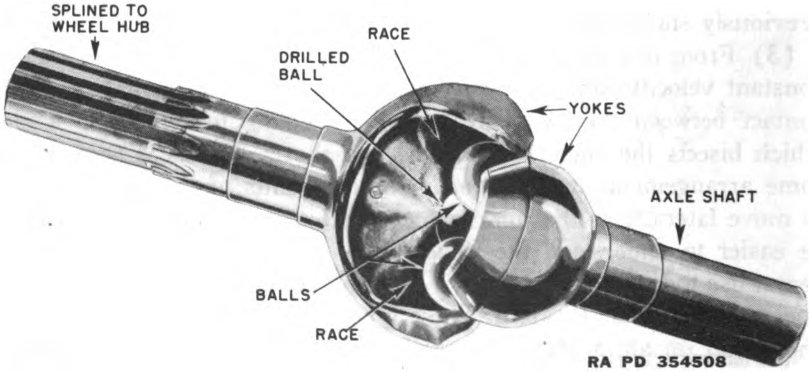


Figure 217a. Bendix-Weiss Constant Velocity Universal Joint Assembled.

b. RZEPPA UNIVERSAL JOINT. (1) The Rzeppa joint is a ball-bearing type in which the balls furnish the only points of driving contact between the two halves of the coupling. The details of the component parts, adapted for use in a front driving axle, are shown in figure 215. The inner race (driving member) is splined to the inner axle shaft; the outer race (driven member) is a spherical housing which is an integral part of the outer shaft; the ball cage is fitted between the two races. The close spherical fit between the three main members supports the inner shaft whenever it is required to slide in the inner race thus relieving the balls of any duty other than the transmission of power.

(2) Operation of this joint is readily understood because the movement of the six balls is controlled by the cage. The cage positions the balls in a plane at right angles to the two shafts when the shafts are in the same line. A pilot pin located in the outer shaft moves the pilot and the cage by a simple leverage in such a manner that the angular movement of the cage and the balls is one-half the angular movement of the driven shaft. When the driven shaft is moved 20°, the cage and the balls move 10°. As a result, the balls of the C.V. universal joint are positioned from the top view, to bisect the angle formed as indicated in figure 216.

c. BENDIX-WEISS UNIVERSAL JOINT. (1) The Bendix-Weiss joint also uses balls which furnish points of driving contact, but its construction differs from that of the Rzeppa in that the balls are a tight fit between the two halves of the coupling and no cage is used (fig. 217). The center ball rotates on a pin inserted in the outer race thus serving as a locking medium for the four other balls. The driving contact remains on the plane which bisects the angle between the two shafts, but it is the rolling friction between the four balls and the universal joint housing that positions the balls.

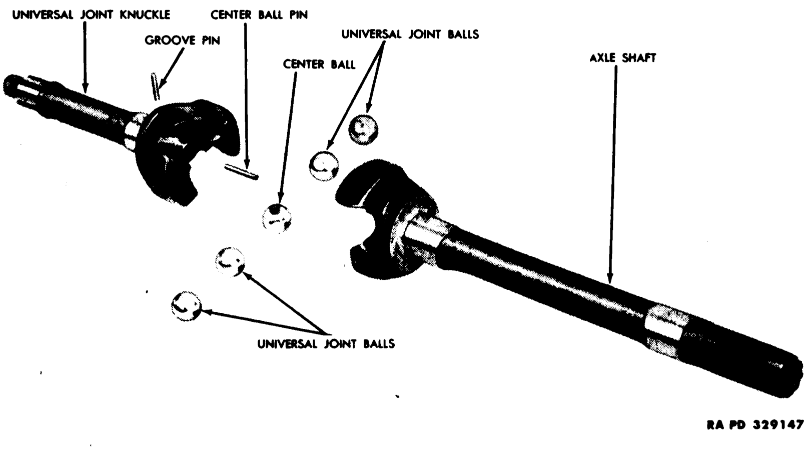


Figure 217b. Bendix-Weiss Constant Velocity Universal Joint Disassembled.

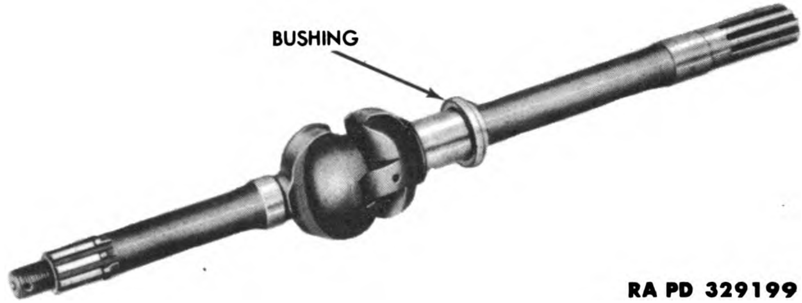


Figure 217c. Tracta Constant Velocity Universal Joint Assembled.

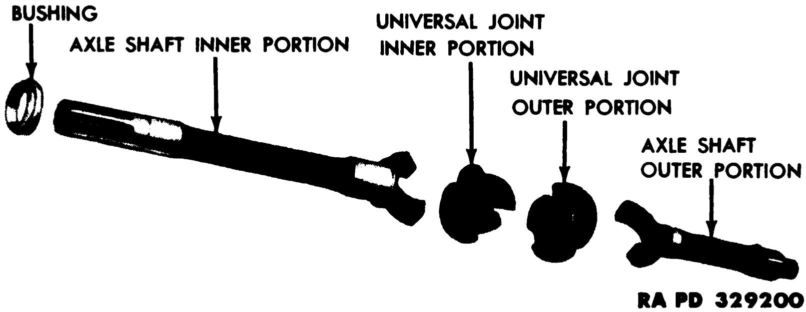


Figure 217d. Tracta Constant Velocity Universal Joint Disassembled.

(2) The manner in which this is accomplished can best be illustrated by placing a ruler across a round pencil on a table; if the ruler is moved to cause the pencil to roll without slipping, the pencil travel is exactly half that of the ruler. In this example there are three objects: the table top, the pencil, and the ruler—two of which are movable members and the third stationary. In a like manner the inner race can be considered as the stationary table top, the ball as the pencil, and the driven race as the ruler. The same relative motion between the pencil and the ruler occurs between the outer (driven) race and the balls in the C.V. joint because the balls fit tight enough in the coupling to prevent slippage. The only difference is that motion of the pencil was limited to rolling in a direction perpendicular to the long axis of the pencil whereas the ball may move in any direction. When both shafts of the C.V. joint are in line—that is at an angle of 180°—the balls lie in a plane which is at 90° to the shafts. If it is assumed that the driving shaft remains in the original position, any movement of the driven shaft out of this line will cause the balls to move one-half the angular distance. Therefore, if the driven shaft moves through an angle of 20°, the angle between the shafts will be reduced to 160°; the balls will move 10° in the same direction and the angle between the driving shaft and the plane in which

the balls lie will be reduced to 80° thereby fulfilling the requirement that the balls must lie in the plane which bisects the angle of drive.

d. TRACTA UNIVERSAL JOINT. (1) The Tracta universal joint (fig. 217) is the simplest to install and service. It is, in effect, one universal joint within another with points of driving contact of the outer portions of the joint. This universal joint consists of four main parts: a forked driving shaft, a forked driven shaft, a female (or slotted) joint and a male (or spigot) joint.

(2) The complete inner joint consisting of the female joint and the male joint floats between the forks; movement between the individual halves of the inner joint is permitted in a direction perpendicular to that permitted by the slotted forks by the action of the spigot moving in the slot. With this arrangement the joints of driving contact are allowed to move as the universal joint rotates, thereby remaining in a plane which bisects the angle between the two shafts. The fork end subtend an angle greater than 180° so as to be self locking once assembled to the inner parts of the joint. A flat is milled on the cylindrical section of the joint to permit the joint to be inserted in place.

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CHAPTER 17

DIFFERENTIALS, FINAL DRIVES, AND DRIVING AXLES

Section I.

175. General

The purpose of differentials, as explained briefly in Chapter 13, is to provide for differences in speed of rotation of wheels as a vehicle rounds a corner or travels over uneven ground, or to enable the operator of a tracked vehicle to turn the vehicle by changing the relative speed of the tracks. Details of the mechanisms are explained below.

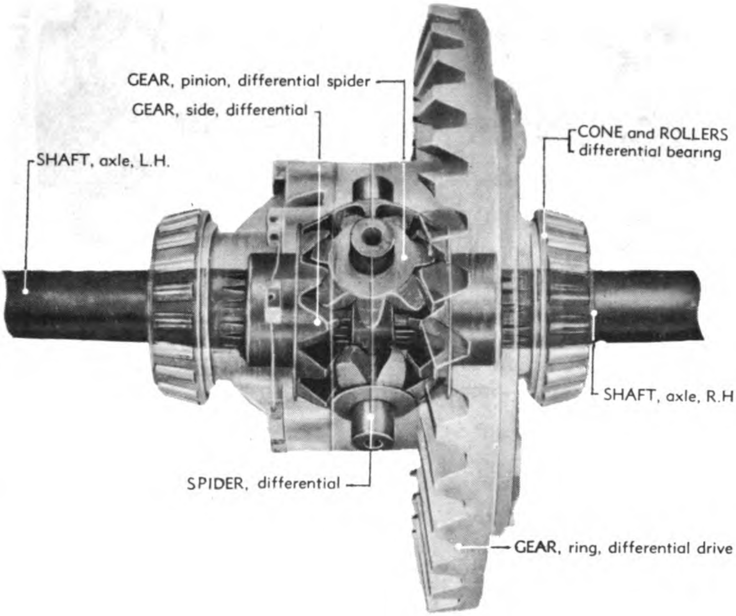
176. Conventional Differential

Operation (fig. 218). The bevel drive pinion rotates the bevel drive gear, and the differential case to which the final drive gear is riveted. The axle shafts are splined to the differential side gears. Were it not for the differential pinions, each wheel, with its respective axle shaft and side gear, could rotate freely with respect to the differential case and bevel drive gear.

a. STRAIGHT-AHEAD. When both wheels are rotating at the same speed as they do on a smooth, straight road, the differential pinions do not rotate about their own axis but serve only to lock all the parts, making them rotate as a unit when the bevel drive gear is turned by the bevel drive pinion.

b. TURNS. When the wheels rotate at different speeds as they do when making a turn, the slowing down of the inner wheel decreases the rotation of its axleshaft and differential side gear with respect to the bevel drive gear and the differential case. The case then forces the differential pinions to rotate along the inner differential side gear, advancing the opposite side gear an equivalent amount with respect to the differential case. The outer wheel thus turns at a higher speed than the inner wheel. If the bevel drive gear makes four revolutions while the inner wheel is making one, the outer wheel will rotate seven times.

c. LOSS OF TRACTION. A fault in the usual differential is that if one driving wheel loses traction and spins, the other wheel which has more traction remains stationary and does not drive the vehicle. In order to overcome this, several devices have been employed from time to time.



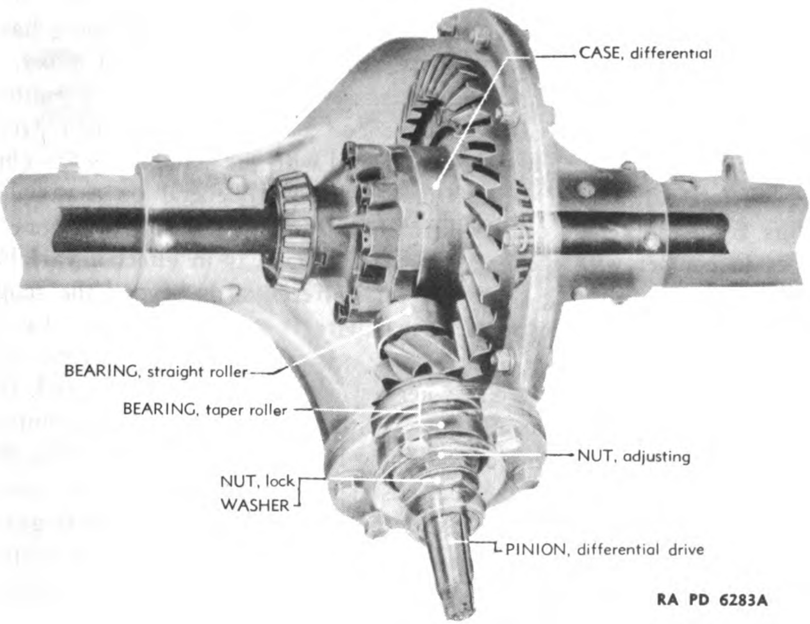


Figure 218. Conventional Differential.

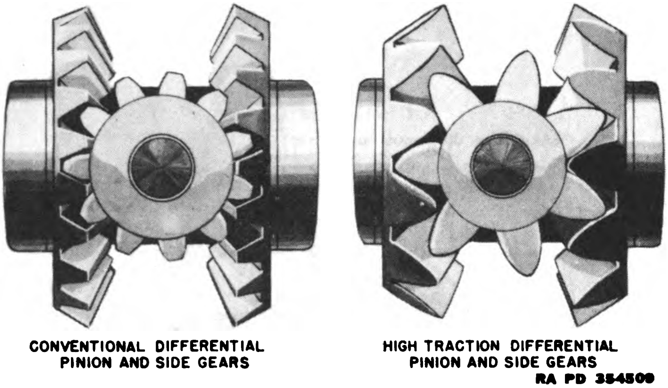
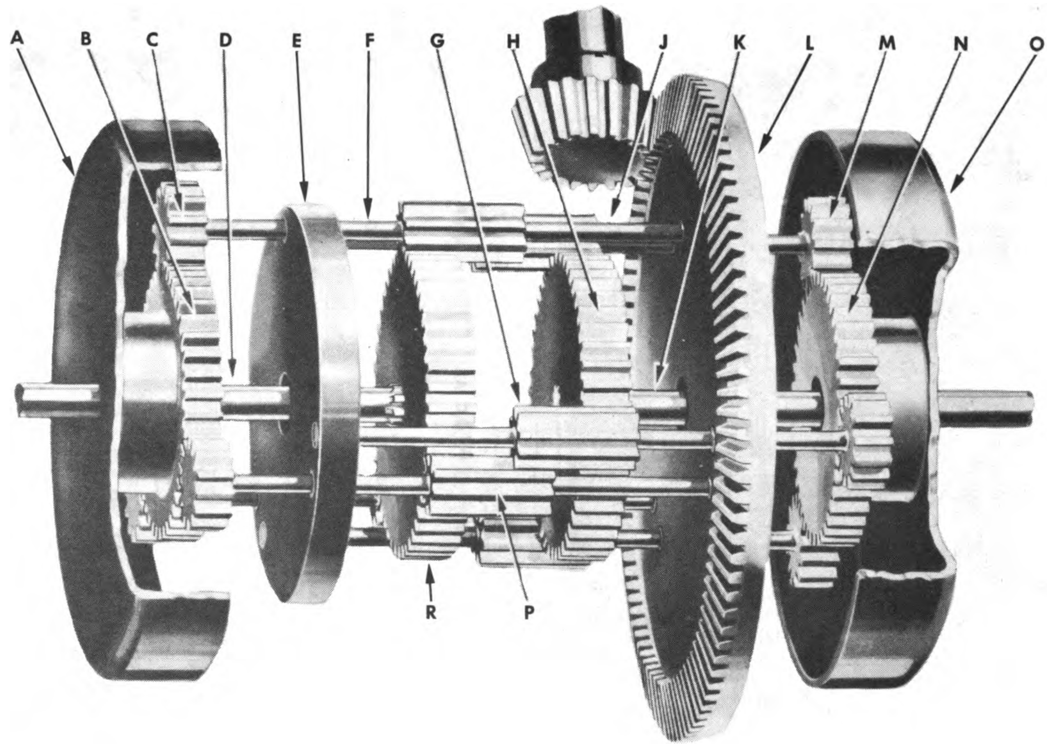


Figure 219. High Traction Differential Gears Compared with Standard Differential Gears.

One of these is the manually controlled differential lock. This is simply a dog clutch, controlled by a hand lever, which clutches one axle shaft fast to the differential case and bevel drive gear. This forms a rigid connection between the two axle shafts and makes both wheels rotate at the same speed as the bevel drive gear while the differential lock is engaged. This device is used very little, probably because a driver often forgets to disengage the differential lock before the differential action is again required. Automatic devices for doing almost the same thing have been designed. One of these, which is rather extensively used today, is the high traction differential. It consists of a set of differential pinions and side gears which have fewer teeth and a different tooth form from the conventional gears. These are compared with the standard gears (fig. 219). These differential pinions and side gears depend on a variable radius from the center of the differential pinion to the point where it comes in contact with the side gear teeth which is in effect a variable lever arm. The operating theory of this differential is beyond the scope of this manual. However, as long as there is relative motion between the pinions and side gears, the torque is unevenly divided between the two driving shafts and wheels; whereas, with the usual differential, the torque is evenly divided at all times. With the high traction differential, the torque becomes greater on one wheel and less on the other as the pinions move around until both wheels start to rotate at the same speed. When this occurs, the relative motion between the pinion and side gears stops and the torque on each wheel is again equal. This device assists considerably in starting the vehicle or keeping it rolling in cases where one wheel encounters a slippery spot and loses traction while the other wheel is on a firm spot and has traction. It will not work, however, when one wheel loses traction completely. In this respect it is inferior to the differential lock.



A—RIM, STEERING BRAKE
B—GEAR, STEERING BRAKE RIM FLANGE
C—PINION, DIFFERENTIAL EXTERNAL, R. H.
D—SHAFT, FINAL DRIVE
E—COVER, COMPENSATING GEAR CASE
F—SHAFT, PINION
G—PINION, INTERNAL, L. H.
H—GEAR, COMPENSATING, L. H.
J—SHAFT, PINION
K—SHAFT, FINAL DRIVE
L—GEAR, SPIRAL DRIVE
M—PINION, DIFFERENTIAL EXTERNAL, L. H.
N—GEAR, STEERING BRAKE RIM FLANGE
O—RIM, STEERING BRAKE
P—PINION, INTERNAL, R. H.
R—GEAR, COMPENSATING, R. H.

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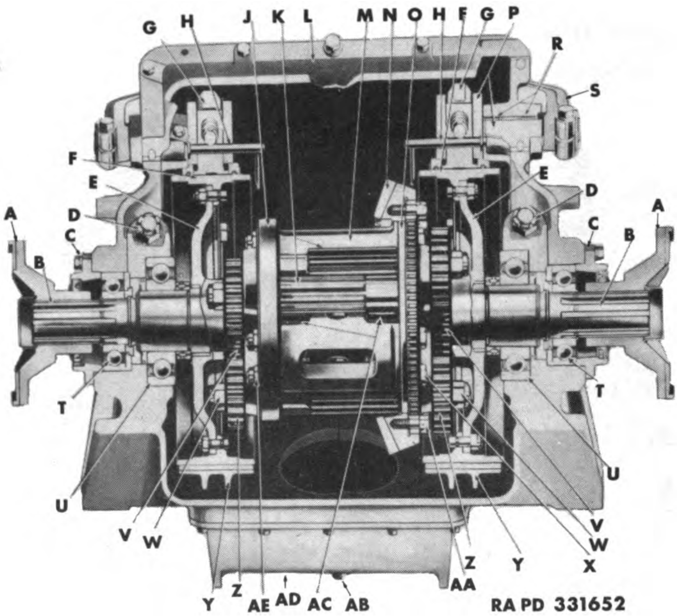
Figure 220. Controlled Differential Schematic.

177. Controlled Differential

a. Construction (Figs. 183 and 220). The controlled differential is in reality two different assemblies having left and right units joined by the differential carrier. Each side consists of a brake drum, a sun gear, three external pinions, three internal pinions, and one compensating gear.

b. Operation. When the vehicle is moving straight ahead the entire differential assembly turns as a unit and transmits equal power and speed to each track (fig. 221). When the left brake band is applied to the drum, the left compensating gear is retarded and rotates slower than



A—OUTPUT SHAFT YOKE
B—OUTPUT SHAFT
C—OUTPUT SHAFT BEARING RETAINER
D—DIFFERENTIAL BEARING CAP NUT
E—FLANGE AND GEAR ASSEMBLY
F—STEERING BRAKE RIM
G—BRAKE ADJUSTING NUT
H—SIDE COVER BUSHING LUBRICATING TUBE
J—DIFFERENTIAL SIDE COVER
K—DIFFERENTIAL INTERNAL PINION
L—DIFFERENTIAL CASE COVER
M—COMPENSATING GEAR CASE
N—SPIRAL DRIVE GEAR
O—DIFFERENTIAL SIDE COVER
P—STEERING BRAKE SHAFT
R—STEERING BRAKE SHAFT NEEDLE BEARINGS
S—STEERING BRAKE LEVER
T—OUTPUT SHAFT BEARING
U—DIFFERENTIAL SIDE BEARING
V—BRAKE RIM GEAR
W—EXTERNAL PINION NUT
X—DIFFERENTIAL SIDE COVER BOLT
Y—BRAKE SHOE ASSEMBLY
Z—EXTERNAL PINION
AA—SPIRAL DRIVE GEAR ATTACHING SCREW
AB—DRAIN PLUG
AC—COMPENSATING GEAR
AD—OIL PAN
AE—DIFFERENTIAL SIDE COVER NUT

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Figure 221a. Controlled Differential Cross Section.

the differential carrier while at the same time the right compensating gear is speeded up and rotates faster than the differential carrier. As each compensating shaft is splined to each compensating gear, the final analysis will result in the left track revolving slower than the right track, causing the vehicle to turn to the left. Exactly the reverse procedure takes place if the right brake is applied.

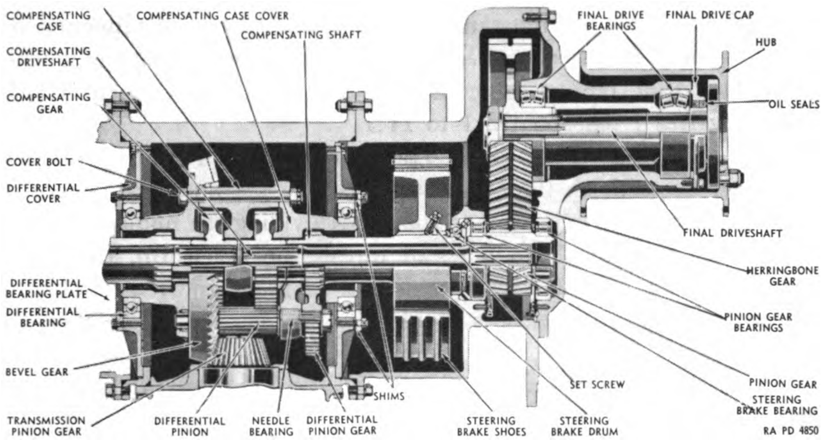

Figure 221b. Controlled Differential and Final Drive Cross Section.

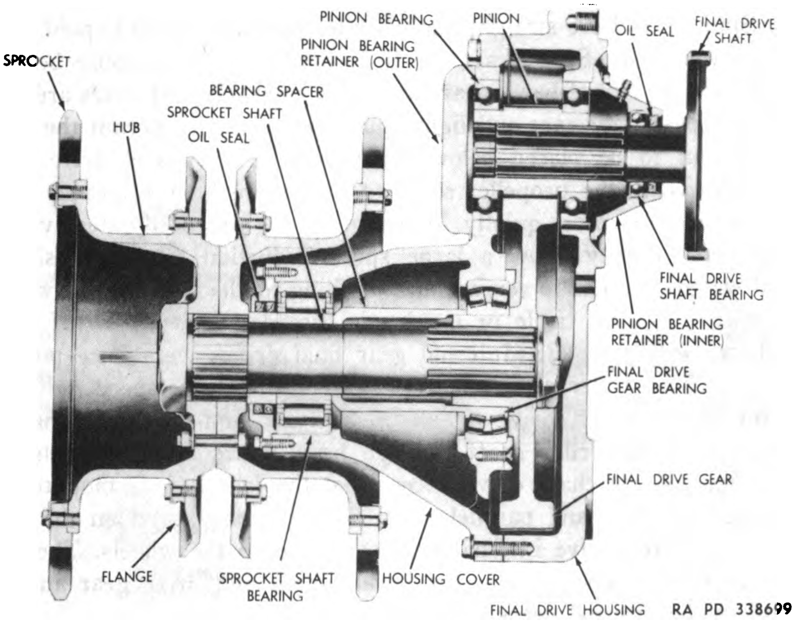

Figure 221c. Final Drive Cross Section.

Section II. FINAL DRIVES AND DRIVING AXLES

178. Final Drives (Wheeled Vehicles).

a. A final drive is that part of a power transmission system between the propeller shaft and the differential. Its function is to change the direction of the power transmitted by the propeller shaft through 90° to the driving axles. At the same time it provides a fixed reduction between the speed of the propeller shaft and the axle driving the wheels. In passenger cars, this speed reduction varies from about 3:1 to 5:1. In trucks, it varies from about 5:1 to 11:1.

b. The gear ratio of the bevel gear final drive is found by dividing the number of teeth on the bevel drive gear by the number of teeth on the pinion. For a worm gear, it is found by dividing the number of teeth on the worm gear by the number of threads on the worm. In case of chain drives, the sprockets are considered as gears and the number of teeth on the driven sprocket is divided by the number of teeth on the driving sprocket.

179. Gear Drives.

All the final drives in general use are geared types. The commonest type consists of a pair of bevel gears, that is, a drive pinion connected to the propeller shaft and a bevel drive gear attached to the differential case on the driving axle. These bevel gears may be spur, spiral, or hypoid. Spur gears have straight teeth, while spiral-bevel and hypoid gears have curved teeth. Spur gears are little used for this purpose because they are noisy. Spiral-bevel gears are most used. Hypoid gears are used in several passenger cars and light trucks because they permit the bevel drive pinion to be placed below the center of the bevel drive gear, thereby lowering the propeller shaft to give more body clearance. This gear also operates more quietly. Worm gears are also used extensively in trucks because they allow a large speed reduction. These consist of helical worms, similar to screws, and meshing toothed gears. The worms have single, double, triple or quadruple threads. These types of gears are shown in figure 222. Internal gear final drives were once popular and are still used in rare instances. They permit a large speed reduction like the double chain drive to which they are similar. A jackshaft is driven by the propeller shaft through bevel gears and differential as it is in the double chain drive except that the jackshaft is mounted on the dead rear axle and parallel to it. Spur pinions keyed on the ends of the jackshaft, drive internal gears attached to the wheels. The first gear reduction takes place in the bevel pinion and drive gear and the second in the internal gears.

180. Live Axles

a. A live axle is one that supports part of the weight of a vehicle and also drives the wheels connected to it. The term is applied to the entire assembly which consists of a housing containing a bevel drive pinion, bevel drive gear, differential and axle shafts together with their bearings, and sometimes additional mechanisms. The term "live axle" is opposed to the term "dead axle." A dead axle is one that carries part of the weight of a vehicle but does not drive the wheels. The wheels rotate on the ends of the dead axle. The usual front axle of a passenger

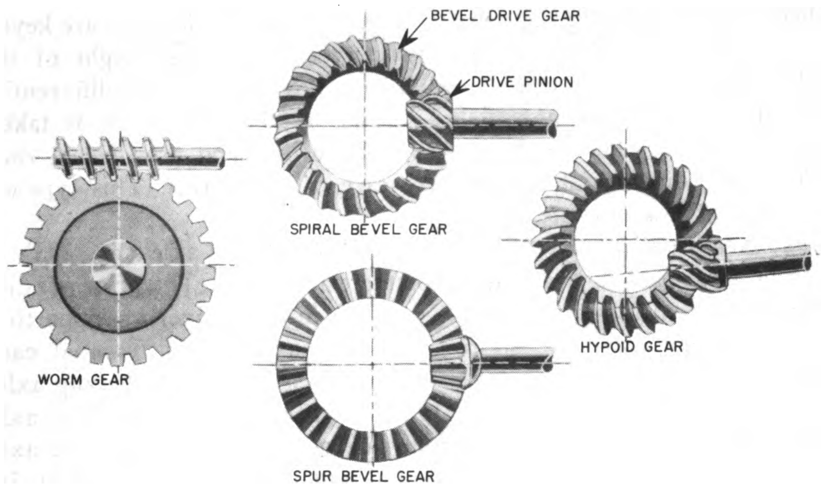

Figure 222. Final Drive Gears.

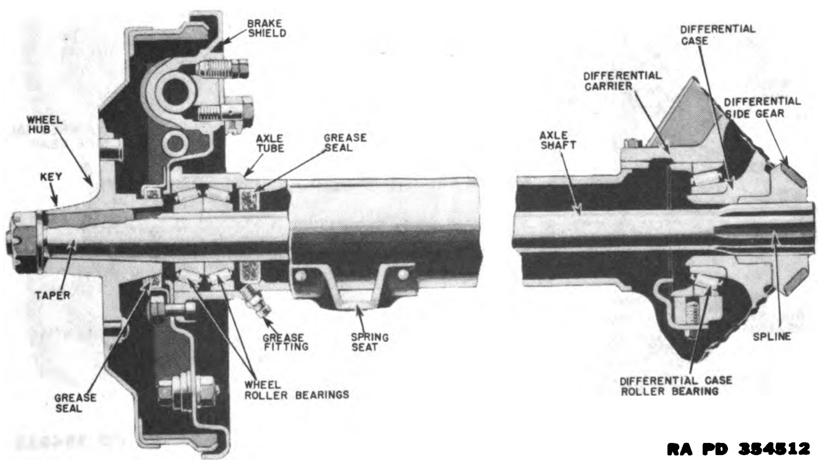

Figure 223. Semifloating Rear Axle.

car is a dead axle and the rear axle is a live axle. In four-wheel drive vehicles, both front and rear axles are live axles, and in six-wheel drive vehicles, all three axles are live axles.

b. There are four types of live axles: plain, semifloating, three-quarter floating, and full-floating. These are distinguished by the way in which the axle shafts are connected and what stresses they must carry.

(1) *Plain live axles.* The plain, or nonfloating, rear axle was one of the first used. In this type, the axle shafts are supported in the housing by roller bearings at the center and outer ends. The rear wheels are keyed on tapers at the outer ends of the axle shafts and held by castle nuts and cotter pins. In addition to turning the wheels, the rotating axle shafts carry the entire weight of the rear of the vehicle on their outer ends. All stresses caused by turning corners, skidding or wobbling wheels are taken by the axle shafts. The differential side gears are keyed on the inner ends of the axle shafts which carry the weight of the differential case. The stresses created by the operation of the differential are taken by the axle shafts. Side thrust on the axle shafts is taken care of by the roller bearings, and ball bearings and provided at each side of the differential case to take care of end thrust. This type of rear axle is now obsolete.

(2) *Semifloating rear axle.* The semifloating rear axle (fig. 223) is used on most passenger and light commercial vehicles. The principal difference between it and the plain live axle is in the manner of supporting the differential assembly. In the plain live axle, the differential case is carried on the inner ends of the axle shafts. In the semifloating axle, it is carried by bearings mounted in the differential carrier. The axle shafts are splined to the differential side gears. This relieves the axle shafts of the weight of the differential and the stresses caused by its operation which are taken by the axle housing. The inner ends of the

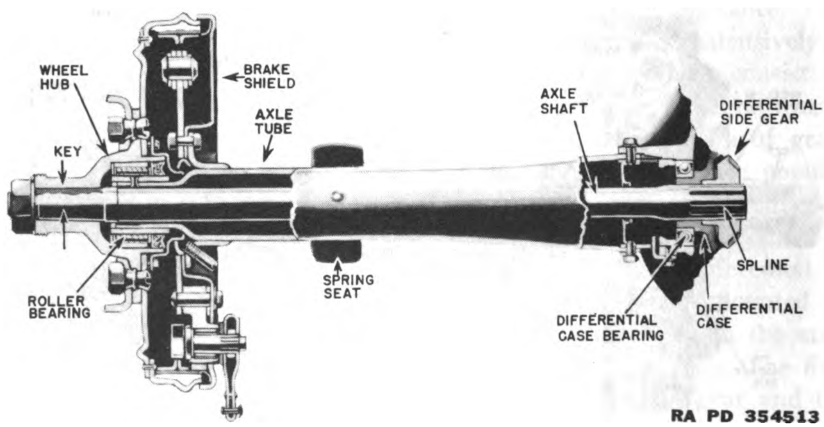

Figure 224. Three-Quarter Floating Rear Axle.

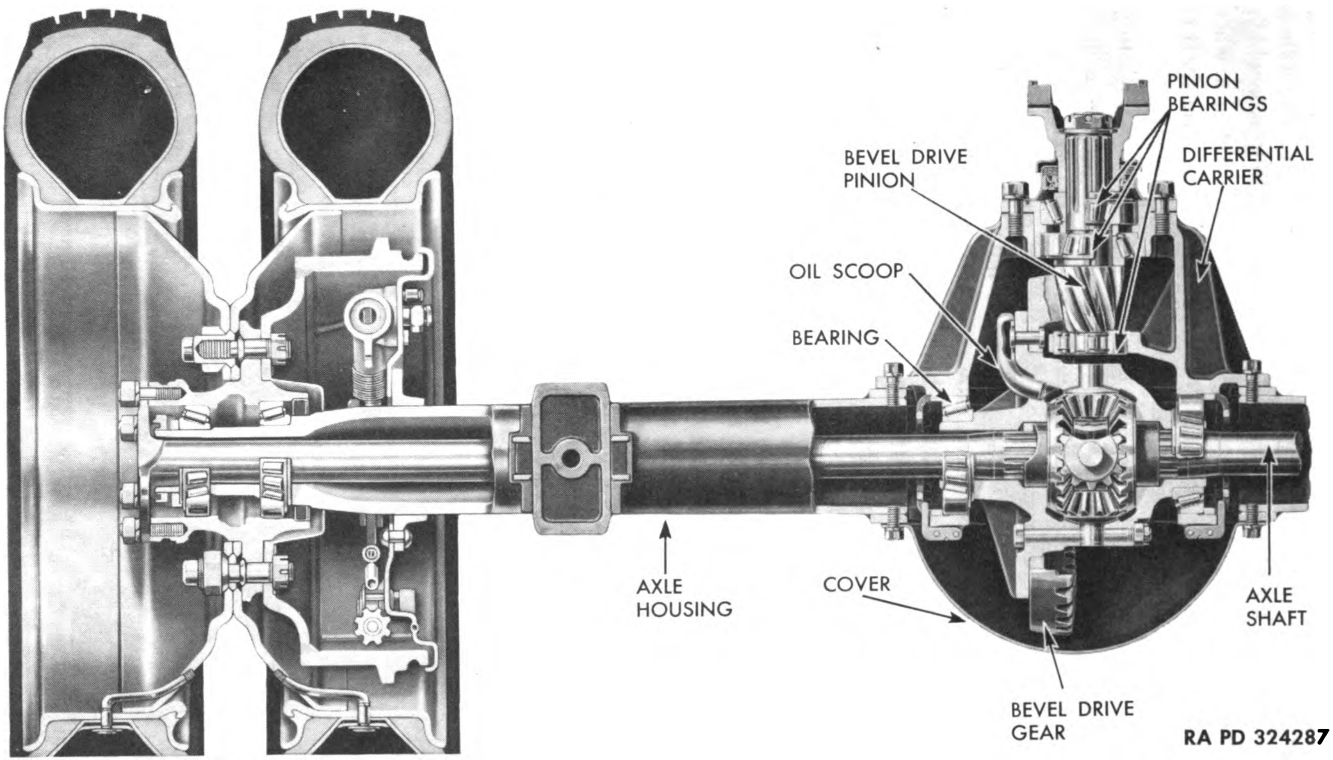

Figure 225. Full-floating Rear Axle.

axle shafts transmit only turning effort, or torque, and are not acted upon by any other force. They are said to be "floated." The wheels are keyed to the outer ends of the axle shafts and the outer bearings are between them and the housing as in the plain live axle. The axle shafts therefore take the stresses caused by turning, skidding, or wobbling of the wheels. In both the plain and semifloating live axles, a wheel can come off in case an axle shaft breaks or twists off. The axle shaft cannot be removed until the wheel is pulled off.

(3) *Three-quarter floating rear axle.* The three-quarter floating rear axle (fig. 224) is used on a few passenger cars. The inner ends of the axle shafts are sometimes secured with nuts and the axle shafts cannot be withdrawn without removing the differential cover. In other designs, the axle shaft can be withdrawn after the nuts holding the hub flange have been removed. The wheels, however, are supported by bearings on the outer ends of the axle tubes. The housing instead of the axle shafts carries the weight of the car. Since the wheel is rigidly keyed on a taper at the end of the axle shaft as in the semifloating axle, the stresses caused by turning, skidding, and wobbling of the wheel are still taken by the axle shaft.

(4) *Full-floating rear axle.* The full-floating rear axle (fig. 225) is used on most heavy trucks. It is the same as the three-quarter floating axle except that each wheel is carried on the end of the axle tube on two ball or roller bearings and the axle shafts are not rigidly connected to the wheels. Each wheel is driven through a dog clutch, or through a spline clutch, or through a flange on the end of the axle shaft that is bolted to the outside of the wheel hub. The latter construction is frequently used but is not truly full floating, since there is a rather rigid connection between the axle shaft and the wheel hub. With the true full-

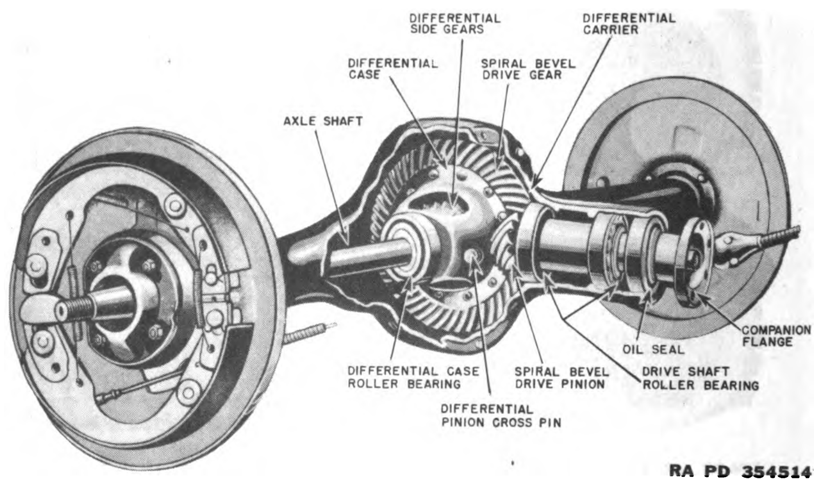

Figure 226. Semifloating Rear Axle with a Spiral Bevel Gear.

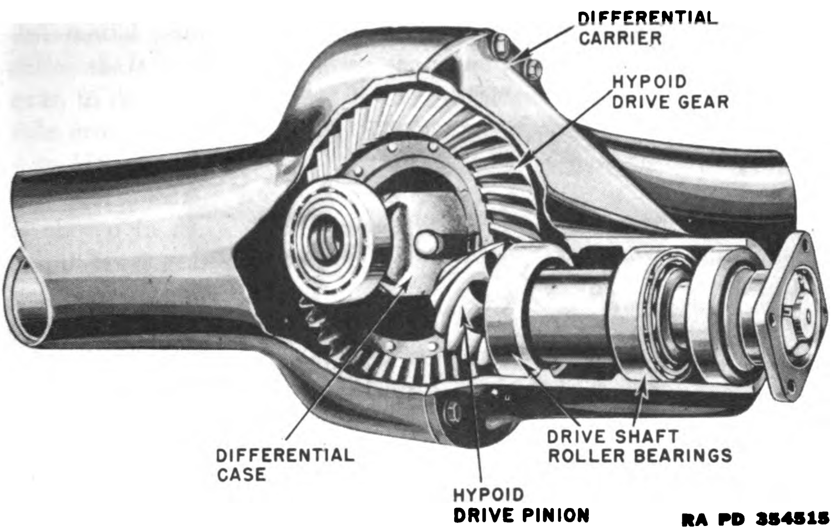

Figure 227. Hypoid Rear Axle.

floating axle, the axle shaft transmits only the turning effort, or torque. The stresses caused by turning, skidding, and wobbling of the wheels are taken entirely by the axle housing through the wheel bearings. The axle shafts can be removed and replaced without removing the wheel or disturbing the differential. All military all-wheel drive trucks have full floating axles.

181. Types of Rear Axle Assemblies

a. SEMIFLOATING. Figure 226 shows a semifloating rear axle of the type generally used in passenger cars. The final drive consists of a spiral bevel pinion and gear. Spur gears were formerly used for this purpose, but they have been generally replaced by spiral bevel gears because they run more quietly. The drive pinion which is connected to the propeller shaft by the companion flange (fig. 226) runs in two tapered roller bearings mounted in the differential carrier and is considered a part of the rear axle assembly. The drive pinion meshes with the spiral bevel drive gear which is riveted to the differential case. The differential case rotates in tapered roller bearings mounted in the differential carrier. The inner races of these bearings fit on machined extensions on each side of the case and the outer races are held in brackets cast integral with the differential carrier. The differential carrier is a casting which holds the final drive and differential. It is inserted in the forward opening of the rear axle housing and fastened with cap screws through a gasket to make the joint oiltight. The axle shafts are splined to the differential side gears. Machined hub extensions on these gears rotate in plain bearings in each side of the differential case. The rear axle has two

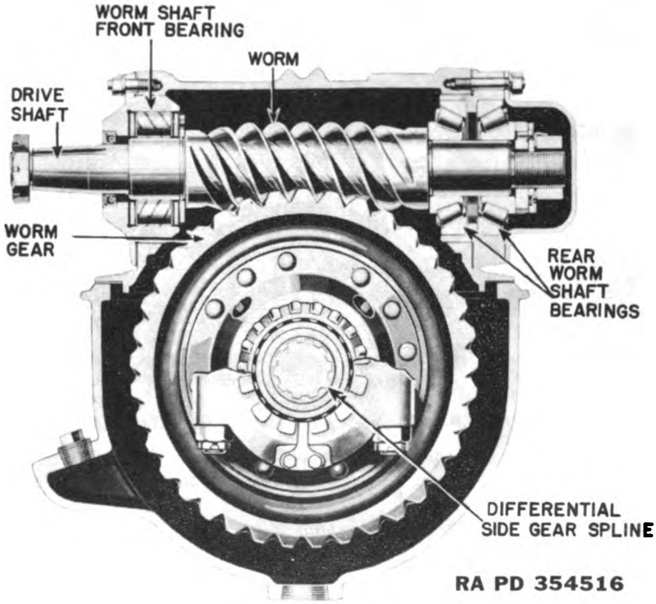

Figure 228. Worm Gear Rear Axle.

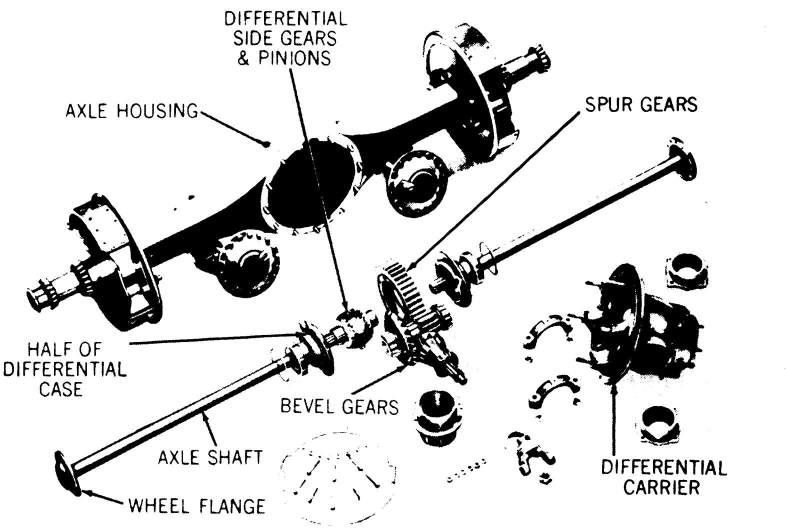

Figure 229a. Gear Arrangement in Double Reduction Rear Axle.

differential pinions. The path of power transmission is from the propeller shaft to the pinion drive shaft and pinion to the spiral bevel drive gear, to the differential case, to the differential pinions, to the differential side gears, to the axle shafts, to the wheels.

b. Hypoid. Hypoid gearing has come into rather extensive use in late years, mainly for passenger cars. A portion of a hypoid rear axle is shown in figure 227. This rear axle is practically the same as the spiral bevel gear rear axle except that the drive pinion and bevel drive gear are cut with a somewhat different tooth form which permits the drive pinion to mesh with the bevel drive gear below the center of the latter. This construction allows the propeller shaft to be lowered and sometimes makes a shaft tunnel in the floor of the rear compartment of the vehicle unnecessary. Due to their design, hypoid gears operate under extremely high tooth pressure and require a special hypoid lubricant.

c. Worm Gear. The worm gear rear axle (fig. 228) is used in some trucks mainly because it allows a large speed reduction. The threads on the worm are similar to screw threads and may be single, double, triple, or quadruple. The worm meshes with a gear having helical teeth cut in its outside circumference. The worm may be compared to a screw and the worm gear to a nut. As the worm rotates, it pulls the gear around. The worm is usually made of steel and the worm gear of bronze. The driving worm may be mounted either at the top of the worm gear or at the bottom. It is usually necessary to place the worm at the top in order to allow sufficient road clearance under the rear axle housing. The rear worm bearing must be very strong and rugged since it takes the entire thrust reaction from driving the worm gear. If play develops in the worm because of wear, this bearing must also withstand repeated impact. When the vehicle is operated in reverse, or when the road wheels are driving the mechanism, the front bearing resists these forces. Sometimes a worm of "hourglass" form is used in the worm gear and therefore provides more tooth bearing surface and consequently less stress in the teeth.

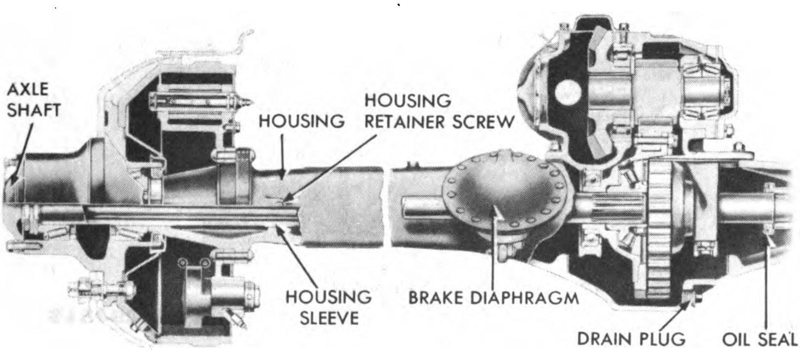

Figure 229b. Gear Arrangement in Double Reduction Rear Axle.

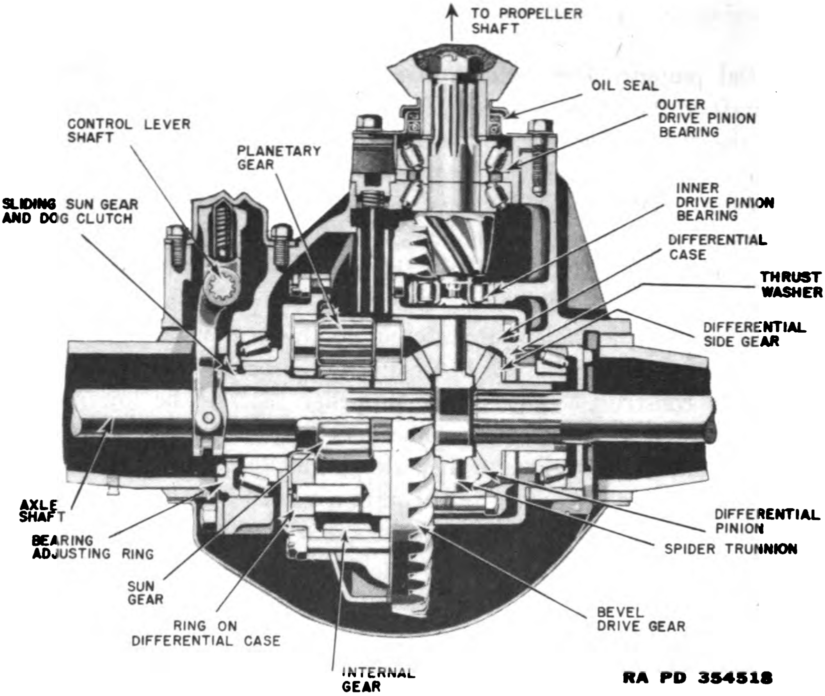

Figure 230. Dual Ratio Rear Axle.

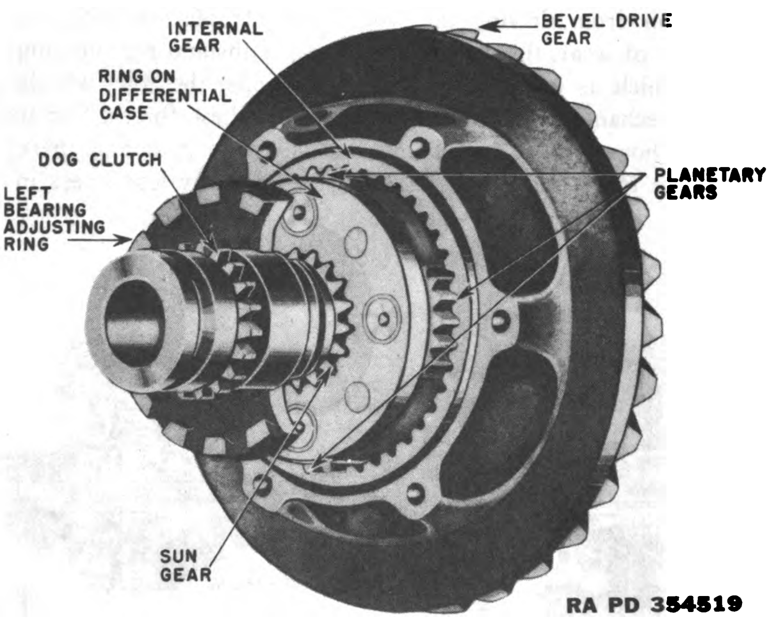

Figure 231. Position of Gears for High Ratio

d. Double Reduction. Double reduction rear axles are often used for heavy duty trucks. A usual design of the full-floating type is shown disassembled in figure 229. The first gear reduction is obtained through a spiral bevel pinion and gear as in the common single reduction rear axles. The bevel pinion runs in brackets on the differential carrier in two roller bearings. The bevel gear is mounted rigidly on a jackshaft with a spur pinion that runs on roller bearings at each end, which are also mounted in the differential carrier. The spur pinion drives a spur gear bolted to the differential case. These parts are shown in their proper relative positions in figure 229. The differential and axle shafts are the same as those already described.

e. Dual Ratio. Dual ratio, or two-speed, rear axles are sometimes used on trucks and passenger cars. They contain two different gear ratios which can be selected at will by the driver, usually by a manual control lever. A dual ratio rear axle serves the same purpose as the auxiliary transmission described in paragraph 169 and, like the latter, it doubles the number of gear ratios available for driving the vehicle under the various load and road conditions. This type of rear axle is shown in cross section in figure 230. It is driven by the conventional spiral bevel pinion and bevel drive gear, but a planetary gear train is placed between the bevel drive gear and differential case. The internal gear of the planetary train is rigidly bolted to the bevel drive gear. A ring on which the planetary gears are pivoted is bolted to the differential case. A member consisting of the sun gear and a dog clutch slides on one of the axle shafts

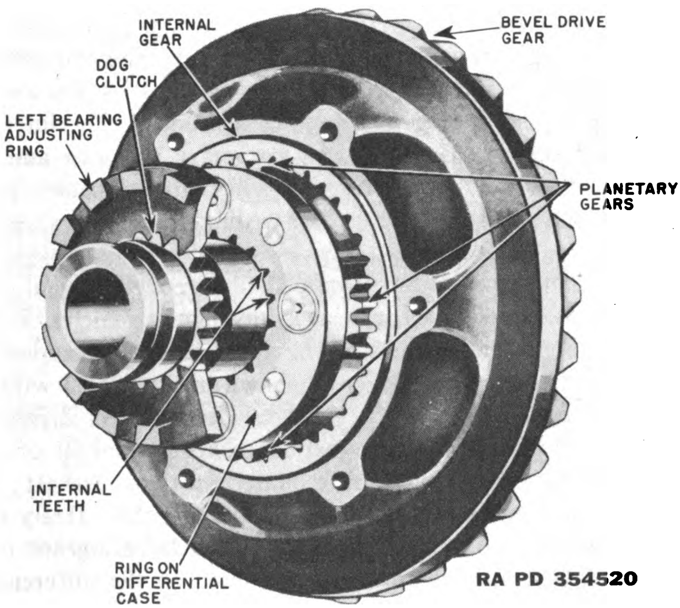

Figure 232. Position of Gears for Low Ratio (Planetary Gears are Free to Rotate).

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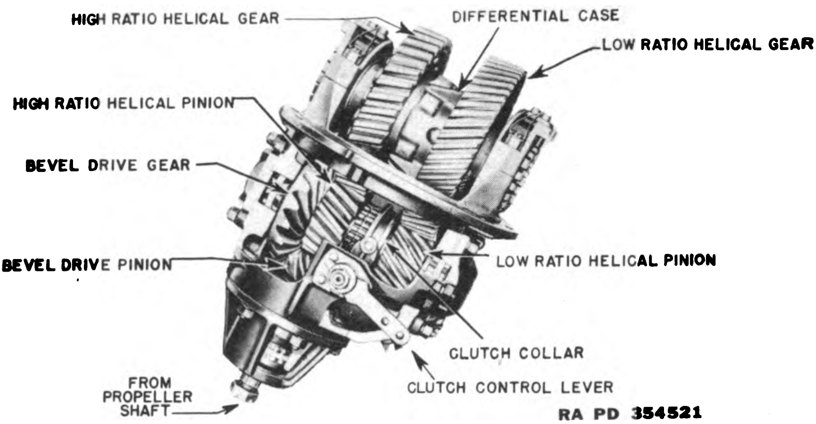

Figure 233. Double Reduction Dual Ratio Rear Axle.

and is usually controlled by a hand lever accessible to the driver. When this sliding part is in the high ratio position, the sun gear meshes with internal teeth on the ring carrying the planetary gears and disengages the dog clutch from the left bearing adjusting ring which is rigidly held in the differential carrier. In this position (fig. 231), the planetary gear train is locked together, there is no relative motion between the gears in the planetary train, and the differential case is driven directly by the bevel drive gear the same as in the conventional, single ratio rear axle. In the lower ratio position (fig. 232), the sun gear is slid cut of mesh with the ring carrying the planetary gears and the dog clutch makes a rigid connection with the left bearing adjusting ring. Since the sun gear is integral with the dog clutch, it is also locked fast to the bearing adjusting ring and remains stationary. The internal gear rotates the planetary gears around the stationary sun gear and the differential case is driven by the ring on which the planetary gears are pivoted. This action produces the gear reduction or low speed of the axle.

f. Double Reduction, Dual Ratio. Double reduction, dual ratio rear axles are also sometimes used in heavy duty motor vehicles. Rear axles of this type combine the features of the double reduction and dual ratio axles in one unit. A popular design is shown in figure 233 with part of the differential housing cut away. A spiral bevel pinion drives a jackshaft through a spiral bevel drive gear. Two helical pinions of different sizes and a two-way dog clutch are mounted on the jackshaft. The two helical pinions are not fast to the jackshaft but rotate freely on it on bearings. They are in constant mesh with two helical gears of correspondingly different sizes, both rigidly mounted on the differential case. The sliding dog clutch is controlled by a hand lever and clutches either one of the helical pinions fast to the jackshaft. The clutch is shown in the low-speed position in figure 233. The drive is from the propeller shaft to the drive pinion, to the bevel drive gear, to the jackshaft, to the right helical pinion, to the right helical gear, to the differential case, to the differential pinions, to the differential side gears, to the axle shafts, to the wheels. When the dog clutch is in the high-speed position (moved to the left) the drive is the same except that it is through the other pair of helical gears.

182. Four Rear-wheel Drives

a. Motor vehicles that carry extremely heavy loads are often equipped with four rear wheels in order to increase traction and to avoid excessive weight on the rear tires; that is, the weight of the load is divided among twice as many tires as when only one rear axle is used. Dual wheels are generally used with this arrangement; therefore, the weight of the rear of the vehicle and load is divided among eight tires instead of four.

b. Different spring suspensions are used but the bogie type is most general. A bogie consists of two axles jointed by a trunnion axle. The trunnion axle passes directly beneath the rear cross member of the frame.

c. Vehicles having this equipment may be either four- or six-wheel drive. Sometimes the dual rear axles are driven by independent propeller shafts from a transfer assembly as shown in figure 234. In this case the

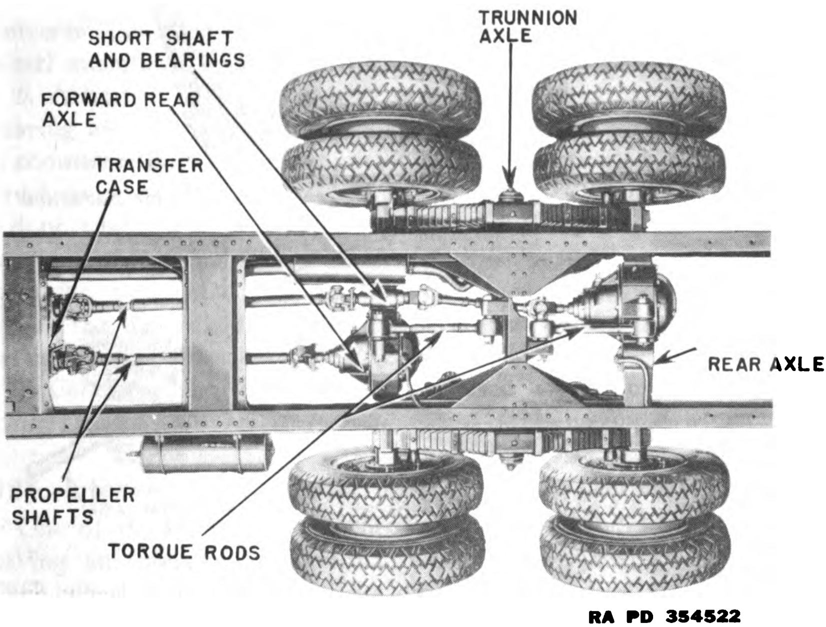

Figure 234. Bogie Four-wheel Drive with Independent Propeller Shafts.

propeller shaft to the rearmost rear axle is divided into three parts, the short middle part passing through bearings mounted on the forward rear axle. The transfer assembly may contain an interaxle differential but usually does not.

d. Another arrangement is the tandem drive (fig. 235) employing double reduction axles. A single propeller shaft from the transmission transfer assembly is connected to the forward rear axle drive pinion through a shaft and another short, interaxle propeller shaft connects

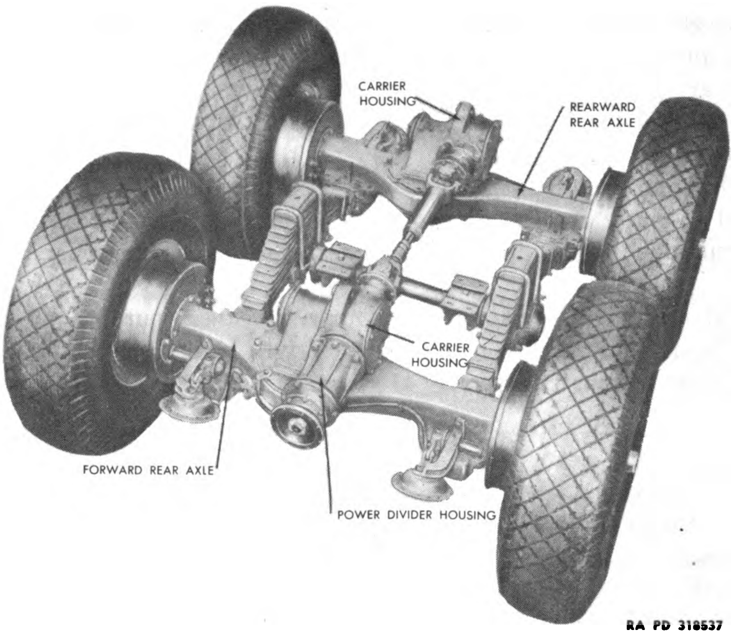

Figure 235a. Tamden Dual Rear Axle Arrangement with Double Reduction Final Drives and Power Divider.

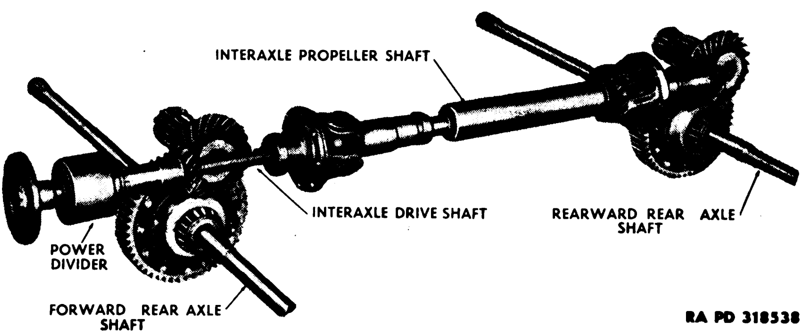

Figure 235b. Tandem Dual Rear Axle Arrangement with Double Reduction Final Drives and Power Divider.

the drive pinion shaft of the forward rear axle with the drive pinion shaft of the rearward rear axle. Ordinarily no interaxle differential is used, but one is sometimes used which is built into the forward rear axle. With the tandem drive, no transfer assembly is required if the vehicle drives on the four rear wheels only. If the front wheels are also driven, a transfer assembly is required.

183. Front-wheel Drives

a. In four- or six-wheel drives the front wheels are driven through a driving axle assembly very similar to a rear axle. It may be of the single or double reduction type. Figures 182 and 236 show a usual arrangement of transfer assembly, propeller shafts, universal joints, driving axles, and springs for a four-wheel drive or six-wheel drive vehicle. Front-wheel drives are ordinarily Hotchkiss drives with the front springs pivoted at the rear and shackled at the front. Axles are of the full-floating type. As in the case of rear live axles, the axle housings are usually built up but they may be pressed steel for light vehicles and single piece castings for extremely heavy duty vehicles. The split type housing is frequently used. The principal difference between front live axles and rear axles is that in front-wheel drives provision must be made for steering. In rear driving axles, the axle shafts are directly connected to the wheels. Since the front wheels must turn on the steering knuckle pivots, they are usually driven by the axle shafts through universal joints concentric with the steering knuckle pivots. Figure 237 shows the housings of the steering knuckle pivots and constant velocity universal joints, as well as the tie rod, brake drums, hub flanges, and wheel mounting studs for a typical front live axle assembly.

b. A type of front-wheel drive which drives the front wheels through gearing and permits them to steer without the use of a universal joint is shown in figure 238. It has been used to a very limited extent. A spiral bevel pinion keyed to the end of the axle shaft drives the lower half of a double bevel gear on the lower end of the steering knuckle pivot. The top half of the double gear meshes with a fourth gear that is integral with the wheel hub. The gear and hub turn on the steering knuckle. When the wheels are cramped the bevel gear on the wheel hub rotates around the bevel gear on the steering knuckle pivot.

c. Constant-velocity universal joints, used with front-wheel drives to avoid strain on the steering mechanism, are discussed in chapter 16.

184. Interwheel Differential

One of the latest developments in front-wheel drives is dual wheels having an interwheel differential which makes them easily steerable. Each wheel is equipped with its own brake. Vertical steering knuckle pivots are used. The differential is of the spur gear type, the pinions having a tooth form that gives it the same action as the high traction

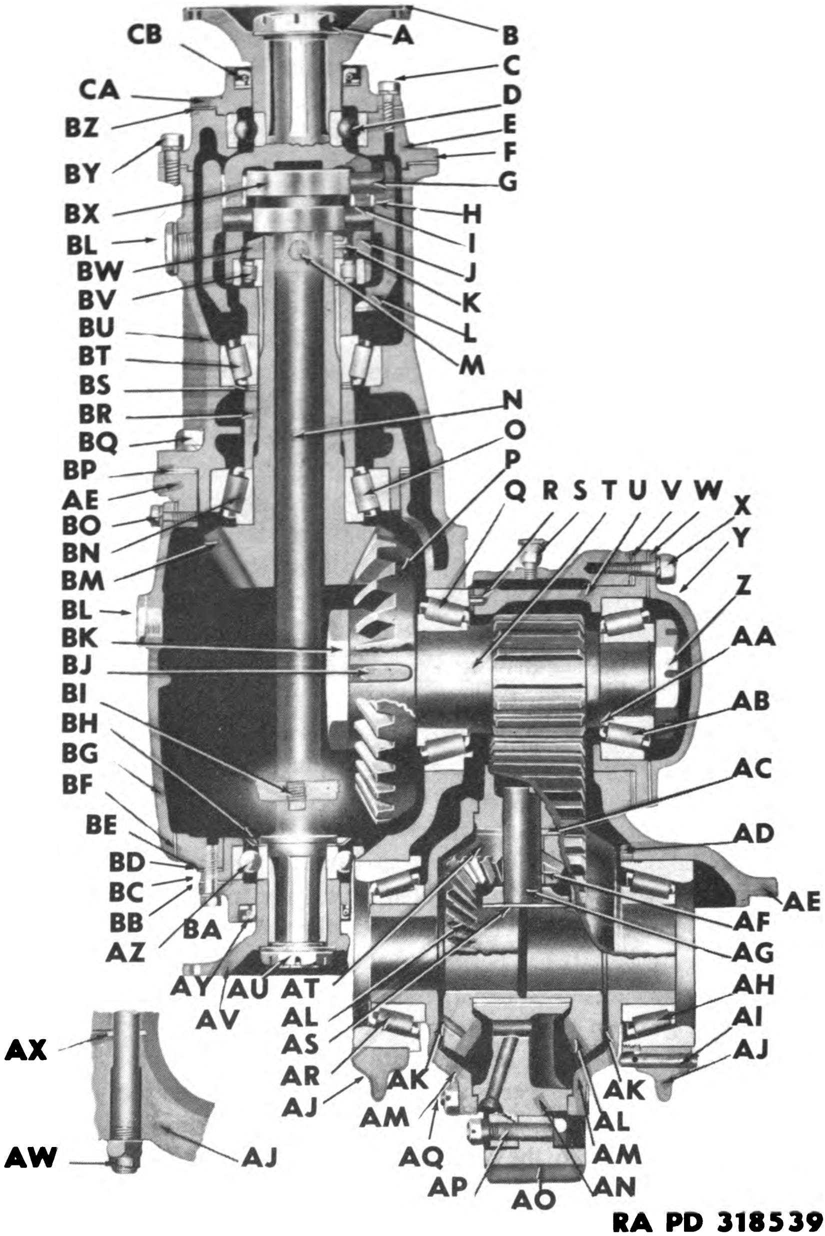

Figure 235c. Gear Carrier and Power Divider Cross Section.

A — FLANGE NUT
B — DRIVESHAFT FLANGE
C — RETAINER COVER SCREW
D — POWER DIVIDER BALL BEARING
E — BALL BEARING RETAINER
F — RETAINER GASKET
G — POWER DIVIDER WEDGE
H — OUTER RETAINER RING
I — INNER RETAINER RING
J — DRIVING CAGE
K — BEARING NUT COTTER
L — POWER DIVIDER CAM (FEMALE)
M — DRAIN PLUG
N — INTER-AXLE DRIVESHAFT
O — BEVEL PINION BEARING
P — BEVEL GEAR
Q — SPUR PINION SHAFT BEARING
R — BEARING RETAINER PIN
S — BREATHER ASSEMBLY
T — SPUR PINION SHAFT
U — BEARING RETAINER
V — RETAINER SHIM PACK
W — BEARING COVER GASKET
X — BEARING COVER SCREW
Y — BEARING COVER
Z — PINION BEARING NUT
AA — BEARING SHIM PACK
AB — PINION SHAFT BEARING
AC — PINION THRUST WASHER
AD — BEARING ADJUSTING NUT
AE — CARRIER HOUSING
AF — PINION BUSHING
AG — PINION STUD
AH — DIFFERENTIAL BEARING
AI — BEARING ADJUSTING NUT PIN
AJ — DIFFERENTIAL BEARING CAP
AK — GEAR THRUST WASHER
AL — DIFFERENTIAL SIDE GEAR
AM — CASING COVER
AN — DIFFERENTIAL CASING
AO — BULL GEAR
AP — BULL GEAR BOLT
AQ — DIFFERENTIAL CASING BOLT
AR — DIFFERENTIAL BEARING
AS — CASING BUSHING
AT — DIFFERENTIAL PINION
AU — FLANGE NUT
AV — DRIVESHAFT FLANGE
AW — BEARING CAP STUD NUT
AX — BEARING CUP LOCK WASHER
AY — OIL SEAL
AZ — DRIVESHAFT BEARING
BA — REAR COVER SCREW
BB — SHAFT BEARING COVER
BC — REAR COVER GASKET
BD — SHAFT BEARING RETAINER
BE — RETAINER GASKET
BF — SIDE COVER GASKET
BG — SIDE COVER
BH — OIL SLINGER
BI — DRAIN PLUG
BJ — BEVEL GEAR KEY
BK — GEAR RETAINING NUT
BL — HOUSING FILLER PLUG
BM — BEVEL PINION
BN — REAR BEVEL PINION BEARING
BO — COVER CAP SCREW
BP — HOUSING SHIM PACK
BQ — HOUSING CAP SCREW
BR — BEARING SPACER
BS — SHIM PACK
BT — FRONT BEVEL PINION BEARING
BU — POWER DIVIDER HOUSING
BV — POWER DIVIDER ROLLER BEARING
BW — BEVEL PINION NUT
BX — POWER DIVIDER CAM (MALE)
BY — RETAINER CAP SCREW
BZ — RETAINER COVER GASKET
CA — BEARING RETAINER COVER
CB — DRIVE FLANGE OIL SEAL

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Figure 235c—Continued.

differential described in paragraph 176c. When dual front wheels are used in addition to dual rear wheels, a greater portion of the total load can be carried by the front axle. This makes possible a greater pay load without increasing the overall length of the vehicle. Interwheel differentials can also be used for front dead axles, live rear axles, tandem rear live axles, and trailer dead axles to provide for the difference in distance traveled by each of the pair of dual wheels in rounding curves and for the different rolling radius of each of the dual wheels caused by the crown of the road, ruts, etc. It is thought that a great saving in tire wear results due to the elimination of slippage which must occur when dual wheels are rigidly bolted together.

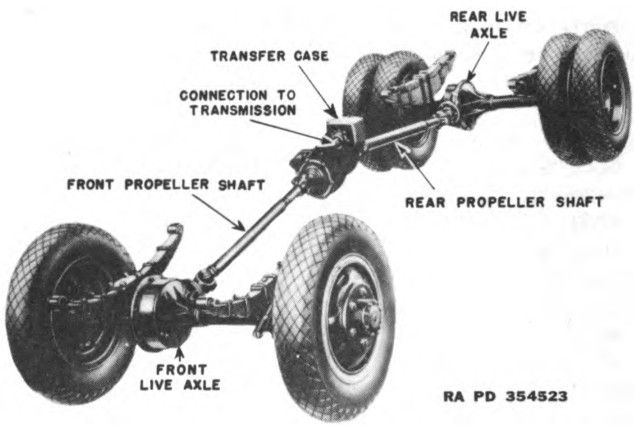

Figure 236. Arrangement of Transfer Assembly, Propeller Shafts, Universal Joints, and Live Axles for Four-wheel Drive.

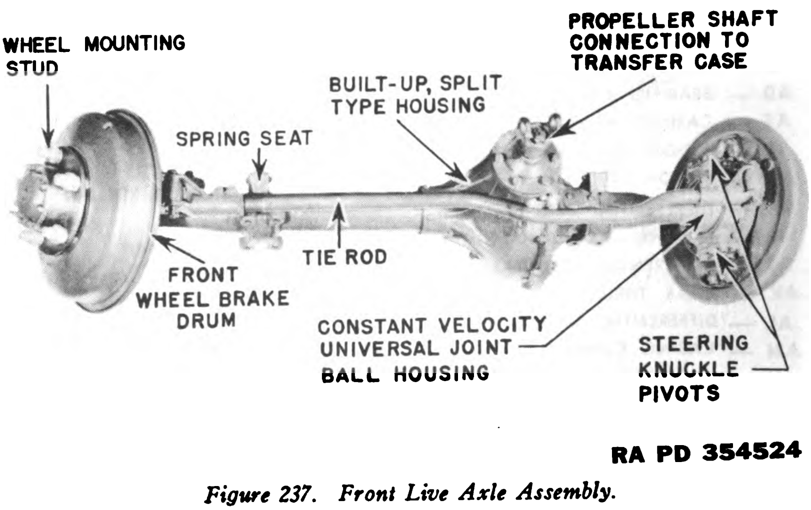

Figure 237. Front Live Axle Assembly.

185. Power Divider

a. The forward rear axle is of the full-floating, double-reduction type having a spiral bevel pinion and gear for the first reduction, and a spur pinion and gear for the second reduction. The spiral bevel pinion is driven through a power divider which also drives the rearward rear axle through a shaft that passes through the pinion of the forward rear axle and is attached to the forward end of the interaxle propeller shaft (fig. 235).

b. The power divider is attached to the forward end of the gear carrier, which is mounted on the upper side of the axle housing. Both forward and rearward axles are driven from the forward drive flange through the power divider by means of a driving cage carrying two parallel rows of radial wedges or plungers engaging at their outer ends with internal, (female) cams on a cage which drives the bevel pinion of the forward rear axle. At their inner ends the plungers engage with external (male) cams on the interaxle drive shaft which drives the bevel pinion of the rearward axle. Due to the wedging action between the cams and the plungers, they rotate together, with no relative movement, unless running conditions require a differential action.

c. Whenever either the front or the rear pair of wheels tends to run ahead of the other pair, due to slippage or uneven road surfaces, there is a relative movement of the external and internal cams, which is permitted by the sliding of the radial plungers in the driving cage. This restricted movement provides a differential action which apportions the

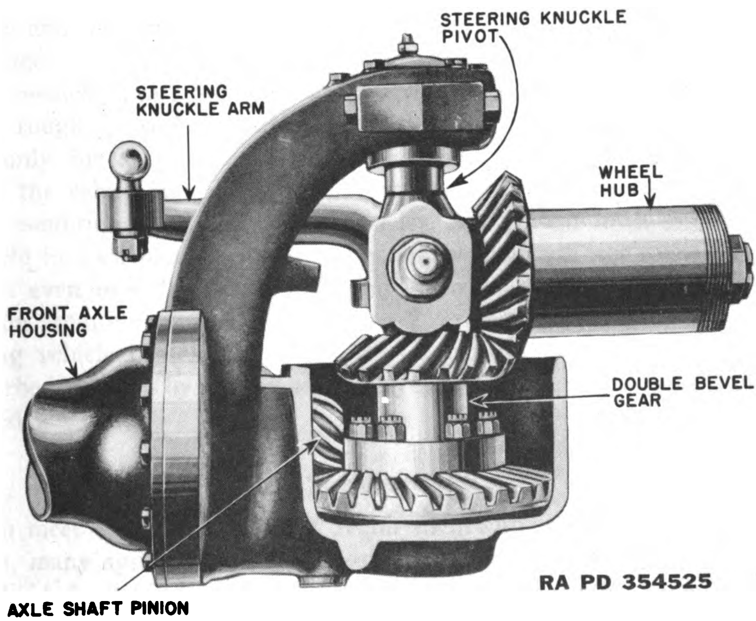

Figure 238. Helical Gear Steering for Front Wheel Drive.

driving effort to the two pairs of wheels to provide the maximum tractive effort. The wheel spindles are pressed into the axle housing, and the brake assemblies are carried by integral flanges. The underslung springs, which tie the two rear axle housings together in parallel relation, are attached by means of rubber shock insulators set in sockets on the bottom of the housing, and retained by caps.

d. A ball-joint torque rod, between the top of the gear carrier housing and a chassis frame crossmember, takes the torque imparted to the axle assembly by the driving and braking.

186. Tracklaying Vehicle Final Drive

a. In tanks the final drive works very much the same as in a wheeled vehicle. The driving axle is splined into the compensating gear of the differential, or is connected to it by a propeller shaft, and has a herringbone or spur gear on the outside end (fig. 221). Forward of this gear, and meshing with it is a driven gear, onto which the driving sprocket of the tank is attached. Each gear shaft is supported by a combination of ball and plain roller bearings.

b. The sprocket itself is worthy of mention, because it is the final connection between the power train and the tank track. Its steel teeth fit in between each connecting link of the track, and in this manner the tank is moved along.

PART FIVE

CHASSIS COMPONENTS

CHAPTER 18

SUSPENSION SYSTEMS

Section I. INTRODUCTION

187. Purpose of Suspension Systems

The purpose of the suspension system of a vehicle is to support the weight of that vehicle. It is therefore an important part of any vehicle, and is particularly important in military vehicles which are often very heavy and must be able to traverse all types of terrain. Since tanks and armored cars are really mobile gun platforms, the suspension systems of these vehicles must provide stability even when the vehicles are moving over rough ground. In wheeled vehicles, the suspension must provide not only for absorption of road shocks, but must allow the driver to steer the vehicle, and must be efficient over a wide range of speed and load conditions. In tracklaying vehicles, the system must support the vehicle in such manner that the immense weight will not cause bogging down even in soft ground, and must provide stability as well as protection from bumps and jolts. Figures 239a and b illustrate how a tracklaying vehicle passes over a 12-inch obstruction. Note that this rise is absorbed entirely by the suspension system; i.e., the vehicle itself is not raised.

188. Types of Suspension Systems

To meet the wide variety of requirements imposed by military situations, many systems have been designed and found efficient. These may be divided into independent axle, bogie axle, independent wheel, single arm, torsion bar, double arm, and double articulated arm.

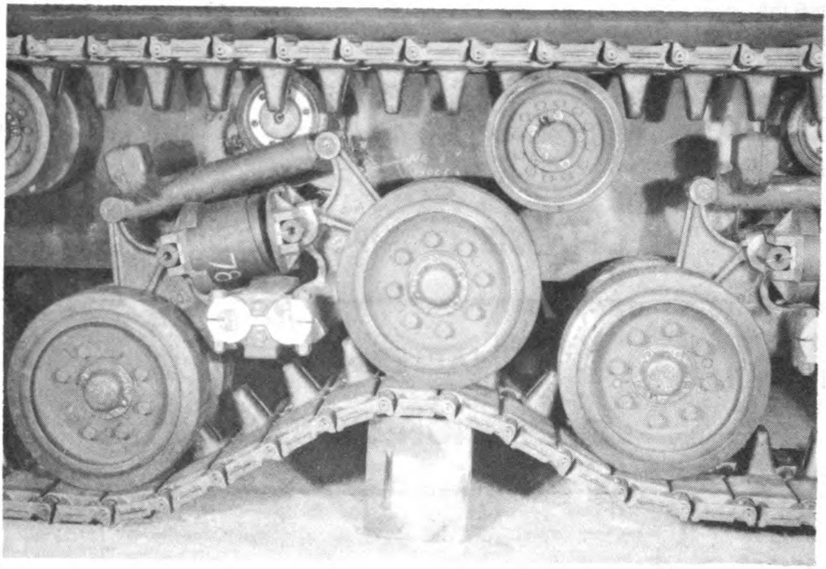

Figure 239a. Horizontal Suspension with 23-Inch Center Guide Track.

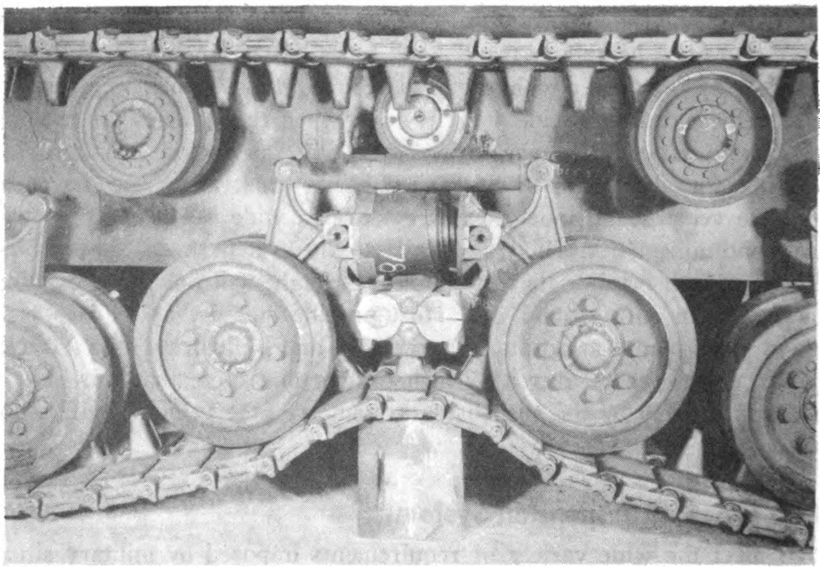

Figure 239b. Horizontal Suspension with 23-Inch Center Guide Track.

189. Principal Parts of Suspension Systems

The parts of suspension systems common to most types are axles, springs or torsion bars, shock absorbers, bogies, wheels and tracks. Since springs, torsion bars, and shock absorbers are used on both wheeled and tracklaying vehicles, they will be described in the following paragraphs. Other components will be discussed under the systems in which they are used.

a. SPRINGS. (1) *Laminated leaf springs (fig. 240).* Laminated leaf springs are commonly used on trucks and other wheeled vehicles.

(2) *Helical coil springs (fig. 241).* These springs have the widest application because they are less costly to manufacture, they are compact, and they are efficient. The main disadvantage is that excessive pitching of the vehicle results from their frictionless action, and shock absorbers must be used if pitching is to be eliminated.

(3) *Rubber springs.* Experimental use of rubber springs on light vehicles has been underway for some time, but until more information is obtained, it is not known whether or not their use will become general. In this system, the elasticity of rubber is utilized in the same manner as the elasticity of steel is used in torsion bars. Rubber is inserted between a bushing in the frame and a bushing in a lever arm connected to the axle, and is bonded to both metal surfaces. As weight is increased or roughness in the road is encountered, the lever arm tends to turn in the frame, but the turning is resisted by the rubber. This principle is also used in some spring hangers (fig. 242).

(4) *Volute springs.* These are helical coil springs made from flat steel tapered both in width and thickness, instead of steel wire. Each coil overlaps the adjacent coil, with the widest and thickest part having the greatest diameter. The greater the pressure placed on the spring, the more resistance the spring offers, because the heavier portion of the

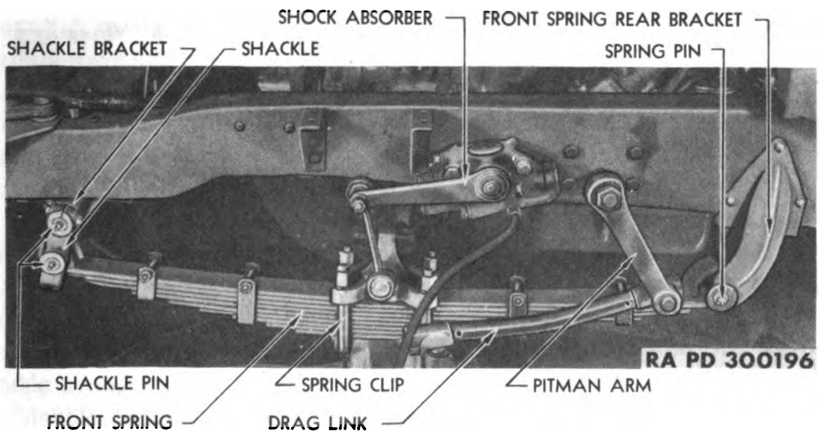

Figure 240. Front Axle Leaf Spring and Shock Absorber.

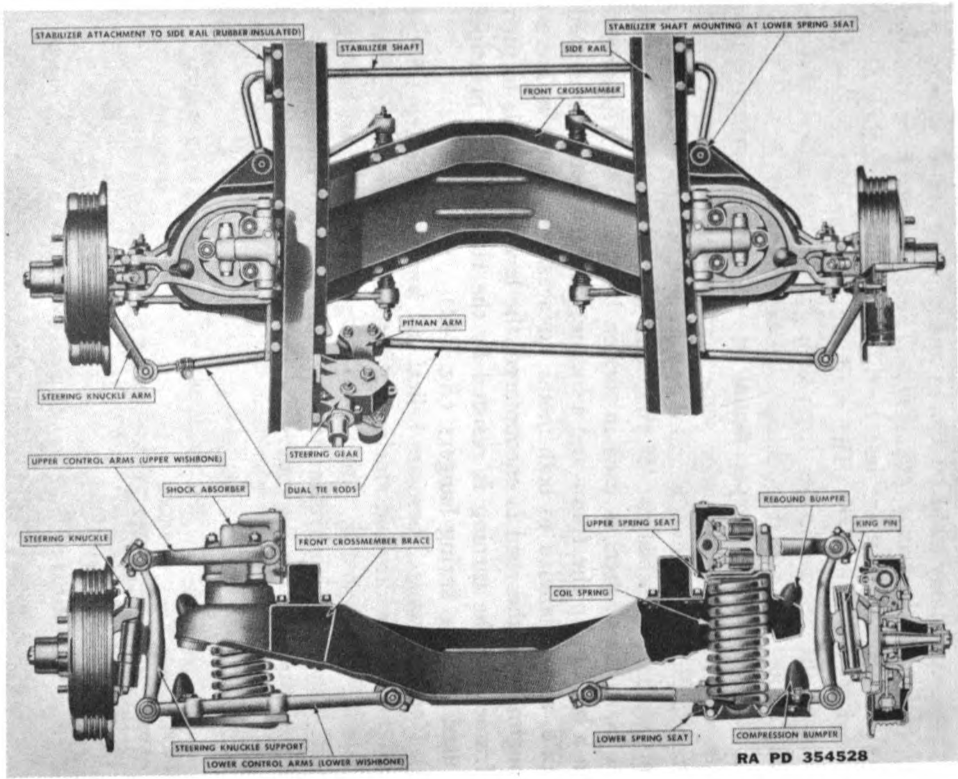

Figure 241. Front Axle Coil Spring Suspension.

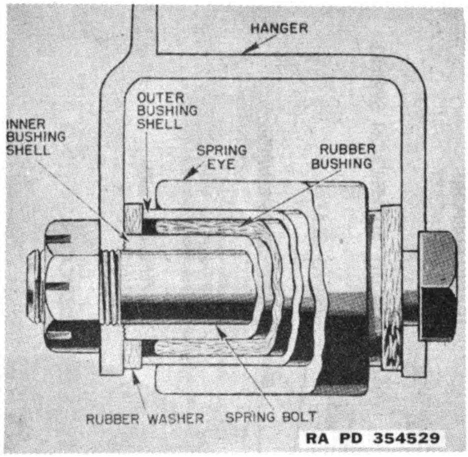

Figure 242. Spring Hanger with Rubber Bushings.

spring is brought into play. This characteristic protects the spring from overload, but tends to lower the endurance because of the unfavorable stresses created. The vertical type is shown in figure 243, and the horizontal type in figures 239a and b. This type of spring is desirable when heavy loads must be supported, and when space limitations prohibit use of conventional helical or laminated leaf springs.

b. Torsion Bar. This device consists of a steel rod, attached to the hull at one end and to the road wheel at the other, usually through a crank-shaped unit. The elasticity of the rod is utilized, and as long as the elastic limit is not exceeded, the torque resistance will return the road wheel to normal position in the same manner as a spring arrangement. The torsion bars, located inside the hull of the vehicle, are better protected from enemy fire, but their manufacture is more difficult and adjustment is more complicated. Torsion bars are marked to indicate proper installation by a narrow stamped into the metal, and it is essential that they be installed properly since they are designed to take stress in one direction only.

c. Shock Absorbers (Fig. 240). (1) The main function of a shock absorber is to regulate the spring rebound so that the spring returns to rest slowly, thus preventing sudden jolts and bounces being transmitted to the vehicle. Shock absorbers which only check the spring rebound are known as single or direct acting (fig. 244).

(2) A shock absorber may also dampen the compression of the spring by absorbing part of the energy as the spring is depressed. Shock absorbers which check compression in addition to rebound are known as double acting (fig. 245). Most shock absorbers used at the present time are double acting because they permit the use of more flexible springs. There are many types of shock absorbers in use today. Some of the more

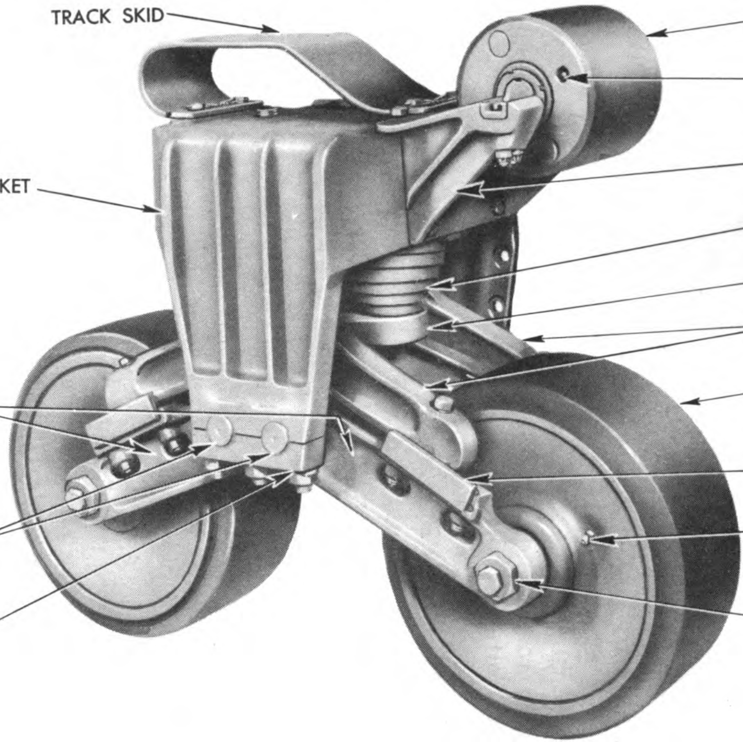

Figure 243. Vertical Volute Spring Suspension.

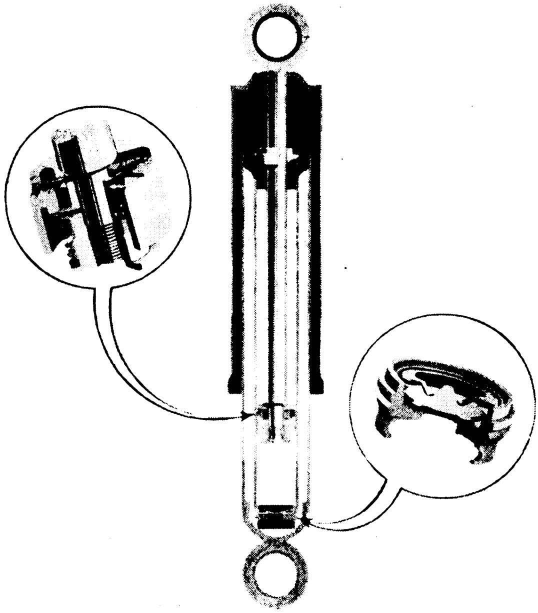

Figure 244a. Single or Direct Acting Shock Absorber.

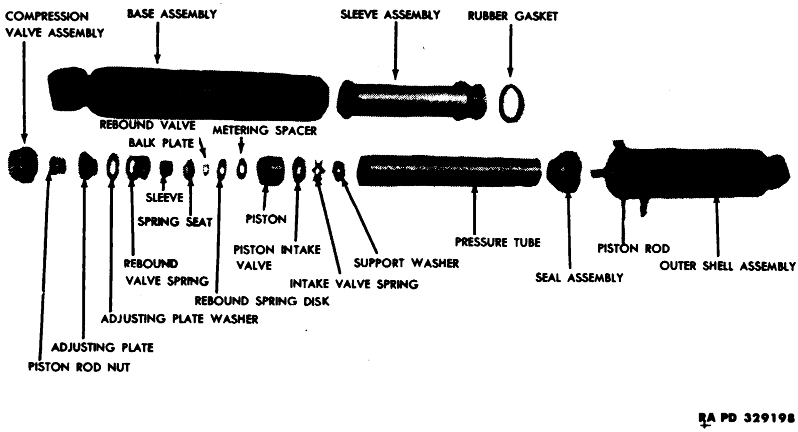

Figure 244b. Single or Direct Acting Shock Absorber.

common are: the cam shock absorbers, both single and double acting; the vane type in which the oil is forced through restricted openings by vanes which act as pistons; the direct acting type with an inner cylinder filled with a special shock absorber oil and divided into an upper and lower chamber by a double acting piston.

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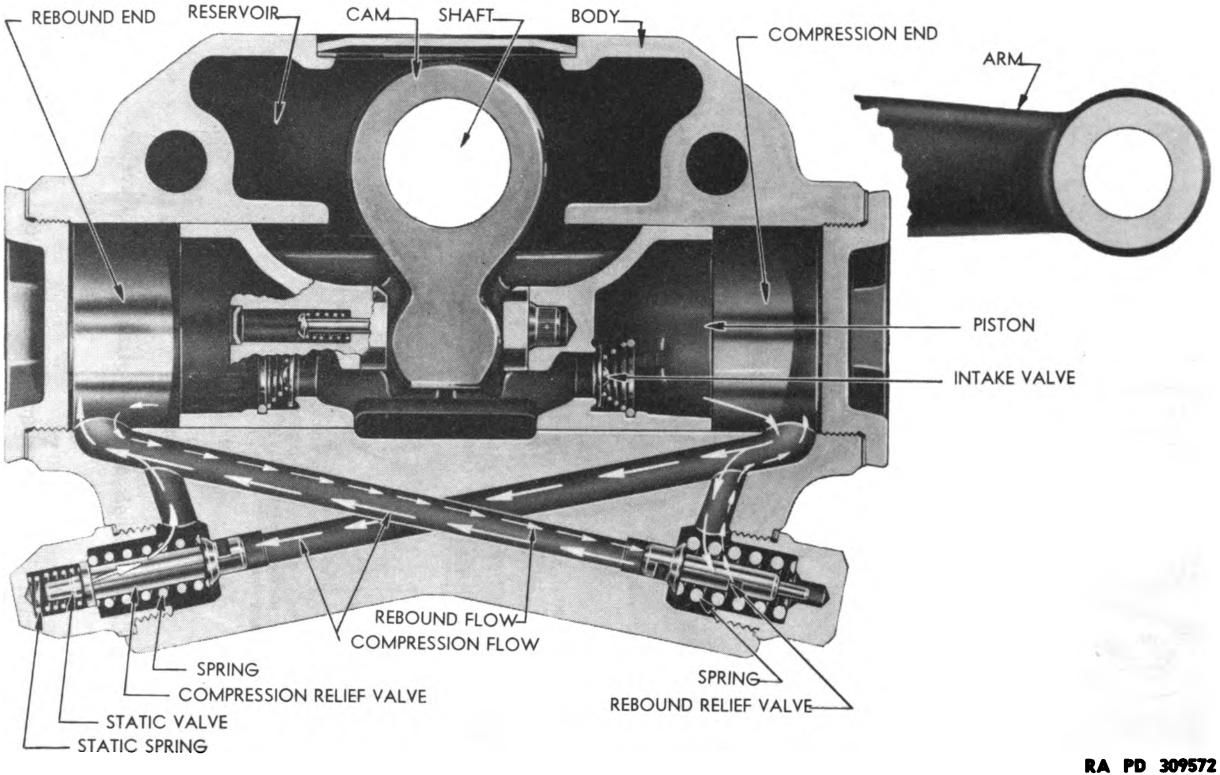


CROSS SECTION OF SHOCK ABSORBER SHOWING FLUID FLOW

Figure 245a. Double Acting Shock Absorber.

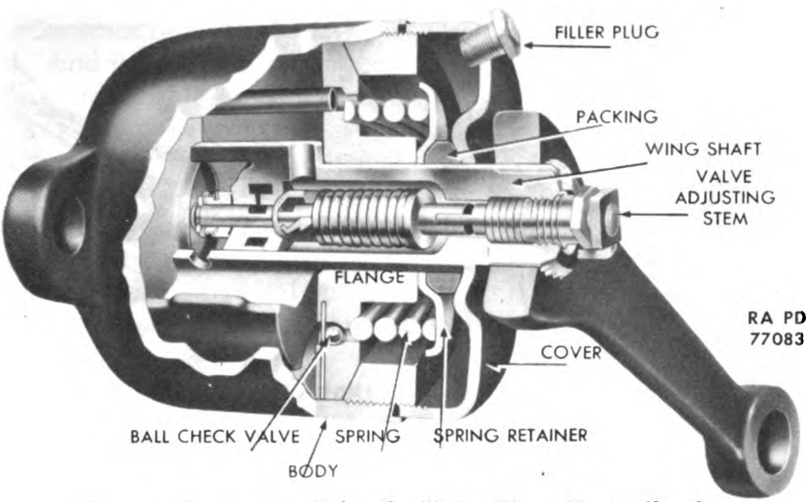


Figure 245b. Double Acting Oscillating Vane Shock Absorber.

Section II. Wheeled Vehicle Suspension Systems

190. General

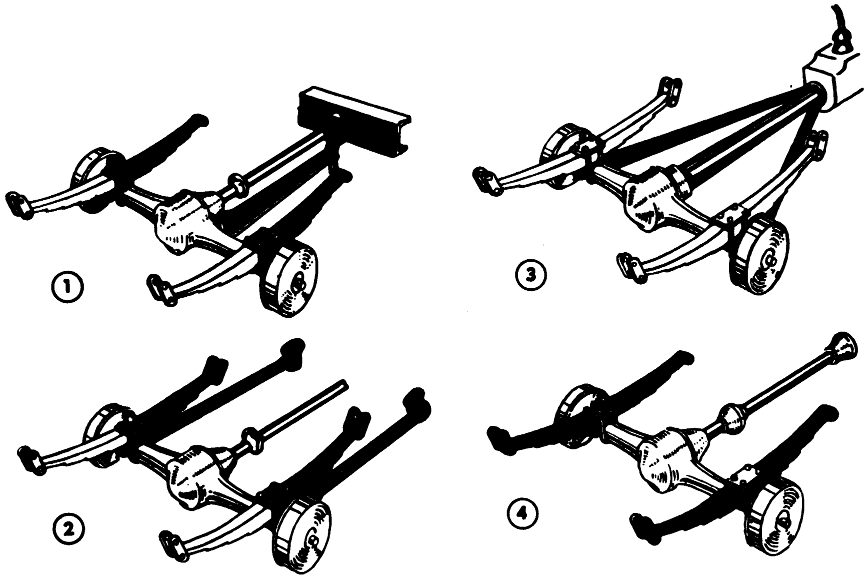
a. The wheels of a vehicle are either mounted on a spring-suspended axle or suspended independently on springs. Driving wheels are mounted on a live driving axle which is suspended by a spring attached to the axle housing (fig. 246). Laminated leaf springs are usually used for suspending live axles, although coil springs are used on a few passenger cars with torque arm or torque tube drive.

b. The front wheels of rear-drive motor vehicles were, until recently, nearly always mounted on a dead axle. Dead front axles are still used on a few passenger cars, however, and are extensively used on trucks and other heavy vehicles. The development of satisfactory independent suspension systems did away with front axles on most passenger cars. A live front axle, which acts as a driving member, is used in front- or all-wheel drive designs. The construction and suspension of the front axle are then similar to the conventional rear axle except for the provision for steering.

191. Dead Axles

a. General. The front axle of a conventional motor vehicle is a dead axle. To permit steering the front wheels of a motor vehicle, the front axle is made in three sections joined together.

b. Requirements. Dead axles must be able to support the weight of the vehicle and also be able to resist the stresses that occur when the brakes are applied. They must have sufficient stability to keep the wheels in proper alignment so that the vehicle holds its course.



(1) TORQUE ARMS
(2) TORQUE RODS
(3) TORQUE TUBES
(4) SPRINGS (HOTCHKISS DRIVE)
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Figure 246. Live Axle Suspensions.

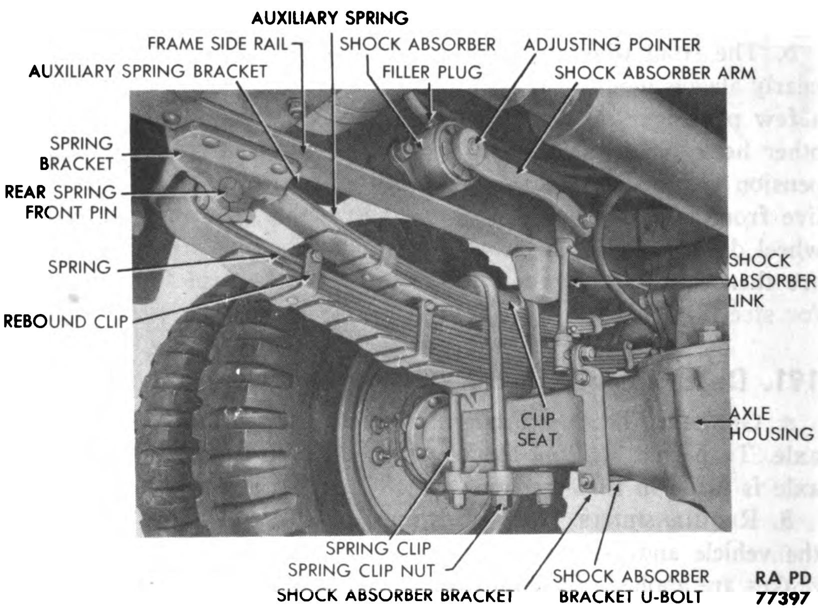

Figure 247. Auxiliary Spring Suspension.

c. CONSTRUCTION. Dead axles are generally made of I-section (fig. 241), drop forged from medium carbon or alloy steel, and heat treated to give them toughness and strength. The more expensive tubular section made from molybdenum steel is often used to reduce unsprung weight and give the axle resistance against high braking torque. The center of the axle is usually dropped in passenger vehicles so that the vehicle weight can be lowered since little road clearance is required. A straight axle is generally used for trucks. Dead axles are nearly always suspended by laminated leaf springs. The springs are held on the axle by spring seats and are attached by U-bolt clips (fig. 240).

192. Independent Suspensions

a. PURPOSE. If one of the two wheels mounted at opposite ends of a rigid axle receives a jar or jolt, the whole suspension system, including the axle, is affected. This means that a large unsprung weight is set in motion, which results in poor riding qualities. When a wheel hits an obstruction, the force of impact is directly proportional to the unsprung weight carried by it. This force of impact strains the wheels, axles, springs, steering mechanism, etc., and it also has a destructive effect on the road. Hence, it is highly desirable to reduce the unsprung weight as much as possible. With independent suspension, the wheels of a motor vehicle are individually supported so that each will function independently of the others. Either the front or rear wheels or both may be independently suspended.

b. ADVANTAGES. The following are the most important advantages of independent suspension: when one wheel passes over an obstruction, the shock is not transmitted to the opposite wheel, thereby aiding steering and reducing chassis distorsion; the unsprung weight, reduced to a minimum, is confined to the weight of the wheel itself and does not include the axle, springs, and steering linkage, thereby improving riding qualities.

193. Heavy Vehicle Suspension

a. SPRINGS. Several methods of spring suspension have been used for vehicles which carry widely varying loads in order to increase the load rating of the spring suspension as the load increases.

(1) Auxiliary springs (fig. 247) are commonly used in addition to the main spring to accomplish this purpose. When the load on the spring reaches a certain amount, the deflection of the main spring brings the free ends of the auxiliary spring against bearing plates on the frame, or axle if the auxiliary spring is secured to the frame. From that point on, the two springs carry the load jointly and their load ratings are added. This enables the vehicle to carry heavy loads without unduly deflecting the wheels.

(2) Another method of suspension that also provides a spring with variable load rating is shown in figure 248. The spring is made with

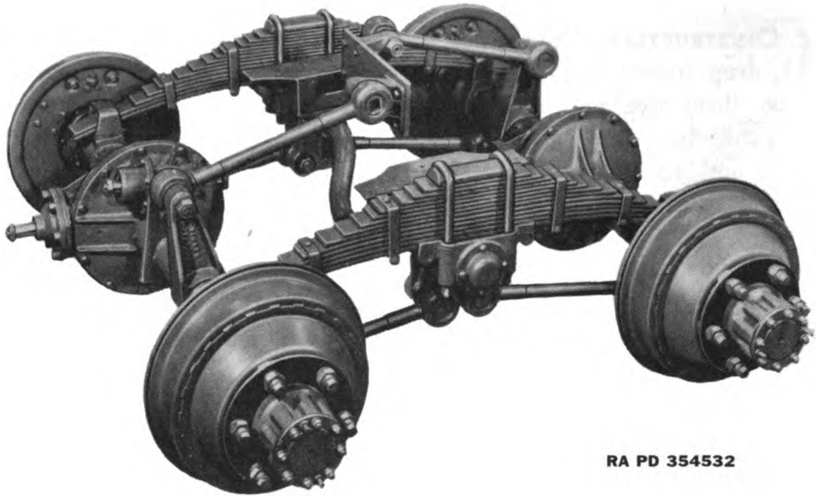

Figure 248. Variable-load Spring Arrangement.

flat ends which bear against curved bearing plates. With a light load, the springs make contact with the outer edges of the bearing plates, hence the effective length of the spring is comparatively large and it has a low load rating. Heavy loads deflect the spring, causing the points of contact to move toward the inner edges of the bearing plates. Hence, the effective length of the spring becomes shorter, giving a higher load rating.

b. AXLES. Two rear axles are used on numerous heavy vehicles to decrease the load on each rear wheel, to decrease the effect of road shocks, and to increase traction. A typical rear end on 6-wheel vehicles consists of an axle mounted on each end of the rear springs, with the load of the vehicle applied at the center of the spring by means of a spring seat supported on the frame. The drive is applied to the forward of the two axles, with the rear axle trailing, or it is applied to both axles by means of an interaxle differential, insuring equal driving effort on both axles. Torque rods apply the driving force to the frame and are usually arranged to relieve the springs of any torque reaction. The rear springs carry the same load they do with a single rear axle, but the load is distributed over two axles instead of one.

c. BOGIE AXLES. (1) A large proportion of 6-wheel vehicles have bogie axles. A bogie (figs. 248 and 249) is a suspension unit consisting of two axles joined by a single cross support (trunnion axle) that acts as a pivot for the entire unit. The tubular trunnion axle is rigidly attached to the frame by two support brackets and girder cross member. The ends of each spring rest on hardened steel bearing plates on the two axle housings, the spring being supported on the vehicle frame by means of a spring seat on each end of the trunnion axle. Both springs are securely clamped on their spring seats by means of spring clips.

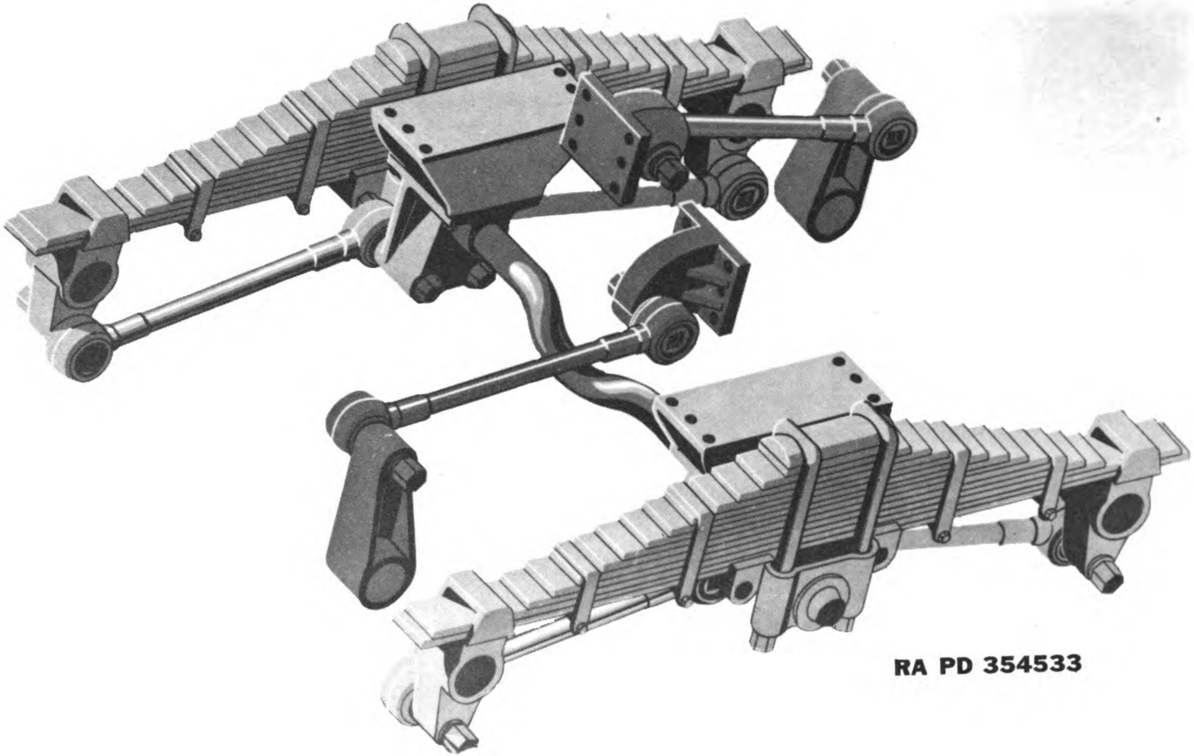

Figure 249. Rear Spring Installation

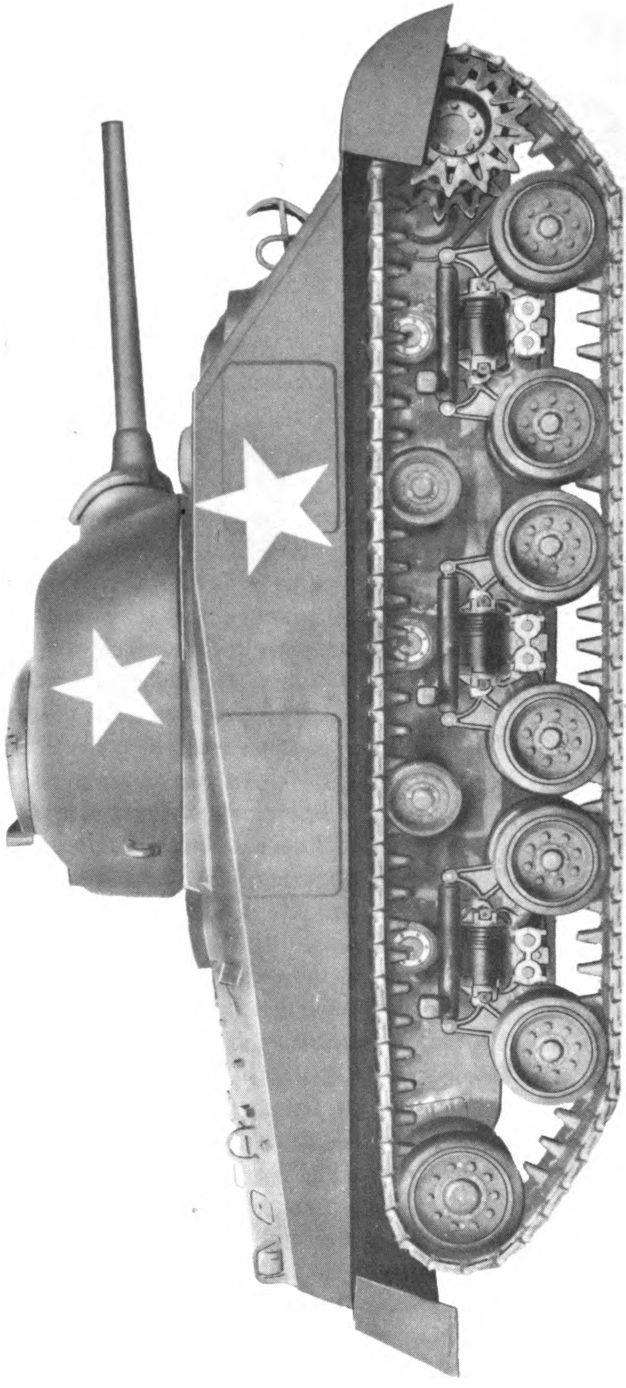

Figure 250. Horizontal Volute Spring Suspension for Center Guide Track.

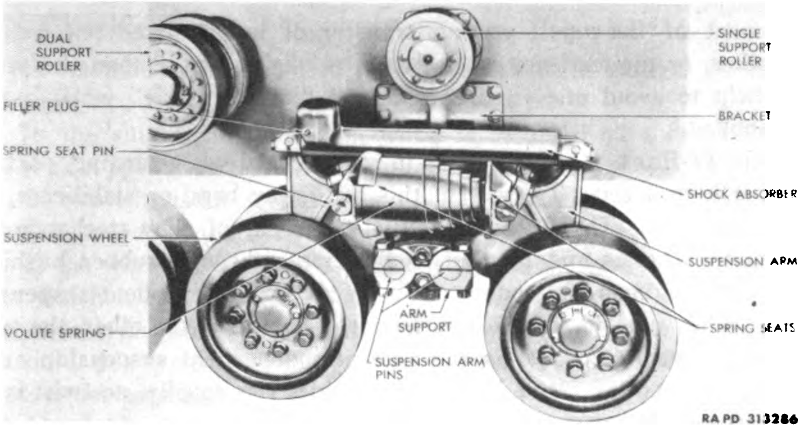

Figure 251. Horizontal Suspension Unit.

(2) Both spring seats are mounted on a spindle on each end of the trunnion axle. Tapered roller bearings take side thrust imposed on the spring and allow it to pivot easily. Springs with very high load rating must be used with this suspension because they carry the entire weight of the rear end. Mounting the springs on central pivots enables them to distribute half of the rear end load to each axle. As a result, the load on the rear of the vehicle is distributed over four wheels, allowing a vehicle to carry much heavier loads than a single rear axle vehicle, without exceeding the safe tire load.

(3) When one wheel is deflected from a road shock, the spring pivots about its center so that both ends of the spring deflect to absorb the energy of the road shock, rather than just one end. Thus, the effect of road shocks is cut in half. When only one axle is deflected up or down from its normal loaded position, the trunnion axle, and therefore the vehicle frame, is raised or lowered half this amount. In this manner, bogie axles reduce by half the impact or shock, not only to the vehicle but also to the road.

194. Auxiliary Units

a. Purpose. Various units are added to the spring-axle-wheel combination to eliminate hazards and to provide longer life for the parts. These will be discussed briefly.

b. Torque Devices. When power is applied, and when brake effort is applied, there is a tendency for the entire axle and spring assembly to rotate. To prevent this, strengthening arms are added to the axles. These are known as torque arms, torque rods, and torque tubes (fig. 246). The function of these three is the same, the major difference being that the torque tubes connect with the power train whereas the other two connect with the frame of the vehicle. Parallel torque arms used between axles in bogie suspensions (fig. 248) insure correct spacing and alignment of the axles, prevent transfer of weight from one axle to the other, or the tendency of one axle to "dig in" more than the other, and help to avoid uneven tire wear and "jumping axle" when brakes are applied.

c. SWAY BARS. A vehicle tends to roll outward when turning, particularly at high speeds. To prevent this roll, sway bars, or stabilizers, are used (fig. 241). The sway bar consists of a bar of alloy steel mounted across the chassis and secured to the frame through rubber bushings with arms on each end connected to the axle or independent suspension arms. When one side of the vehicle rises faster than the other, the twist set up in the bar reacts on the axle or independent suspension arms, tending to keep the frame level. If both sides rise equally, no twist is set up in the sway bar.

Section III. TRACKLAYING VEHICLE SUSPENSION

195. General

Tracklaying vehicles are designed for the purpose of affording transportation where ordinary cars and trucks cannot travel. The suspension systems, therefore, must perform the same functions as those of wheeled vehicles and in addition be able to absorb much greater shock and vibration and have greater flexibility. The tremendous weight of tracklaying vehicles determines the area of the tracks in contact with the ground. As far as is possible, tracks are of such size that the pressure on any square foot of ground is about equal to that exerted by a man of normal size. To accomplish this amazing distribution of weight, and to meet all these requirements, a number of suspension systems have been adopted. Basically, a tracklaying vehicle does just what its name implies; it lays its own road, then picks it up and again lays it. Keeping this in mind, it is easy to see that the suspension system is really the same as that of wheeled vehicles with added features to meet the additional requirements mentioned above.

196. Principal Parts

a. SPRING ARRANGEMENT. Arrangement of the springs on bogie suspensions has never been entirely satisfactory. Vertical volute springs (fig. 243) cannot be satisfactorily damped, and horizontal springs (fig. 250) are favored for most tracklaying vehicles.

b. SUSPENSION WHEELS. In modern tracklaying vehicles, suspension wheels are usually rubber-tired. This affords quieter operation and a great reduction in wear of wheels and tracks.

c. IDLER WHEELS AND TRACK SUPPORTING ROLLERS. These are used to keep the track up out of the suspension mechanisms, to guide the track, and to maintain tension (fig. 243).

197. Classification

Systems that have been used may be classified in general groups as follows:

a. In the single-arm type, each wheel is mounted on a crank-shaped axle with a spring or torsion bar to keep it in place, i.e., on the ground.

b. If two wheels are mounted on a bar, and that bar is attached to the crank-shaped axle, the system is called a double-arm type.

c. If the wheels are mounted on two bars, and the bars have a common pivot which is movable, then the system is known as the double articulated arm type. Since the wheels can move independently or together as a unit, this system has the greatest flexibility, and accordingly is one of the most popular.

d. Vertical volute springs are also used. Systems employing them are known as vertical suspension systems (fig. 243).

e. Horizontal volute springs as illustrated in figures 250 and 251 are also used. Systems of this type are called horizontal suspension systems.

f. Articulated bogie systems (fig. 252) are used in some vehicles.

g. A system used on many foreign tracklaying vehicles is the Christie. Full size wheels are used in place of the small bogie and track-supporting wheels, with a large saving in power required.

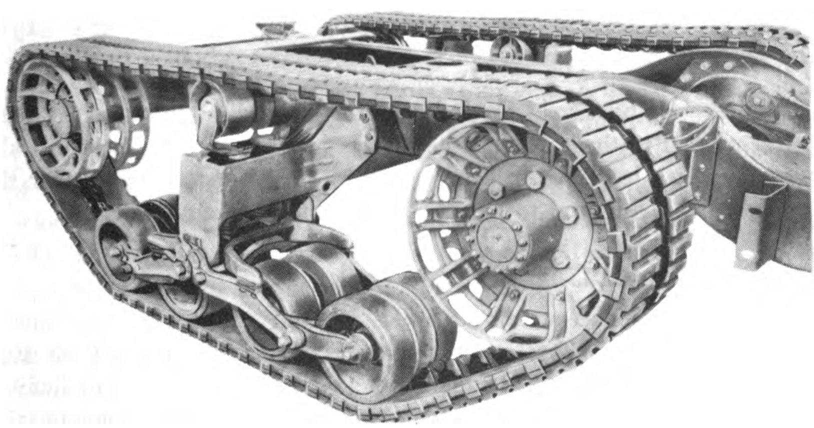

Figure 252. Articulated Bogie and Track.

CHAPTER 19

WHEELS, TIRES, AND TRACKS

Section I. WHEELS

198. Wheels, General

Wheels must have sufficient strength and resiliency to carry the weight of the vehicle, transfer driving and braking torque to the tires, and withstand side thrust over a wide range of speed and road conditions. Modern speeds, which demand low centers of gravity, have resulted in the adoption of perfectly balanced wheels of small diameter. Even a slightly unbalanced condition of the wheel-and-tire assembly will cause steering troubles and rapid tire wear at high speeds; therefore small balance weights often are attached to the wheel to remedy any unbalanced condition. Passenger car wheels are of the steel *disk* type. All of the modern types are demountable from the brake drum, which, in addition to having a braking surface, serves as the true hub for mounting the wheel upon the axle spindles. Modern trucks use demountable disk wheels of this type, or cast or welded spoke wheels.

199. Disk Wheels (fig. 253).

The disk may be a solid plate or a slotted steel disk. In both cases, the disk is welded to the rim, and the wheels are demountable at the brake drum. The disk is dished to bring the point of ground contact under the large wheel bearing and to permit the mounting of dual wheels.

200. Pressed and Cast Spoke Wheels

Pressed-steel spoke wheels as used on light vehicles are commonly called steel artillery wheels. The hub and rim are connected by steel spokes, and the wheels are demountable at the brake drums. For heavier trucks, the spokes are formed integral with the hub, and a demountable rim is used.

201. Wire Wheels

Wire wheels are used only on motorcycles. They are light, resilient, and easy on tires. However, they are hard to clean, permit the use of only full-circle antiskid chains and are not adapted to use with dual wheels. The modern type consists of a pressed-steel hub and rim connected by welded rather than adjustable (bicycle-type) spokes.

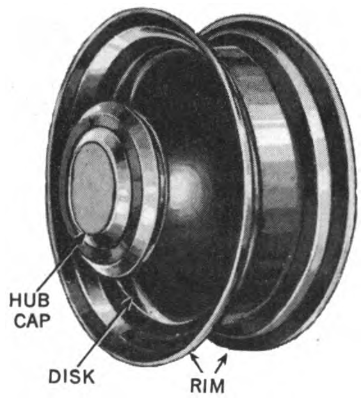

Figure 253. Passenger Car Disk Wheel.

Section II. TIRES

202. The Tire Assembly

The tire assembly generally consists of the tire, inner tube, flap, and the rim.

a. Structural parts of a tire are the tread, breaker, cushion, plies, and bead. Each part of the tire serves a definite purpose as follows:

(1) The tread is a layer of rubber on the outside circumference of the tire, and is the wearing surface. It has a nonskid design to provide traction. The tread also protects cords from cuts, bruises, and moisture. Rubber extends down over the sidewalls for protection.

(2) Breakers are layers of rubber-covered cords, similar to plies, except that the cords are spaced further apart. Breakers distribute road shocks and prevent separation between tread and carcass.

(3) The cushion is soft, heat-resisting rubber. It absorbs road shocks and bonds plies and breakers together.

(4) Cord plies give strength to resist internal pressure, to support loads and absorb road shocks.

(5) The bead is that portion of the tire which contains the steel wires and which comes in contact with the rim.

b. The inner tube contains the air. The flap protects the tube in the rim and bead area. The rim holds the tire in place.

203. Types of Tires

Standard tires are used in normal commercial and military service. Combat tires, although having the same basic construction as standard tires, are designed to operate without air pressure for a limited distance only in an emergency; they should be operated without air pressure only in combat where tactical situation requires it. A combat tire is of much

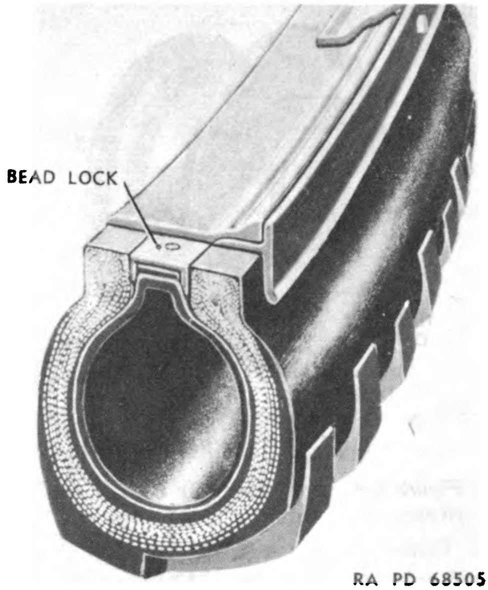

Figure 254. Combat Tire.

heavier construction than a standard tire, has more rigid sidewalls and heavily cushioned plies spaced wider apart. On the inside is a heavy section of rubber. A bead lock fits between the beads to prevent the tire from slipping on the rim and to hold it in position if deflated while supporting the load (fig. 254).

204. Types of Treads

Nondirectional tread gives good traction in either direction in mud and snow, on dirt or temporary roads, and cross-country. It is also practical for hard-surfaced roads (fig. 255). The directional tread, when properly mounted gives maximum traction in mud, snow, dirt roads, and cross-country driving (fig. 256). Standard highway tread gives satisfactory traction on highways and delivers long mileage (fig. 257).

205. Markings on Tires

a. Manufacturers' Names and Type Markings. These are imprinted on sidewalls of tires. Recommended air pressures are likewise imprinted on some tires.

b. Size and Ply Marking. The size is marked on the side of each tire, for example, "7.50-20/8." The first figure, 7.50, is the approximate width in inches when the tire is properly mounted on the rim and inflated, but not carrying a load. The second figure, 20, is the inside diameter of the bead in inches. The third figure, 8, is the number of plies of cord fabric (fig. 258).

Figure 255. Mud and Snow Non-Directional Tread Tire.

Figure 256. Mud and Snow Directional Tread Tire.

Figure 257. Standard Highway Tread Tire.

Figure 258. Size and Ply Markings on Tire.

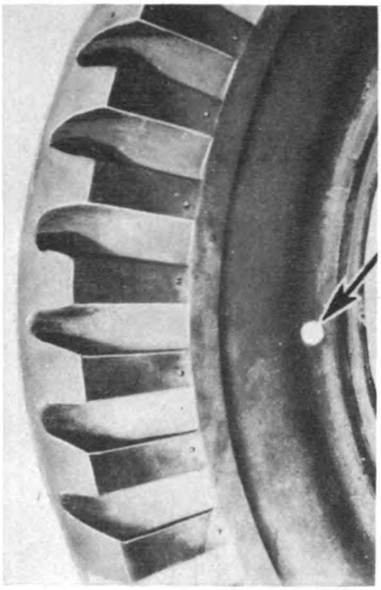

Figure 259. Balance Mark on Smaller Tires.

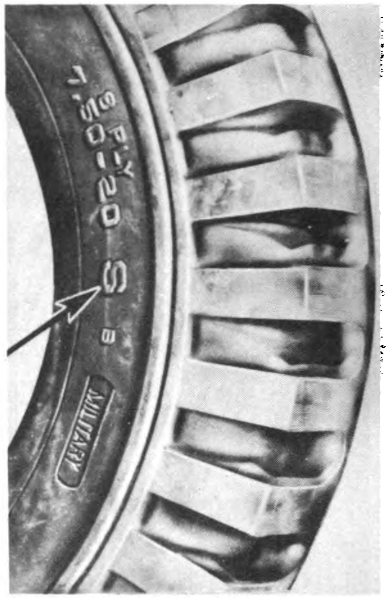

Figure 260. Identification of Synthetic Tires.

c. BALANCE MARK ON SMALLER TIRES. A small red mark, approximately ¼ inch in diameter, on the sidewall near the bead of some tires indicates where the valve of the tube should be placed in order to effect best balance of tire and tube (fig. 259).

d. IDENTIFICATION OF SYNTHETIC TIRES. Synthetic tires usually can be identified by a red mark, approximately ¾ inch in diameter, or the letter "S", "S1", "S2", etc., on the sidewalls. The letter "R" identifies tires constructed of rayon fabric (fig. 260).

e. COMBAT TIRES. These tires are marked "Combat" on the serial number side (fig. 261).

f. 6.00-16 FOR BEADLOCKS. The letters "BL" are imprinted on sidewalls near the size markings on the serial number of 6.00-16 tires, which are designed for use with beadlocks (fig. 262).

g. SERIAL NUMBER. The serial number is shown by numbers indented in the sidewall. Raised numbers in bead area indicate the number of the mold in which the tire was cured (fig. 263).

206. Types of Tubes

a. The tube is a continuous, circular rubber container that fits inside the tire, and holds the air which supports the vehicle. Only strong enough to stand a few pounds of air pressure when not confined, the tube bears extremely high pressures when enclosed in the tire. Because the tube is made of comparatively soft rubber to fulfill its function, it

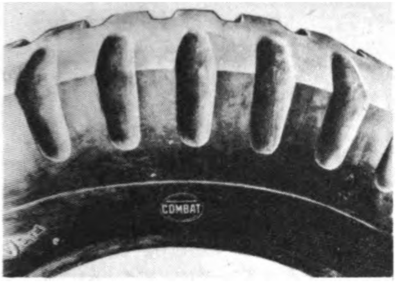

Figure 261. Combat Tire Markings.

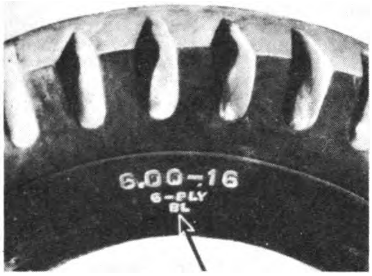

Figure 262. 6.00-16 Size Tire for Beadlocks.

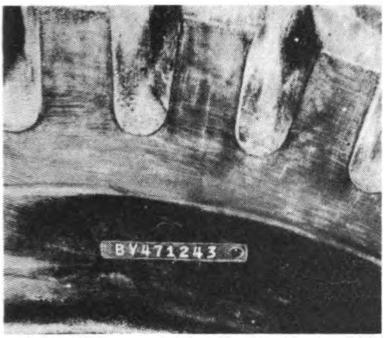

Figure 263. Tire Serial Number.

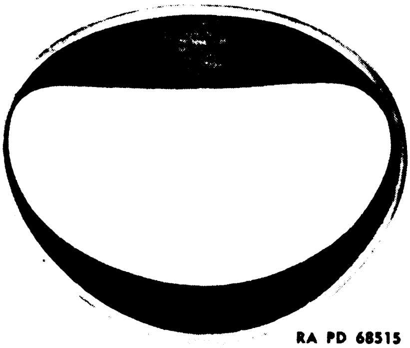

Figure 264. Standard Tube.

is easily chafed, pinched, punctured, or otherwise damaged. The three types of tubes are described below.

b. Standard tubes are made of one layer of rubber molded in the shape of a doughnut. They are regularly used for standard type tires (fig. 264).

c. Tubes for combat tires are constructed the same as standard tubes except that they are smaller than standard tubes with the same size markings, since the inside air space of combat tires is smaller. Combat tubes are stamped "Combat" and should always be used exclusively with combat tires (fig. 265).

d. Bullet-resisting tubes are of heavy, thick construction, which automatically seals bullet punctures. Bullet-resisting tubes are identified by their extra weight and thickness and generally have green-painted valve stems (fig. 266).

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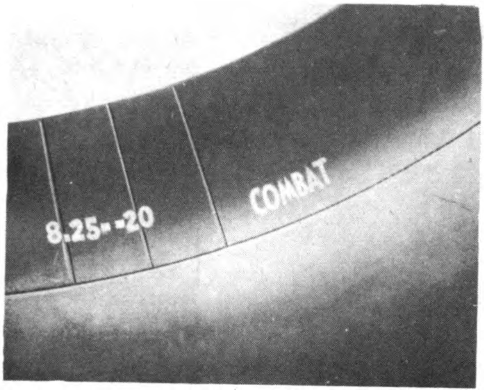

Figure 265. Standard Tube for Combat Tires.

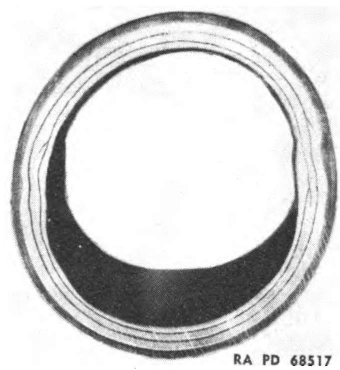

Figure 266. Bullet-resisting Tube.

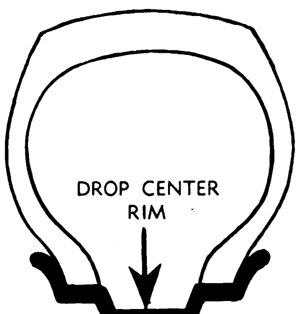

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Figure 267. Safety-type Rim.

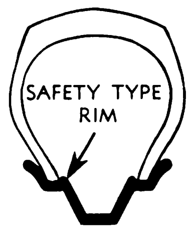

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Figure 268. Drop-center Rim.

207. Types of Rims

a. The rim completes the enclosure for the tube, holds the tire beads rigidly in place, and connects the tire to the wheel. Usually, rim and wheel are permanently fastened together as one unit and bolted to hub. On spoked type wheels, the rim is attached with lugs. For correct mounting, demounting, and tire fit, it is necessary to recognize the differences in rim types.

b. The drop-center rim is made in one piece and is permanently fastened to the wheel. Its important feature is a well which permits mounting and demounting of tire. Bead seats are tapered, to match a corresponding taper on the tire's beads. Drop-center rims are generally used on smaller vehicles, such as passenger sedans and ¼-ton, 4 x 4 trucks. NOTE: Some passenger cars and light trucks are equipped with safety type drop-center rims. Safety rims have a slight hump at the edge of the bead ledges which hold the beads in place when tires go flat (figs. 267 and 268).

c. The semidrop-center rim is also permanently fastened to the wheel. It has a shallow well, double head seats to fit the tapen of the beads of the tire, and a demountable flange. The demountable flange, or side ring, which fits into a gutter on the outside edge of the rim, holds the tire in place. This type rim is standard equipment on ½-ton, 4 x 4 trucks (fig. 269).

d. The flat base rim is generally fastened permanently to wheels used on military vehicles. It has a flat seat for the bead, and the tires must have correspondingly flat beads. As the name indicates, the rim has no well. This type rim has a demountable side flange to permit mounting and demounting the tire. Flaps are required on the flat base rim to protect that part of the tube not covered by the tire (fig. 270).

e. The type of divided wheel shown in figure 271 is used only with small size tires, such as those on the ¼-ton, 4 x 4 truck. Note that the sections, fastened together by studs, are of equal width. The wheel

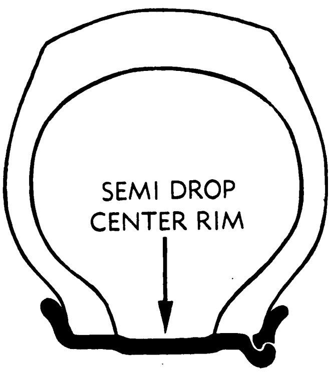


Figure 269. Semi-drop-center Rim.

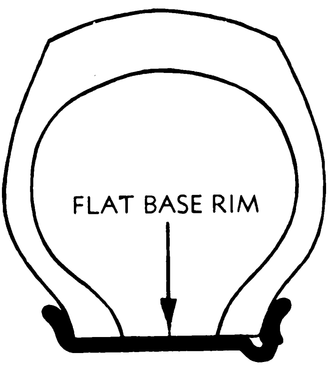


Figure 270. Flat Base Rim.

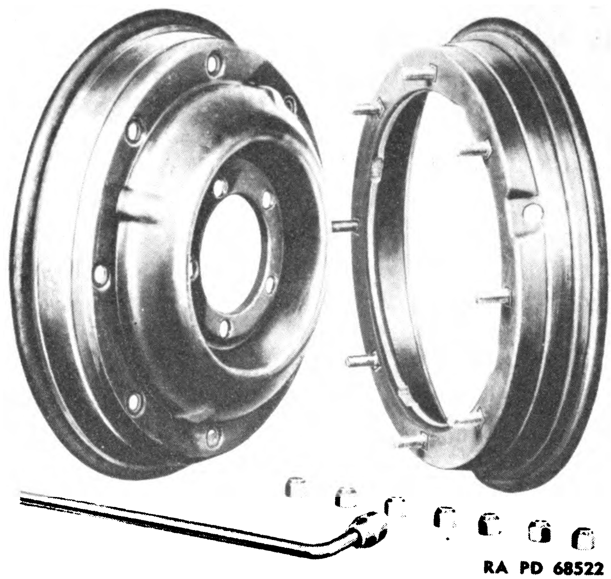


Figure 271. Divided Wheel for Small Vehicles.

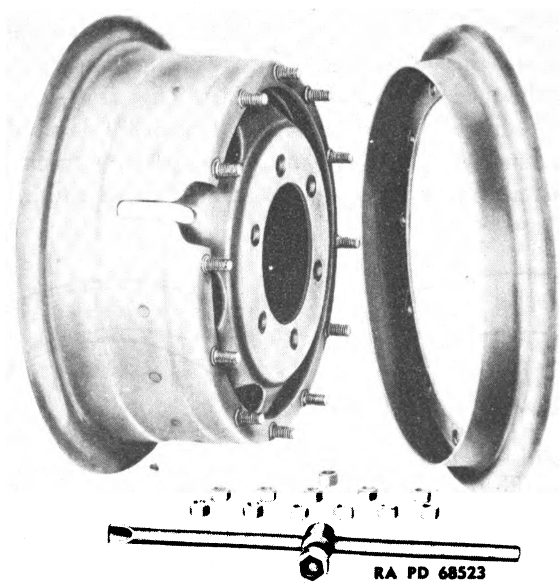


Figure 272. Divided Rims for Large Vehicles.

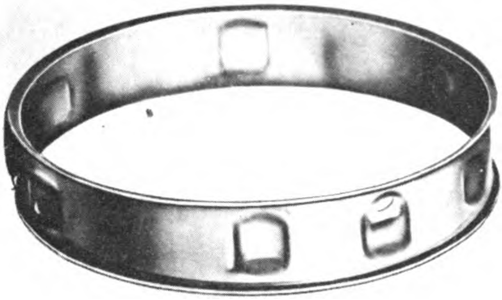


Figure 273. Channel Type Beadlock.

is built to accommodate continuous channel type beadlocks. Although this type wheel is designed for use with combat tires, conventional tires can be used when they have "BL" molded on the sidewalls.

f. Divided rims are equipment on ¾-ton, 4 x 4 trucks, scout cars, half tracks, etc. The two sections of this type rim are not of equal width. They are fastened together with studs or bolts. With this type rim, the tire is held in position by a hinged type or segmental type beadlock. Divided rims are designed for use with combat tires, but standard tires can also be used (fig. 272).

208. Types of Beadlocks

a. A metal device called a "Beadlock" fits between the beads of the tire, so that pressure can be applied by tightening the rim flanges against the outside of the bead. The beadlock is slightly wider than the space between the tire beads when mounted on the rim. Thus a compression fit is obtained which locks the beads into place, so that they will not slip on the rim and will hold the tire in position. In combat this is necessary in order to support the load when operating tires without air pressure.

b. The continuous or channel type beadlock is a solid band of steel, which can be readily inserted in its position in the tire. Flaps are not required with this type beadlock (fig. 273).

c. The hinged type, through the use of a hinge, will collapse so that the diameter is smaller, thus permitting insertion in the tire. After insertion it can be snapped into place between the beads. Flaps are not necessary with this type beadlock (fig. 274).

d. The segmental, or spacer block type, beadlock has blocks of hard metal, which are fastened together with a flexible steel band. This type can be collapsed for removal from, and insertion in, the tire. The segmental beadlock requires the use of a correct size and type rubber flap (fig. 275).

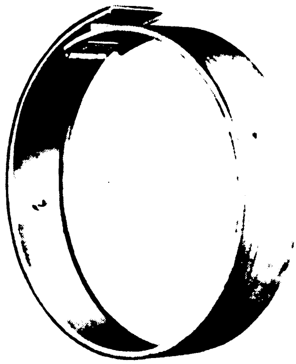


Figure 274. Hinged Type Beadlock.

e. Beadlocks are identified as follows:

(1) Channel and hinged types — size and code number are branded near valve hole.

(2) Segmental type — size and code number are stamped on rim side of each segment.

209. Types of Valves

a. Tubes are inflated by air under pressure, forced into the tube through the valve, which automatically prevents air from escaping. The valve stem is threaded inside and out at the end to accommodate the valve core and cap. Stems on truck tubes are bent to make them more accessible for installation and provide protection against flying stones. Valves are classified according to the method of mounting on tube.

b. The cured-in rubber-covered valve is vulcanized directly into the tube and cannot be removed unless cut off for replacement. It is used on passenger cars and some light trucks. It is made in two types — non-bendable such as used on cars and hand-bendable such as used on ¼-ton 4 x 4 trucks (fig. 276).

c. The all-metal, cured-in valve is vulcanized to the tube, and cannot be removed (fig. 277).

d. The spud-mounted valve has two parts for attaching to the tube. The spud is inserted in the tube. Then the stem is screwed down on the spud, making an airtight seal (fig. 278).

e. The clamp-in valve is inserted into the tube and is held in place by a bridge washer and valve nut. The bridge washer is positioned so that the ends point lengthwise with the tube (fig. 279).

210. Valve Accessories

a. The valve core is screwed into the stem and permits air under pressure to enter, but prevents it from escaping.

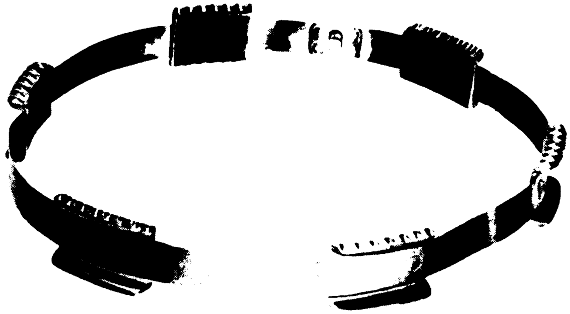


Figure 275. Segmental Type Beadlock.

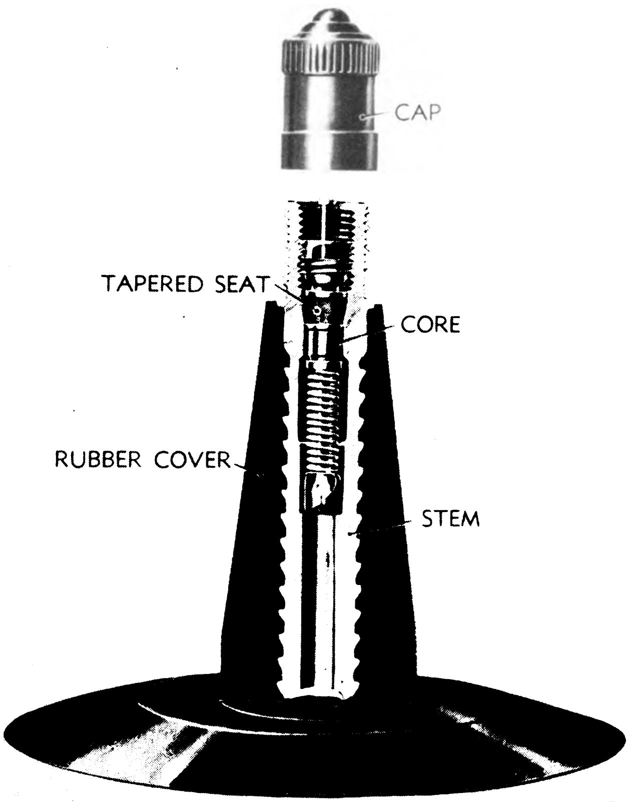


Figure 276. Rubber Covered Valve.

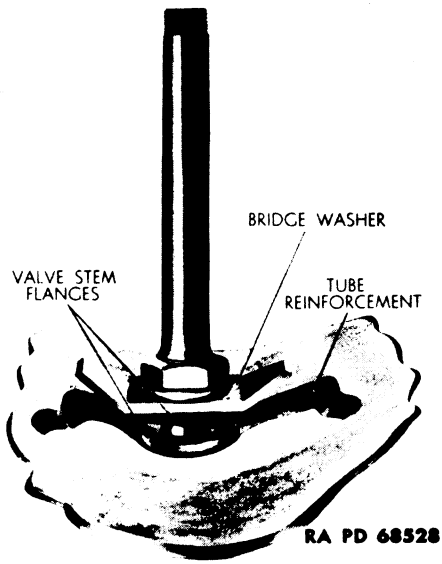


Figure 277. All-metal Cured-in Valve.

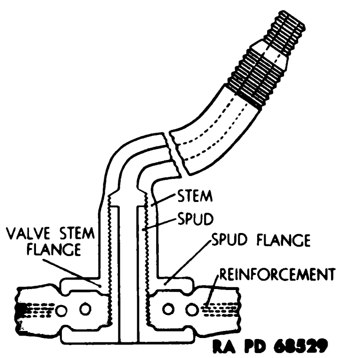


Figure 278. Spud-mounted Valve.

(1) This type core shell has a rubber washer which fits airtight against the tapered seat inside the stem. In closed position, a spring holds a rubber-seated cup firmly against the shell. In open position, the pin forces spring and cup away from shell (fig. 280).

(2) In the concealed spring type core, the spring is inclosed within the shell, but it operates the same way and is interchangeable with the visible spring type (fig. 281).

b. The valve cap keeps the core clean and serves as the final seal fig. 282).

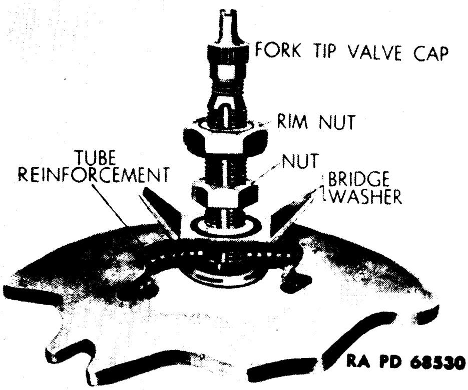


Figure 279. Clamp-in Valve.

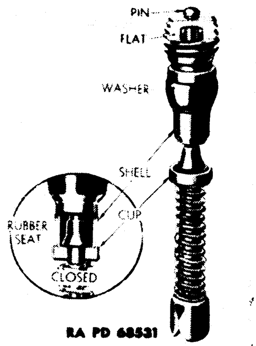


Figure 280. Visible Spring Type Core.

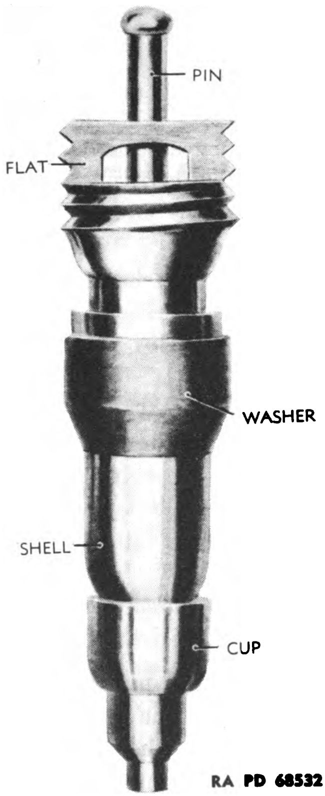


Figure 281. Concealed Spring Type Core.

Figure 282. Valve Cap.

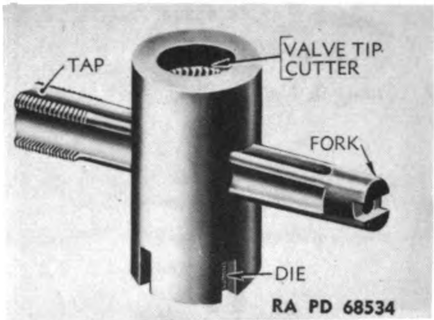


Figure 283. Valve Tool.

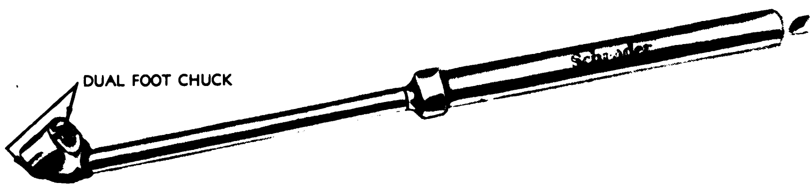


Figure 284. Dual Foot Gage.

c. The valve stem repair tool has four uses. The forked end removes and replaces cores, the tap cleans the inside threads, the die cleans the outside thread, and the cutter smooths burred valves (fig. 283).

d. A gage is necessary to determine correct air pressure. The dual foot hand gage simplifies checking dual tires (fig. 284).

e. Another type gage is one in combination with chuck on the air line of the compressor (fig. 285).

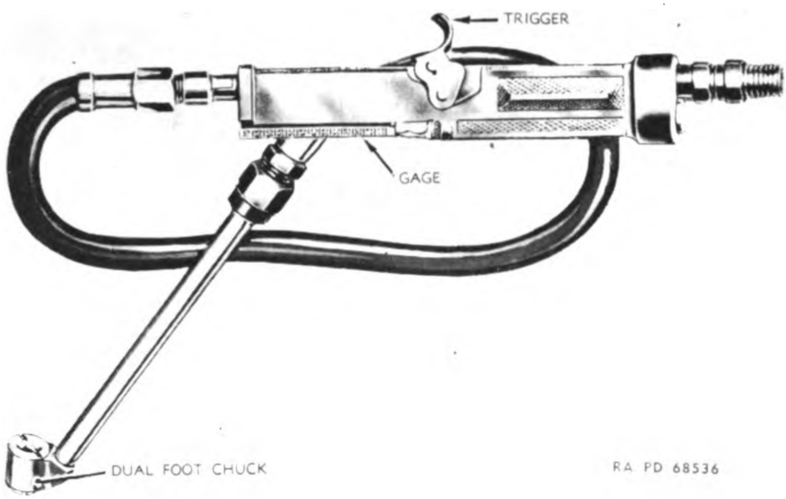


Figure 285. Dual Foot Gage and Chuck.

Section III. TRACKS

211. Tracklaying Vehicle

Two individually driven tracks provide the traction necessary to propel a tracklaying vehicle. Each track consists of individual track blocks, held together by steel connectors between track block pins to form a continuous track. Each rubber track block consists of a rubber block molded around two forged steel tubes, connected at each end by steel links (fig. 286). Steel tracks are made up of steel track blocks, connected in the same way as the rubber blocks. The track block pins are not an integral part of the block, but are assembled into the forged tubes. Doughnut-shaped rubber spacers are molded onto each pin, and form the bond between the pin and the forged tube. So that the entire track can be electrically grounded each pin has two bronze clips which make contact between the pin and the tube. Since rubber track blocks are entirely symmetrical, with the same amount of rubber on each side, they can be turned over to give added service after one side has become badly worn (except for rubber tracks with chevron tread). Steel tracks cannot be turned. Drive sprockets on each side of the vehicle pull the tracks forward over the supporting rollers, and lay them down in the path of the advancing track wheels (fig. 286).

212. Tracks for Half-tracks

The half-track derives its name from the type of suspension supporting the rear of the vehicle. Two tracks supported by rollers are driven by sprockets on the rear axle and drive the vehicle. The tracks are the end-

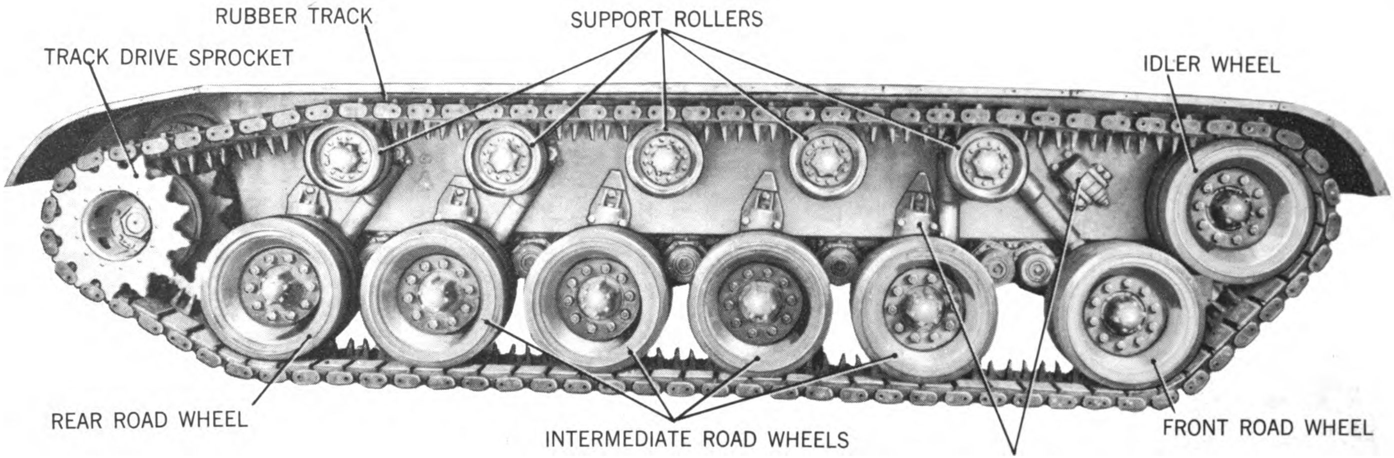


Figure 286a. Track and Suspension.

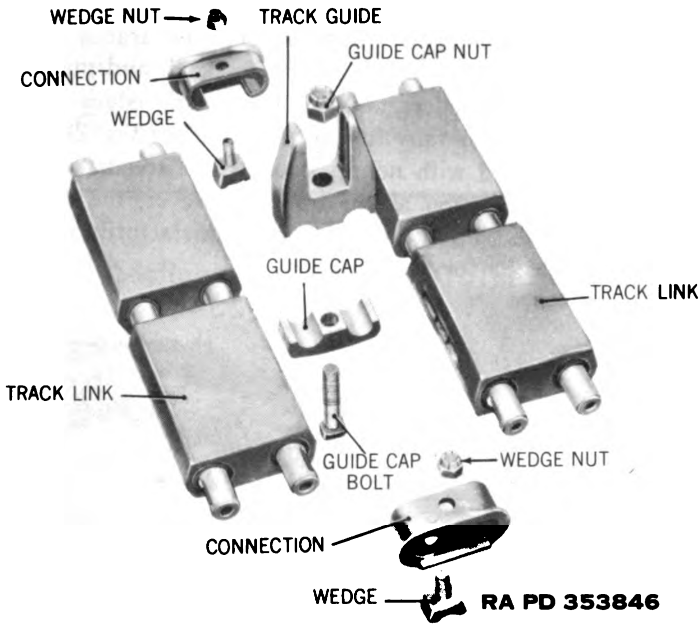
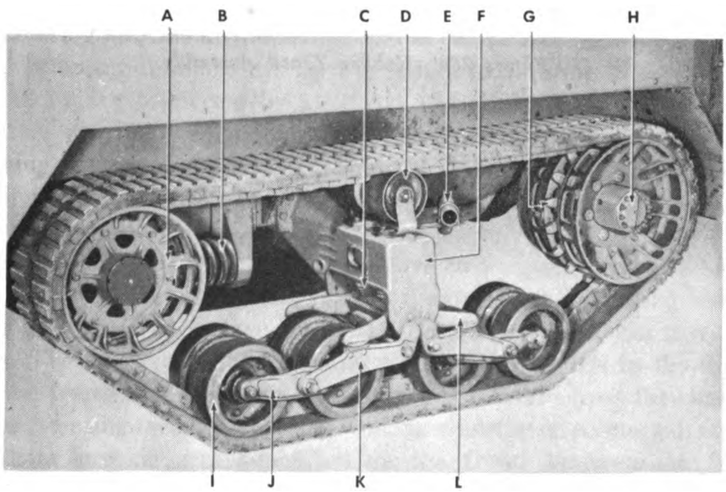


Figure 286b. Center Guide Rubber Track Links.



A—IDLER WHEEL
B—IDLER SPRING
C—VOLUTE SPRING
D—BOGIE UPPER ROLLER
E—TAIL PIPE
F—BOGIE AND FRAME ASSEMBLY
G—TRACK DRIVING SPROCKET
H—REAR AXLE SHAFT FLANGE
I—BOGIE ROLLER
J—BOGIE FRAME
K—BOGIE ARM
L—CRAB

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Figure 287. Bogie and Track Assembly.

less-band type, made of rubber molded to steel cables which extend throughout the track length. Metal guide plates with steel cross members are bolted to the cables along the inside center of the tracks. These serve as contacts for the jackshaft driving sprocket teeth and guides to keep the tracks on the bogie rollers and sprockets. The edges of the track incorporate projections, or tabs for added traction (figs. 287 and 288). The tracks are provided with nondirectional type treads which operate equally well in one direction as the other; however, the center guides are not uniform in width and do not operate satisfactorily with the wide part of the guide in the forward position.

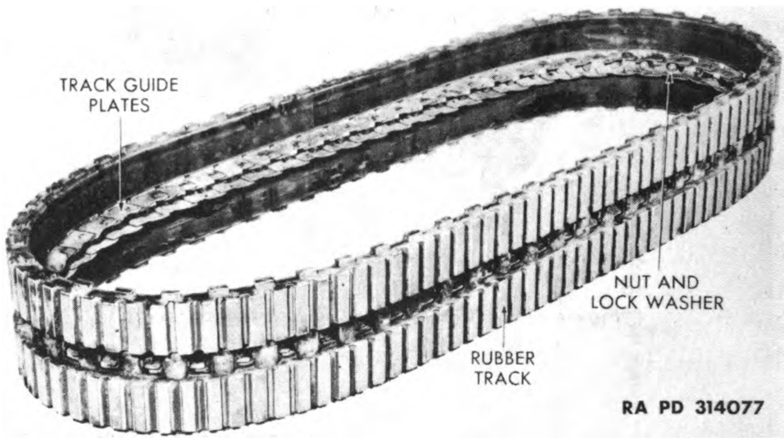

Figure 288. Rubber Track Assembly.

CHAPTER 20

STEERING SYSTEMS AND WHEEL ALINEMENT

Section I. STEERING SYSTEMS

213. Steering Methods

In order to steer a vehicle the wheels must be changed from their straight-ahead position. A "fifth wheel" which serves as a central pivot for the entire front axle was an early method of steering (fig. 289). This method serves for vehicles that are pulled, such as trailers and horse-drawn vehicles, but it is not practical for self-propelled motor vehicles.

b. The Ackerman system is used for automotive vehicles. In this method of steering, the front wheels are mounted on pivoted knuckles, and a steering linkage is used to tie the knuckles together so that the wheels rotate together about their pivots.

214. Steering Linkage

a. A steering knuckle arm is bolted and keyed to each steering knuckle. A 2-bolt fastening is sometimes used to reduce localization of stress. The knuckle arms are connected by a tie rod (fig. 290) to tie the knuckles together. A steering gear connecting rod is attached to one knuckle arm for turning the steering knuckles about their pivots. This steering gear connecting rod is connected to the steering gear arm, which is operated by the steering gear.

b. One of the steering knuckles may have two separate knuckle arms, one for the tie rod and the other for the steering gear connecting rod. A double arm (fig. 290) is frequently used to provide for these two connections. The steering gear connecting rod usually extends in the direction of the frame side members, though it may extend across the chassis.

c. The steering gear connecting rod is sometimes connected to an intermediate knuckle arm supported on the frame between the front wheels (fig. 291). Tie rods then extend from the intermediate knuckle arm to the two steering knuckles. This linkage is advantageous with parallel arm suspension, since each tie rod will move with its corresponding control arm so that vertical movement of the wheels does not disturb the wheel alinement or otherwise affect steering. The steering gear connecting rod is sometimes eliminated, and the tie rods are connected directly to the steering gear arm.

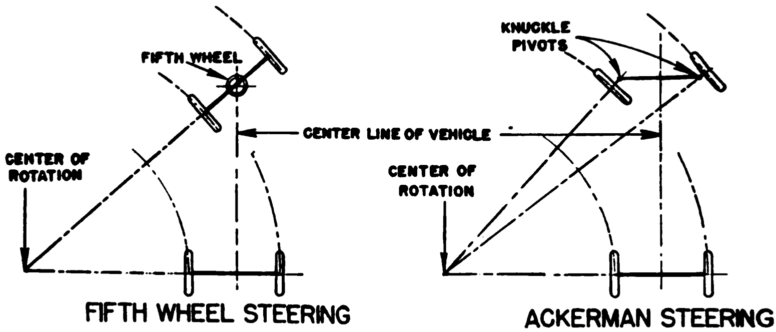

Figure 289. Methods of Steering.

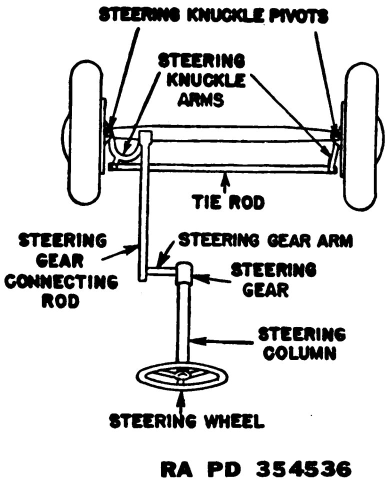

Figure 290. Steering Linkage.

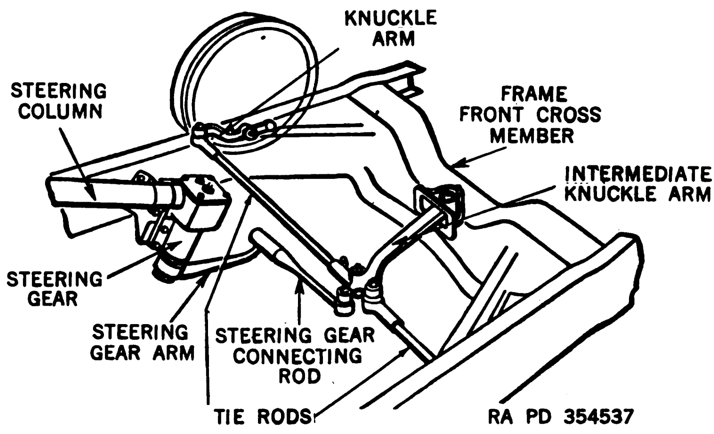

Figure 291. Steering Linkage with Intermediate Knuckle Arm.

215. Tie Rod

a. The tie rod is usually located behind the axle or the center line of the wheels, though it may be located to the front. It may be of tubular or solid rod construction. The rod is threaded at the ends and is screwed into the tie rod ends (fig. 292). Thus the length of the tie rod can be adjusted to keep the front wheels in proper alinement and can be secured by the tie rod and clamp bolts.

b. Owing to the relative motion between the tie rod and its knuckle arms, it is necessary to have a swiveling connection between them. The tie rod end is usually fastened to the knuckle arm with a stud. Some form of socket is provided within the tie rod end to hold the end of the stud, which is in the form of a ball or yoke and to allow movement between the knuckle arm and the tie rod. A lubricant fitting is usually provided to keep the ball and socket joint properly lubricated. A dust seal covers the tie rod end to prevent dust from entering the joint and loss of the lubricant.

216. Steering Gear Connecting Rod (Drag Link)

a. The length of the steering gear connecting rod (drag link) (fig. 290) should be such that the steering gear arm is vertical when the front wheels are straight ahead. Maximum leverage is then available for turning the wheels. The steering gear connecting rod, commonly termed the drag link, is made in tubular or rod form and provided with springs to cushion shocks and prevent their transmission to the steering gear.

b. A housing is provided on one end of the steering gear connecting rod to receive the ball end of the steering gear arm. Ball sockets, coil springs, spring seats, and a screw plug secured by a cotter pin are inserted into this housing to hold the steering gear arm ball (fig. 293). Sometimes the slot through which the steering gear arm is inserted

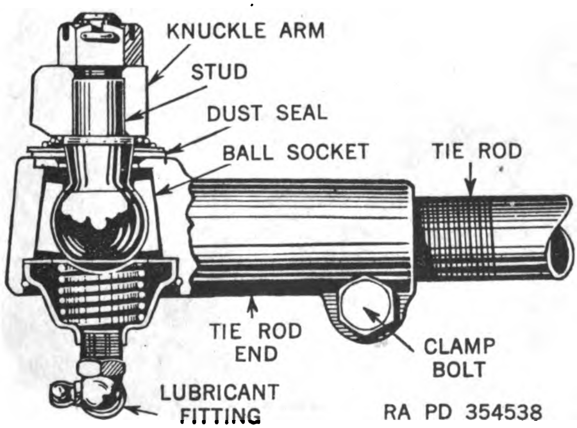

Figure 292. Tie Rod End.

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extends the entire length of the housing, in which case the end of the housing has a screw cap. The end of the steering gear connecting rod attached to the steering knuckle arm is usually somewhat similar, though it may be made like a tie rod end.

c. Lubrication fittings are provided for each joint. Dust shields are fitted over the ball and socket joints to hold in the lubricant and to prevent dust entering the joint.

217. Steering Gears

a. A steering gear mounted on the end of the steering column operates the steering gear arm which moves the steering linkage. A steering gear should permit easy steering without too many revolutions of the steering wheel to turn the vehicle wheels from hard over one way to hard over the other. Steering gears provide reductions of 11 or 12 to 1 for

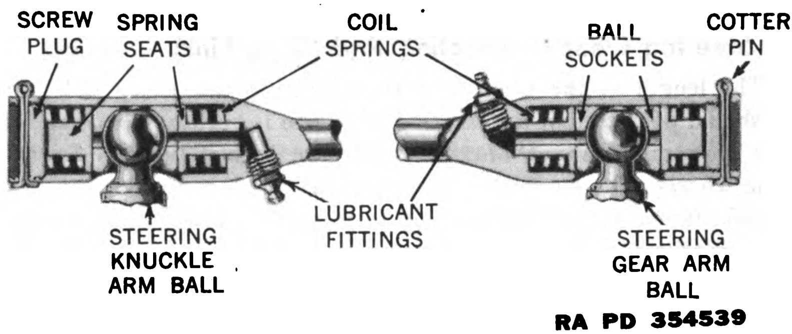


Figure 293a. Steering Gear Connecting Rod (Drag Link) Cross Section.

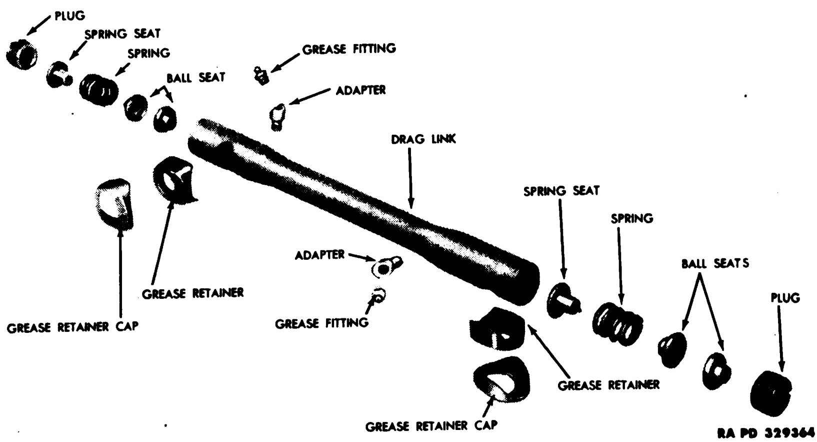


Figure 293b. Steering Gear Connecting Rod (Drag Link) Disassembled.

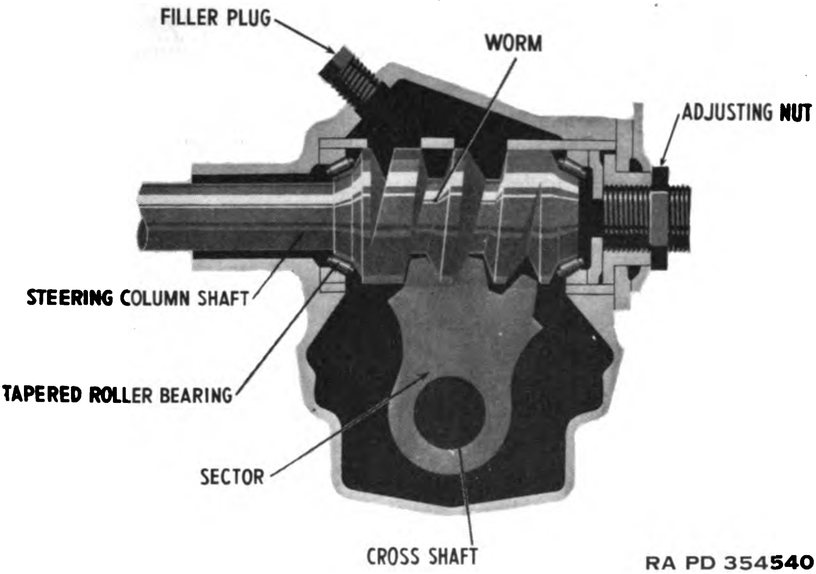


Figure 294a. Worm and Sector Steering Gear.

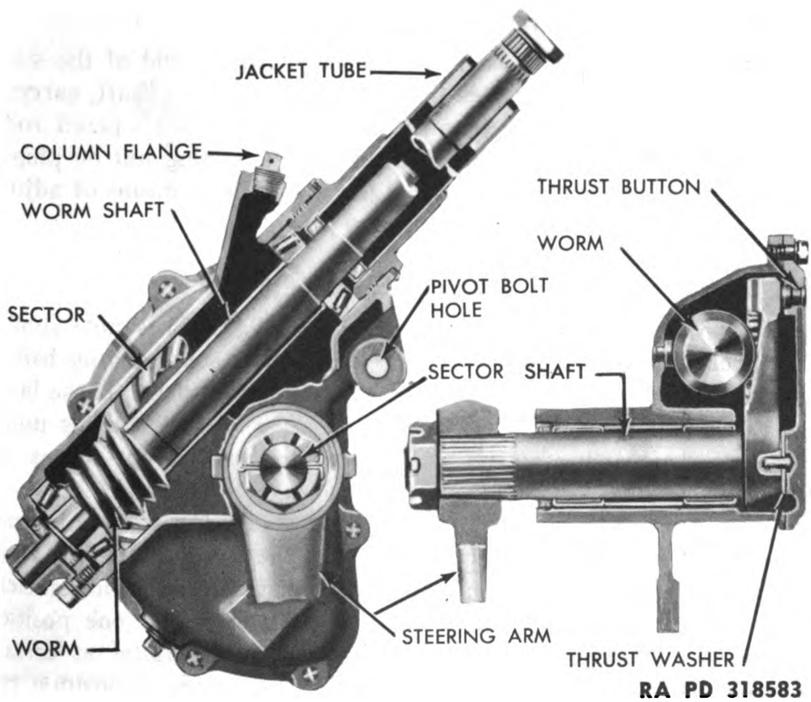


Figure 294b. Archimoid-type Worm and Sector Steering Gear

light cars up to 18 or 1 or more for heavy trucks. This means the steering wheel must be turned from 2½ to 3½ complete revolutions (turning the steering gear arm through an arc of about 70°) to turn the wheels from hard over one way to hard over the other.

b. Steering gears are designed so that they will transmit motion very easily in one direction for steering and transmit practically no motion in the other direction to reduce to a minimum the transmission of shocks to the driver.

c. Some of the early steering gears were of the plain pinion and bevel gear type, some were of the planetary type, others were spur gears. Some form of modification of the worm and gear principle is now the most widely used.

d. The steering wheel is mounted on the top of the steering column and turns a shaft within the steering column. This shaft has a worm mounted on its lower end within the steering gear housing. The worm is geared to a cross shaft that contains the steering gear arm. The method of gearing the steering column shaft to the cross shaft varies considerably with different types of steering gears.

218. Worm and Sector Steering Gear

a. In this type of steering gear (fig. 294) the cross shaft carries a gear that meshes with the worm on the steering column shaft. Only a sector of a gear is generally used since it turns through an arc of only 70°.

b. The steering wheel turns the worm on the lower end of the steering column shaft, which rotates the sector and the cross shaft, carrying the steering gear arm. The worm is assembled between tapered roller bearings which take both thrust and load. An adjusting nut or plug is provided for adjusting the end play of the worm. Some means of adjusting the end play of the cross shaft is also provided.

219. Worm and Roller Steering Gear

a. The worm and roller type of steering gear (fig. 295) is quite similar to the worm and sector type except that a roller is supported by ball or roller bearings within the sector mounted on the cross shaft. These bearings assist in cutting down frictional losses. As the worm turns under control of the steering wheel, the roller turns with it but forces the sector and the cross shaft to rotate.

b. The hourglass form of he worm, that is, tapering from both ends to the center, affords better contact between the worm and roller at all positions. It provides a variable ratio to permit faster and more efficient steering. Variable ratio means that the ratio is larger at one position than another; therefore, the road wheels are turned faster at certain positions than at others. At the center or straight ahead position the steering gear ratio is high, giving more mechanical advantage. However,

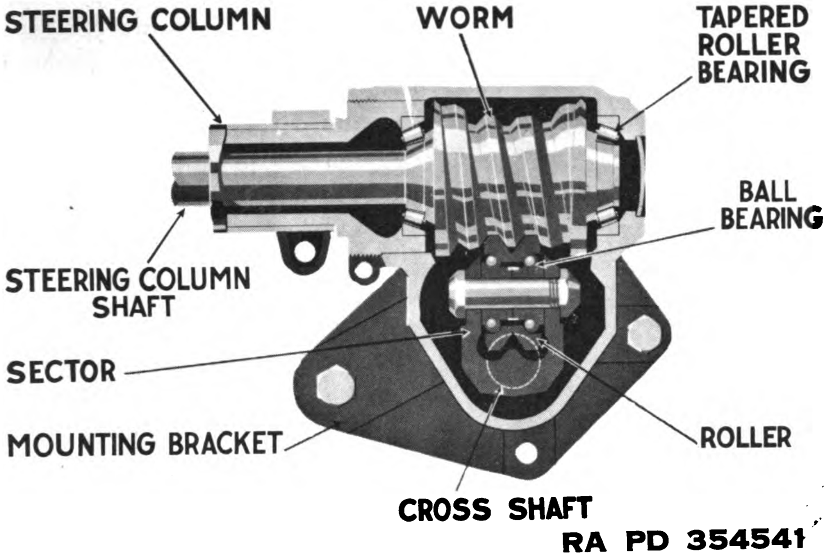


Figure 295. Worm and Roller Steering Gear.

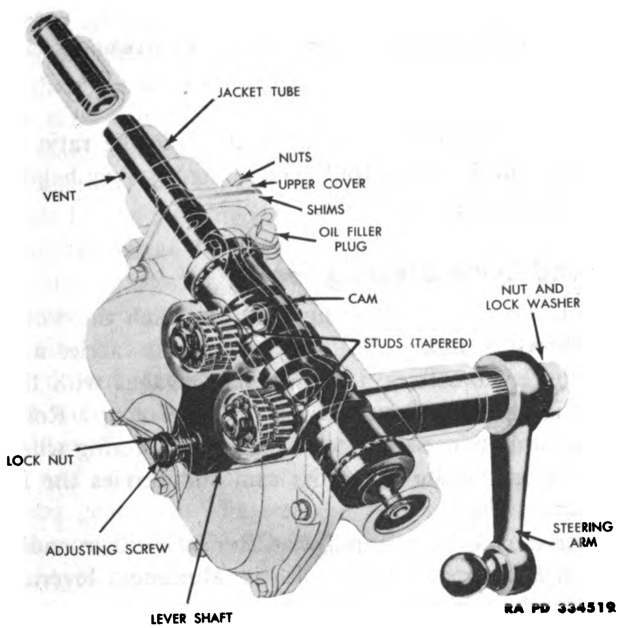
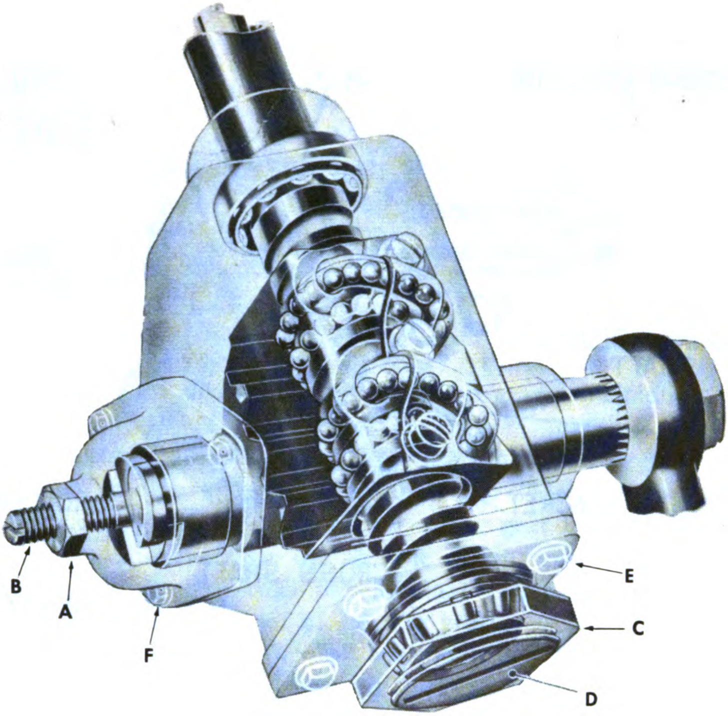


Figure 296. Cam and Twin Lever Steering Gear.



A LASH ADJUSTER SCREW LOCK NUT
B LASH ADJUSTER SCREW
C ADJUSTING SCREW LOCK NUT
D WORM BEARING ADJUSTING SCREW
E END COVER CAP SCREWS
F HOUSING SIDE COVER CAP SCREWS

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Figure 297. Worm and Nut Steering Gear (Recirculating Ball Type).

as the wheels are cramped or turned to the side the ratio decreases so that the action is much more rapid. This design is very helpful for parking or for maneuvering the vehicle.

220. Cam and Lever Steering Gear

a. A cam and lever type steering gear in which the worm is known as a cam is shown in figure 296. The cross shaft carries a lever on the inner end. This lever carries a stud which engages with the cam. The stud may be integral or mounted on roller bearings. Roller bearings reduce friction and allow easier steering. As the steering wheel is turned, the stud moves up and down on the cam and carries the lever with it to rotate the cross shaft.

b. The lever moves more rapidly as it nears either end of the cam since it is then at a greater angle with it. Maximum leverage occurs at the straight ahead position when the lever is at right angles to the cam. This makes the initial turning of the wheels easier. It is seen, therefore, that a variable ratio is obtained with cam and lever steering. A twin lever provided with two studs is used on a recent design for heavier vehicles to obtain more stable and positive steering.

221. Worm and Nut Steering Gear

a. Another form of steering gear is the worm and nut, which is made in several different combinations. A nut is meshed with the worm and screws up and down on it. The nut may operate the steering gear arm directly through a lever or through a sector on the cross shaft.

b. An example of the recirculating ball type of the worm and nut steering gear is shown in figure 297. In this steering gear the nut, which is in the form of a sleeve block, is mounted on a continuous row of balls on the worm to reduce friction. This ball nut is fitted with tubular ball guides to return the balls diagonally across the nut to recirculate them as the nut moves up and down on the worm. With this design, the nut is moved on the worm by rolling instead of sliding contact. Turning the worm moves the nut and forces the sector and the cross shaft to turn.

222. Four-wheel Driving and Steering

a. Four-wheel drive—a construction in which all four wheels of the vehicle drive, and sometimes steer—is used on many military vehicles. A typical construction for a wheel that drives and steers is illustrated in figure 298. A universal joint is used at the end of the axle shaft so that the wheel will be free to pivot at the end of the axle as well as be driven through the axle. The end or the axle housing encloses this universal joint and is provided with vertical trunnion pins which act as a steering knuckle pivot. The wheels, mounted on steering knuckles attached to these trunnion pivots, are thus free to turn about the pivots at the same time that they are driven through universal joints on the inner axle shaft. Steering knuckle arms are mounted on the steering knuckles so that the wheels can be turned about the trunnion steering knuckle pivots by the steering linkage.

b. All four wheels can be steered from the steering wheel by connecting the steering linkage of these wheels to the steering gear arm. The rear wheels are connected together by knuckle arms and a tie rod so that the steering linkage for both the front and rear wheels is similar to that already described for 2-wheel steering. Since the rear wheels must be turned in the opposite direction to the front wheels to travel in the same arcs about the center of rotation, the steering gear connecting rods to the front and rear wheel steering linkage cannot be directly connected to the steering gear arm. The steering gear connecting rod to the front wheels must move forward while the steering gear connecting rod to the rear wheel moves rearward, and vice versa. To accomplish this, an intermediate steering gear arm is pivoted on the frame side member near the middle of the vehicle. The steering gear connecting rods are connected

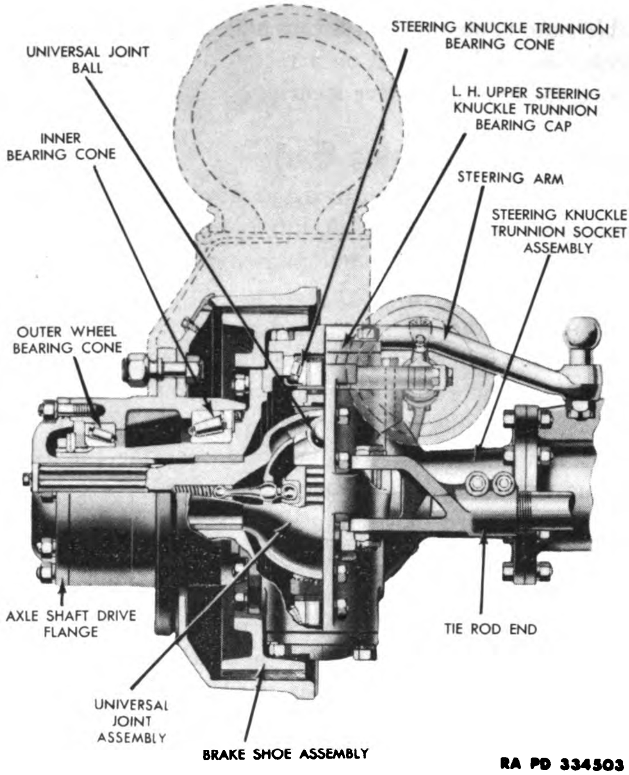


Figure 298. Axle End Construction for a Wheel That Both Drives and Steers.

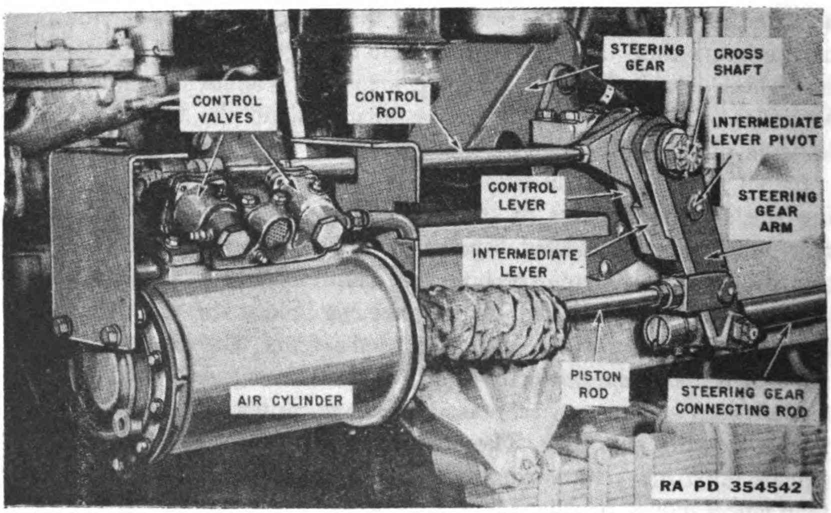


Figure 299. Air-steering Control.

to opposite ends of this arm so that, as it is turned by direct connection to the steering gear arm (by means of an intermediate steering gear connecting rod), the front and rear steering gear connecting rods are moved in opposite directions.

223. Air Steering

a. Heavy vehicles are difficult to steer because large loads on the tires increase their turning resistance. This difficulty cannot be overcome satisfactorily by using a steering gear with a very high reduction ratio, because it would require numerous revolutions of the steering wheel to turn the vehicle wheels. Some form of power steering to aid the driver in steering, the heavier vehicles is therefore desirable. Air steering is a very satisfactory method of power steering, because the heavier vehicles on which it would be used usually have an air-braking system from which the air pressure can be obtained. If there is no air-braking system, an air compressor and reservoir are required to obtain the necessary air pressure.

b. Air-steering control (fig. 299) consists primarily of three major units: a combination of levers mounted on the steering gear cross shaft; two control valves; and an air cylinder containing a double acting piston. The control valves are mounted directly on the air cylinder, each valve controlling one side of the cylinder. The air pressure delivered from the air line to the cylinder is proportional to the force applied on top of the valve piston plunger by the control rod (fig. 300). The valves are actuated by a rocker arm so that air is delivered to one side of the cylinder at a time. These valves are so adjusted that the air can be exhausted from both sides of the cylinder simultaneously, but air pressure can be delivered to only one side at a time.

c. Three levers (fig. 299) are mounted on the steering gear cross shaft: the control lever, the intermediate lever, and steering gear arm. The control lever is fixed directly to the steering gear cross shaft. The intermediate lever is pivoted near its center to the steering gear arm and at its lower end to the control lever.The upper end of the intermediate lever is bored slightly larger than the cross shaft, so that free motion is obtained, and is connected by a yoke to the control rod. The steering gear connecting rod is connected to the end of the steering gear arm, and the cylinder piston rod is connected just above it.

d. Turning the steering wheel turns the cross shaft and rotates the control lever in one direction or the other. If the control lever is moved to the right, the upper end of the intermediate lever, which is free moves to the left, because the intermediate lever is pivoted on the steering gear arm. This causes the control rod to move to the left and, through the rocker arm (fig. 300), to exert pressure on the plunger of the left control valve, which is connected to the left side of the cylinder. Thus, air under pressure will be admitted to the cylinder until the force on the piston in the cylinder is equivalent to the turning resistance of the wheels, and will move the piston rod to force the steering gear arm to the right. As long as the steering wheel is turned the valve will remain open. When the steering wheel stops turning, the piston continues to travel until the upper end of the intermediate lever shifts the control rod to the right and closes the left control valve, thereby cutting off any additional flow of air. The right control valve is operated in a similar manner when the control lever is rotated to the left and admits air to the right side of the piston, thereby moving the steering gear arm to the left.

e. Air-steering control reduces road shock and the tendency of the wheels to shimmy because operation of the control valves is reversed by a very slight movement of the steering gear connecting rod. The driver, in steering, must overcome a certain resistance predetermined by the system of levers exactly proportional to the angle of turn. If the air pressure fails the wheels can still be steered by physical effort.

224. Hydraulic Steering System (fig. 301)

The steering system consists of the steering gear assembly, which has a hydraulic cylinder with piston secured to the top of the steering gear housing, and a hydraulic control valve secured to the bottom of the steering gear housing. The hydraulic portion of the system consists of a hydraulic oil reservoir, secured to the inside of the rear engine cover, and connected by oil lines to a hydraulic pump located on the left side of the engine and driven by the engine sprocket chain. The hydraulic

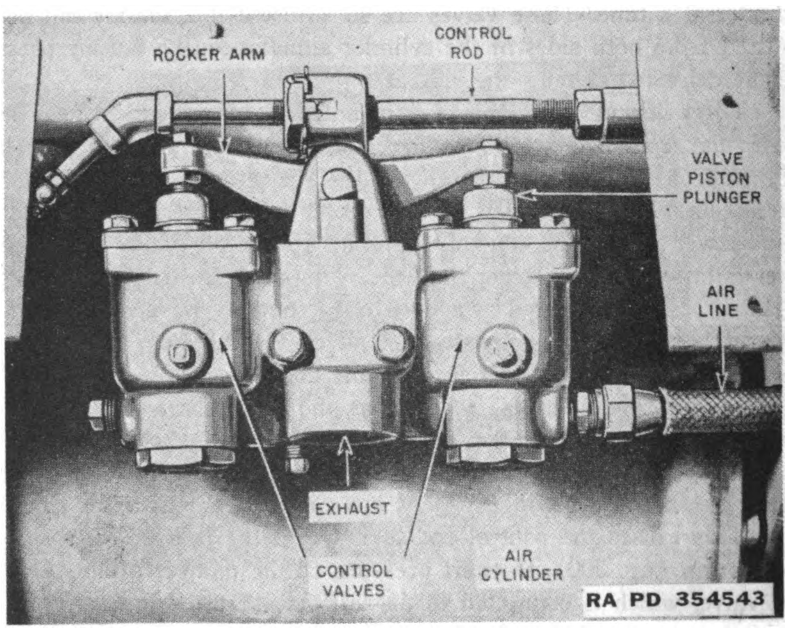


Figure 300. Top View of Air Cylinder Control Valves.

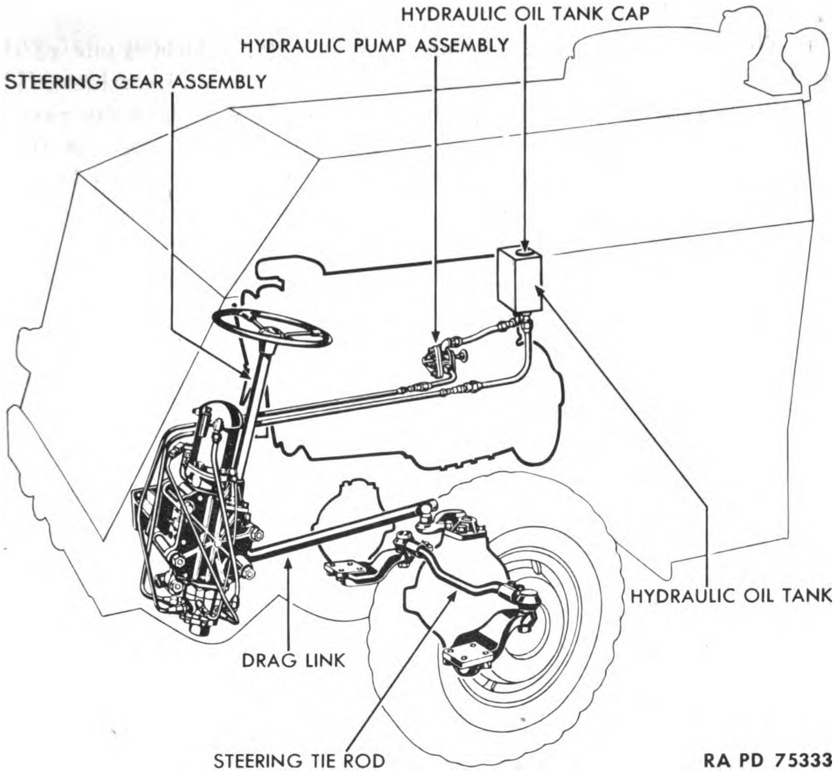


Figure 301. Hydraulic Steering System Schematic.

pump delivers the oil under pressure to the hydraulic control valve. A bypass is provided in the pump so that if oil is not required at the control valve, it is bypassed. If the steering wheel is turned to the right, or the left, the hydraulic system comes into operation automatically and is of great assistance to the operator in turning the vehicle. This is accomplished by piping the oil under pressure from the control valve to the hydraulic cylinder where it actuates the piston which applies pressure on the steering gear levers. Whenever effort at the steering wheel is released, the oil pressure becomes balanced and the hydraulic system is inoperative, causing the oil again to be bypassed at the pump.

Section II. WHEEL ALINEMENT

225. General

a. Wheel alinement is the mechanics of keeping all the interrelated parts of the front wheels properly adjusted. This is done to prevent pulling to the right or left, scuffed tires, wander, shimmy, tramp, and hard steering.

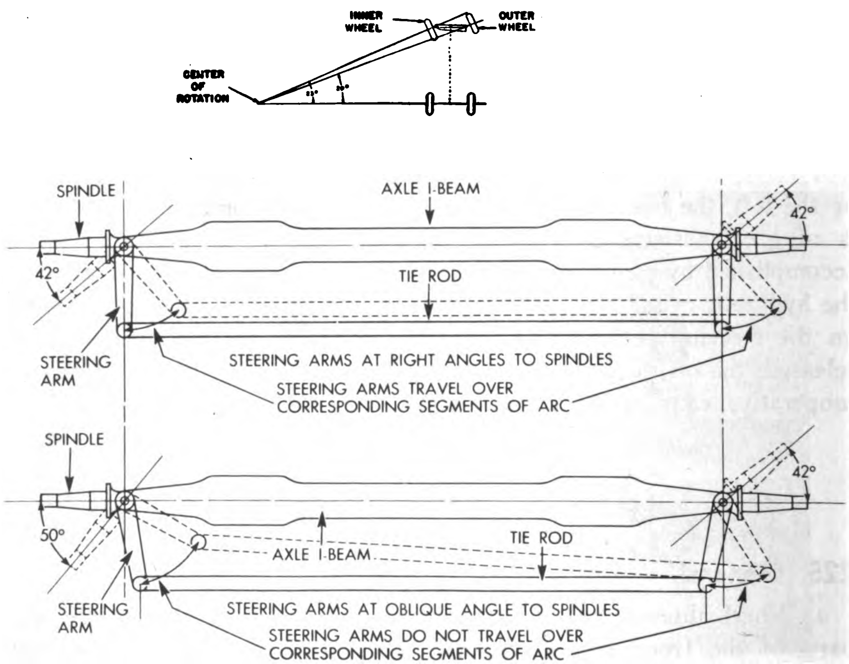
b. The front end assembly of the modern motor vehicle is one of the most remarkable engineering accomplishments on the entire vehicle. The steering linkage must be designed so the wheels will have the proper toe-out when turning. The steering knuckle pivots are castered, or tilted backward, and also cambered or tilted inward, to give a steering knuckle pivot inclination. The wheels are cambered, or tilted outward, and are also "toed-in" at the front.

c. Thus five main factors, all of them related and dependent upon each other, determine proper wheel alinement:

(1) Toe-out.
(2) Caster.
(3) Camber.
(4) Pivot inclination.
(5) Toe-in.

226. Steering Geometry

a. The front end assembly of the modern motor vehicle requires careful design and adjustment because each front wheel is separately pivoted on a steering knuckle ("Ackerman" steering) (fig. 289). Because of this construction, the front wheels, when a vehicle is making a turn, are not on the same radius line, drawn from the center of rotation (see



Turning Radius **RA PD 354544**

Figure 302. Steering Geometry (Illustrating Toe-out).

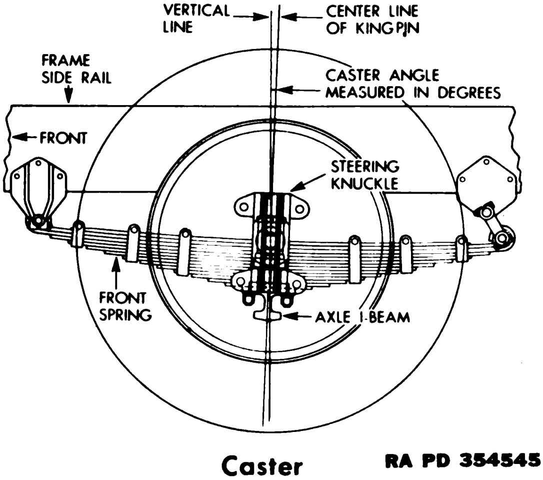


Figure 303. Positive Caster.

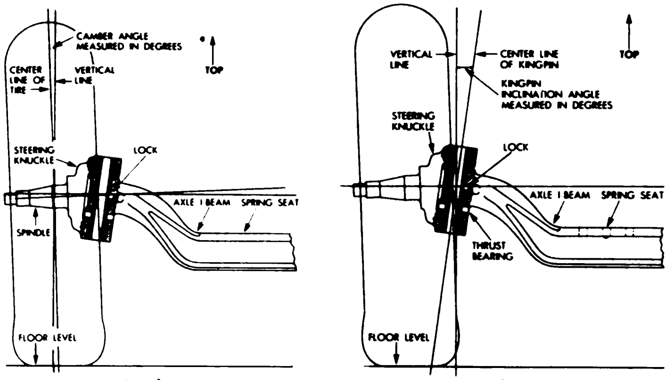
upper diagram, fig. 302). Since each wheel should be at right angles to its radius line, it is necessary for the front wheels to assume a toed-out position when rounding curves. If they do not, the tires slip which causes excessive tire wear.

b. The knuckle arms are tilted toward each other (fig. 302) so that when the wheels are turned they will no longer be parallel, the inner wheel (the one closer to the center of rotation) being turned more than the outer wheel so it will travel in a smaller radius. This difference, termed "toe-out", in the turning ratios of the two wheels due to steering geometry is usually specified as the number of degrees over 20 through which the inner wheel is turned when the outer wheel is turned 20°, that is, 3° in figure 302.

c. Analysis of this linkage will show that even though the wheels are turned different amounts, they do not have an exactly common center of rotation. All steering designs are necessarily close approximations to the ideal condition. They attempt to bring the center of rotation of both wheels close to the vehicle's center of rotation under all turning conditions. The exact amount of inclination of the steering knuckle arms toward each other is very carefully studied on any particular design.

227. Caster

a. Caster is the amount, measured in degrees, that the steering knuckle pivots are tilted forward or backward from the vertical when viewed from the side (fig. 303). Caster tends to keep the front wheels pointed straight ahead, hence making it easy to return the wheels to a straight ahead position after a turn has been made. The principle is exactly the same as that used in tilting the front fork of a bicycle, which makes it



Camber **Kingpin Inclination**

Figure 304. Camber and Pivot Inclination.

possible to ride the bicycle without grasping the handle bars. Part of the effort applied for turning castered wheels out of the straight ahead position slightly raises the front end of the vehicle upward. Consequently, when the steering gear is released, the weight of the vehicle forces the front end down and straightens the wheels. Caster is designated as positive for backward tilt and negative for forward tilt of the steering knuckle pivots.

b. With axle suspension, caster may be obtained by inserting a thin wedge or shim between the axle and the spring. The axle can be made so that the supports for the steering knuckle pivots are tilted from the vertical. In parallel arm suspension, caster is obtained by mounting the steering knuckle support in the control arms so that it is tilted the desired amount. If the axis of the steering knuckle pivot is extended, it must strike the ground ahead or behind the point where the tire meets the ground. The caster varies from ½ to 3° on modern vehicles.

228. Camber

Wheel camber (fig. 304) is the angle made by the wheel with the vertical when it is in the straight ahead position. Cambered wheels are closer together at the bottom than they are at the top. For many years, front wheel camber as great as 3° has been used. For driving on crowned roads, this camber permitted better rolling contact by bringing the wheel perpendicular to the road and made steering easier. In recent years, the use of flat roads and low pressure tires has led to a decrease in camber. If the vehicle should run on a flat road and had no lost motion at the bearings, zero camber would be ideal; but it is not practicable to build front axles with zero camber because of the possible accumulation of bearing clearances and the slight deflection of the axle under the vehicle load. Therefore, a camber of about 1° is recommended at present. Exces-

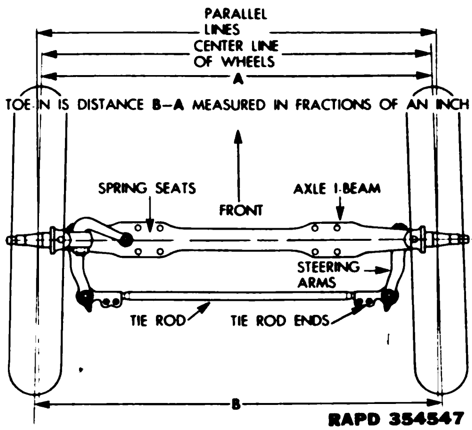


Figure 305. Toe-in.

sive camber causes continual slippage of the tire on the road, because each wheel tries to follow a path away from that traveled by the vehicle. This is due to the fact that a cambered wheel tends to roll like a cone because its axis is not horizontal.

229. Pivot Inclination

a. Pivot inclination is the amount in degrees that the steering knuckle pivots are tilted sideways toward the center of the vehicle (fig. 304). Inclination of the steering knuckle pivots tends to keep the wheel spindles pointed outward, in line with the axle, just as caster tends to keep the wheels of a vehicle pointed straight ahead. The effect is the same and will also result in easier steering.

b. Setting the steering knuckle pivot at an angle causes the pivot axis to meet the ground close to the center of tire contact (fig. 304). The wheel, therefore, has a small turning radius so that it will be easy to turn and will roll in a very small arc on the ground. Too much inclination makes it difficult to park a vehicle because, if the intersection of the pivot axis with the ground falls at the center of tire contact with the ground, the tire slides rather than rolls when the wheel is turned on a stationary vehicle. Pivot inclination is usually from 3° to 7°.

c. Careful distinction should be made between camber and pivot inclination (fig. 304). They are closely related and dependent on each other. Wheels with large camber require large pivot inclination and those with small camber require small pivot inclination. Pivot inclination allows the front wheel brakes to be applied with little effect on steering.

230. Toe-in

a. Toe-in (fig. 305) is the amount in inches that the wheels point in; that is, the distance between the front wheels is less at the front, A, than it is at the rear, B, figure 305. Toe-in and camber are definitely related and depend upon the crown of the road. For a flat road, experience indicates that a desirable condition is to have zero camber and zero toe-in. However, such a condition is difficult to maintain.

b. Toe-in balances the effect of camber on the tires. A cambered wheel is not vertical to a flat road, and the axis of the wheel, if prolonged, will intersect the road at some point to the side of the vehicle. The natural tendency of the wheel then, is to rotate like a cone about this point. If both front wheels are forced to follow a straight path by the motion of the vehicle, there is a continual tendency for tires to slip away from each other. Toed-in wheels tend to travel toward each other and counteract this condition. By properly relating camber and toe-in, tire wear is reduced to a minimum, the motion of the wheel is balanced between two opposing tendencies, and pull on the steering mechanism is reduced. The amount of toe-in is adjustable by changing the length of the tie rod.

CHAPTER 21

BRAKES

Section I. PRINCIPLES

231. Action

Braking action is the use of a controlled force to reduce the speed of, or stop a moving vehicle, or to keep a vehicle stationary. When the braking force is applied it develops friction, which does the braking. Friction is the resistance to relative motion between two surfaces in contact. Thus by forcing a stationary surface into contact with a moving surface, the resistance to relative motion or the rubbing action between the two surfaces will slow down the moving surface. Automotive vehicles are braked in this manner. Braking action may also be accomplished by establishing a rubbing contact with the roadway as is done by some trolleys which apply a braking surface to the rails. When a vehicle is decelerated, in gear, the engine itself produces some braking action, but this is of no concern in a discussion of the braking system.

232. Requirement

a. It is generally known that to increase a vehicle's speed requires an increase in the power output of the engine. It is equally true, although not so apparent, that an increase in speed requires an increase in the braking action necessary to bring a vehicle to a stop. A moving vehicle, just as any other moving body, has what is known as kinetic energy. This kinetic energy, which increases with the square of the speed, must be overcome by braking action. If the speed of a vehicle is doubled, its kinetic energy is increased fourfold; four times as much energy must therefore be overcome by the braking action.

b. Brakes must not only be capable of stopping a vehicle but must stop it in as short a distance as possible. Because brakes are expected to decelerate a vehicle at a faster rate than the engine can accelerate it, they must be able to control a greater power than that devloped by the engine. This is the reason that well-designed, powerful brakes have to be used to control the modern high speed motor vehicle. A comparison between the horsepower developed by the engine and the horsepower controlled by the brakes of a passenger car is shown in figure 306.

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c. It is possible to accelerate an average passenger car with an 80-horsepower engine from a standing start to 80 mph in 36 seconds. By applying the full force of the brakes, such a vehicle can be decelerated from 80 mph to a full stop in 4.5 seconds. The time required to decelerate to a stop is ⅛ the time required to accelerate from a standing start, hence the brakes handle eight times the power developed by the engine. Thus, about 640 (8x80) horsepower has to be expended by the friction surfaces of the brakes of an average passenger car to bring it to a stop from 80 mph in 4.5 seconds.

233. Vehicle Stopping Distance

Because of the physical laws of nature, no vehicle can be decelerated by brakes quicker than a definite rate even under ideal conditions. Therefore the minimum distance in which a vehicle can be stopped by brakes is limited. Another factor is driver reaction time—the time required for a mental response before the brakes are actually applied. During the time that the driver is thinking of applying the brakes and moving his foot to do so the vehicle will move a certain distance, depending on

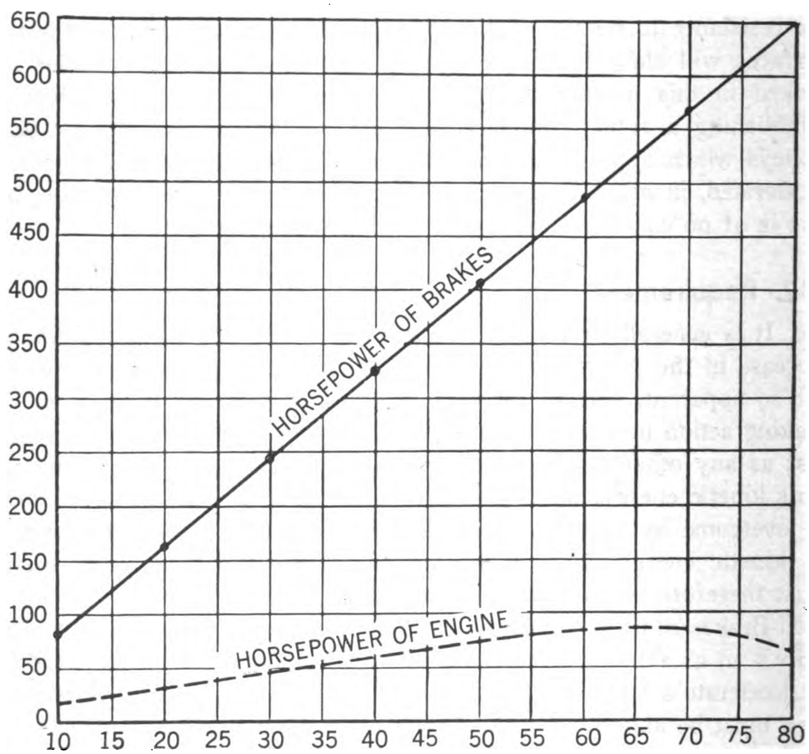

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Figure 306. Comparison of Engine Horsepower and Required Horsepower of Brakes.

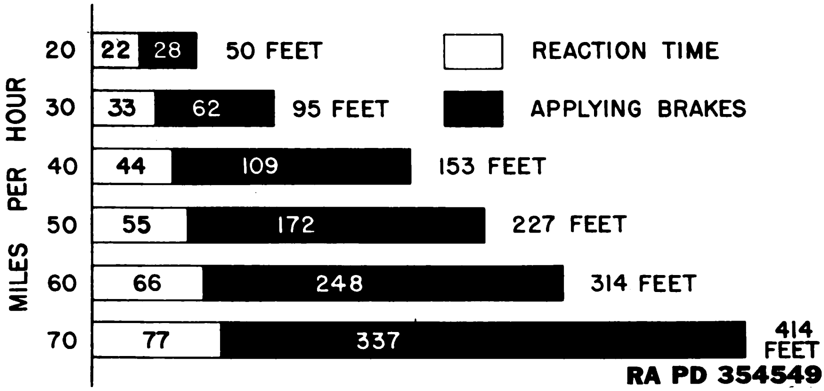


Figure 307. Total Vehicle Stopping Distances.

its speed. Thus, total stopping distance of a vehicle is the total of the distance covered during driver's reaction time and the distance during which brakes are applied before the vehicle stops. Figure 307 gives total stopping distance required at various vehicle speeds, assuming an average reaction time of ¾ second and that good brakes are applied under most favorable road conditions.

234. Factors Affecting Retardation

a. The amount of retardation obtained by the braking system of a vehicle is affected by several factors. For wheel brakes used on motor vehicles these are:

(1) Pressure exerted on braking surfaces (lining and drum).

(2) Weight carried on wheel.

(3) Overall radius of wheel (distance from center of wheel to outer tread of tire).

(4) Radius of brake drum (rotating member).

(5) Coefficient of friction between braking surfaces.

(6) Coefficient of friction between tire and road.

b. For a definite amount of retardation, exerted pressure required on braking surfaces will become greater when weight carried on the wheel or overall radius of the wheel is increased. These factors are independent of the design of the braking system and are generally a fixed value. However, limitations of these factors, particularly the weight of the vehicle to be carried by the wheels, must be considered when designing a braking system. If the radius of the brake drum or coefficient of friction between the braking surfaces is increased, less pressure will be required to obtain the same degree of retardation. The best results are obtained when these factors are correlated within the limits permitted by the design of the braking system. The coefficient of friction between tire and road determines maximum retardation obtained by the application of brakes.

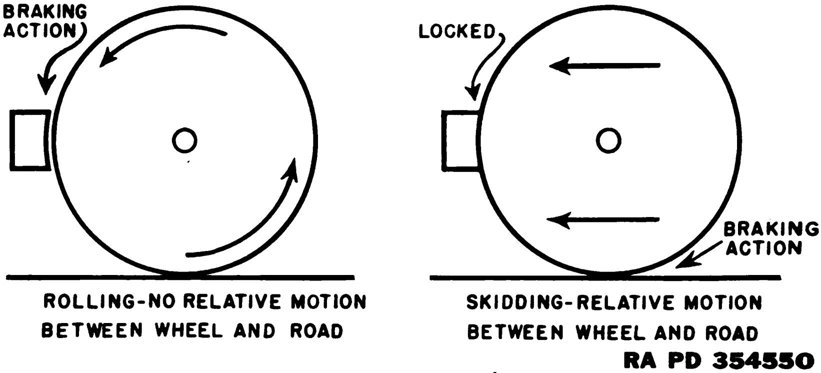


Figure 308. Action Produced When Wheel Rolls or Skids.

235. Maximum Retardation Point

a. When brakes are applied the wheel will either roll or skid, depending on relative values of coefficients of friction between braking surfaces and between tire and road. Rapidly jamming the braking surfaces together will tend to increase the friction to such a degree that the wheel will lock and skid along the road. When this happens braking action is caused by friction between tire and road, which heats and wears the tire.

b. Maximum retardation is reached when friction between the brake surfaces is such that the wheel is about to lock. At this point friction

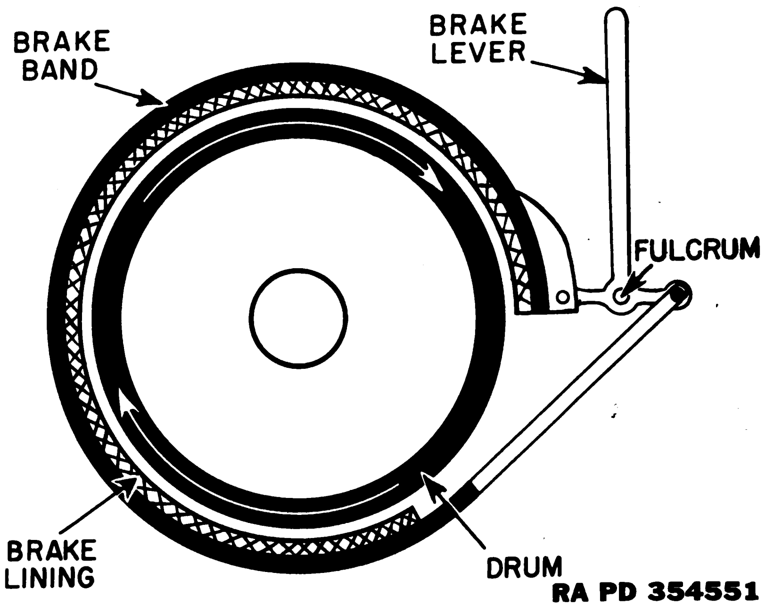


Figure 309. External Contracting Brake.

between the brake surfaces is almost the same as that between tire and road. This is the maximum amount of friction that can be used in retarding motion of the vehicle. Friction encountered between tire and road is the limiting factor of braking. Should friction between braking surfaces go beyond this, the braking surfaces will lock and the wheel will skid. The action produced when a wheel rolls and when it skids is shown in figure 308. When a wheel rolls along a road there is no relative motion at the point the tire makes contact with the road because the wheel rolls with the road surface, but when a wheel skids there is relative motion at the point of contact because the wheel is not rotating while moving over the road surface. When a wheel skids friction is reduced, which decreases the braking effect. Nevertheless, brakes are designed so that the vehicle operator is able to lock the wheels if he applies enough pressure on the foot pedal.

Section II. MECHANISMS

236. Rotating and Nonrotating Units

Brake mechanisms may be of various designs but they all require a rotating unit and a nonrotating unit, each containing one of the braking surfaces that are rubbed together to achieve the braking action. The rotating unit on motor vehicle wheel brakes consists of a drum secured

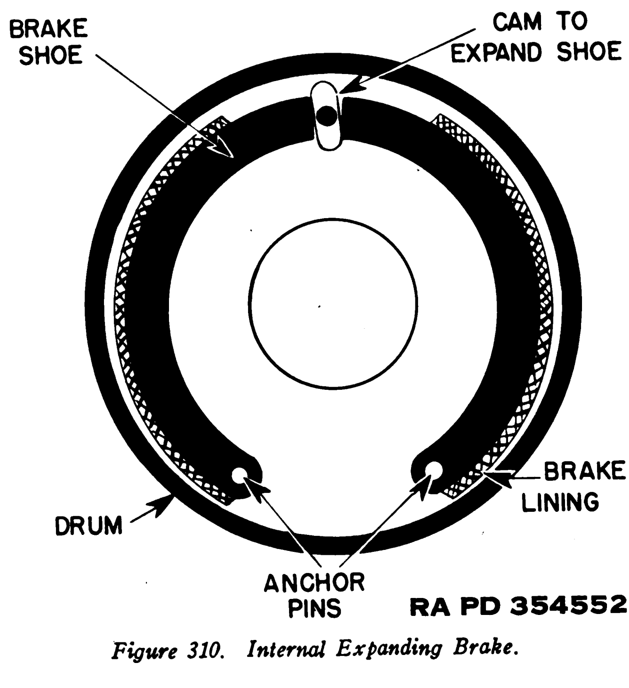


Figure 310. Internal Expanding Brake.

to the wheel. The nonrotating unit consists of brake shoes and linkage necessary to apply the shoes to the drum. Brakes are either of the external contracting or internal expanding type, depending on how the nonrotating braking surface is forced against the rotating braking surface.

237. External Contracting Brake

a. When brake shoes or a brake band is applied against the outside of the rotating brake drum, the brake is known as an external contracting type since the nonrotating braking surface must be forced inward around the drum to produce the friction necessary for braking. A brake using an external contracting band is shown in figure 309. The brake band is tightened around the drum by moving the brake lever.

b. Unless an elaborate cover is provided, the external contracting brake is exposed to dirt, water, and other foreign matter which rapidly wears the lining and drum and destroys their frictional properties. This is particularly true with wheel brakes.

238. Internal Expanding Brake

The nonrotating unit may be placed inside the rotating drum with the drum acting as a cover for the braking surfaces. This type of brake is known as an internal expanding brake because the nonrotating braking surface is forced outward against the drum to produce braking action. A brake using internal expanding shoes is shown in figure 310. This type of brake is used on the wheel brakes of the modern motor vehicle because it permits a more compact and economical construction. The brake shoes and brake operating mechanism may be conveniently mounted on a backing plate or brake shield made to fit against the open end of the brake drum and protect the braking surfaces from dust and other foreign matter.

239. Brake Drum

a. Brake drums are made of pressed steel, cast iron, or a combination of the two metals. Cast-iron drums dissipate the heat generated by friction more rapidly than steel drums and have a higher coefficient of friction with any particular brake lining. However, cast-iron drums of sufficient strength are heavier than steel drums. To provide light weight and sufficient strength, centrifuse brake drums (fig. 311) of steel with a cast-iron liner for the braking surface are used the most. A solid cast-iron drum of the same total thickness as the centrifuse drum would be too weak while one of sufficient strength would be too heavy for the average passenger car. To give greater strength and better heat dissipation, cooling ribs are sometimes added to the outside of the drums.

b. Braking surfaces of drums may be ground or they may be smoothly machined to a finish. For good braking action the drum should be perfectly round and have a uniform surface. Brake drums become "out of

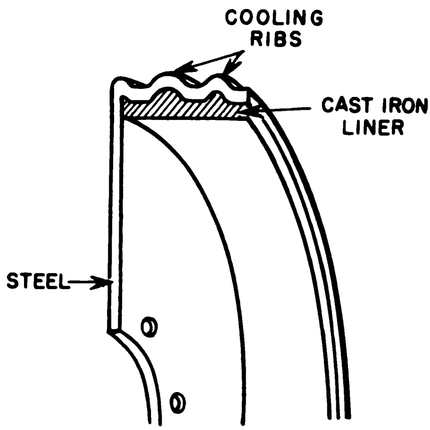


Figure 311. Centrifuse Brake Drum.

round" due to pressure exerted by brake shoes or bands and due to heat developed by application of the brakes. The brake drum surface becomes scored when it is worn by braking action. When the surface is badly scored or the drum more than .010 in. out of round, it is necessary to replace the drum or regrind it or turn it down in a lathe until the drum is again smooth and true. Care must be taken that the drums do not become too thin as pressure exerted by the brake band or shoe may distort them or cause a severe squeak.

240. Brake Shoe

a. Brake shoes are made of malleable iron, cast steel, drop forged steel, pressed steel, or cast aluminum. Pressed steel is generally used because it is cheaper to produce in large quantities. Steel shoes expand at about the same rate as the drum when heat is generated by brake application, thereby maintaining the clearance between the brake drum and shoe under most conditions.

b. A friction lining riveted to the face of the shoe makes contact with the inner surface of the brake drum. Semitubular brass rivets are used because brass does not unduly score the drums when the lining is worn. Aluminum rivets are not very satisfactory because they are corroded very readily by salt water.

c. It is not always necessary to rivet the lining to the shoes. In some brakes the lining is not fastened to either the shoes or the drum, but floats between them and is held in place by a lining retainer on one side and the brake shield on the other.

241. Lining

Variation in brake design and different conditions of operation make it necessary to have various types of brake lining. Woven or molded

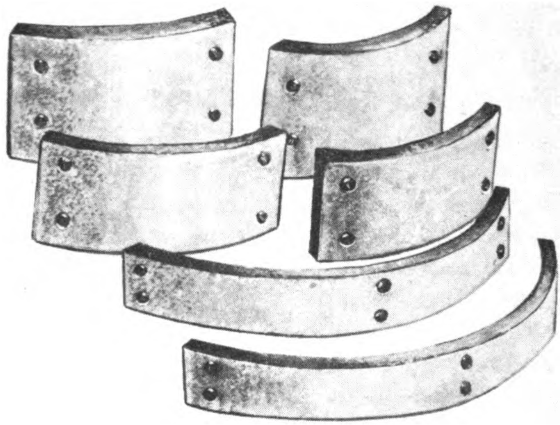


Figure 312. Molded Brake Lining.

brake linings are used in automotive vehicles. Molded lining is made of dense, hard, compact materials and cut into blocks to fit different sizes of brake shoes (fig. 312). Its frictional qualities are low because it has a smooth surface, but it dissipates heat rapidly and wears longer than the woven type. Woven lining is made of asbestos fiber, cotton fiber, and copper or bronze wire (fig. 313). After being woven, the lining is treated with compounds intended to lessen the effects of oil and water if they should come in contact with it. However, even after treatment, oil in particular will reduce the frictional quality of the lining. The lining is also compressed and heat treated before being installed. The main advantage of a woven lining is its high frictional qualities. It does not dissipate heat as rapidly as molded lining.

242. Transmission Brake

a. General. The auxiliary brake mechanism is often a separate mechanical hook-up applied to the transmission. This arrangement provides a separate means for braking the vehicle if trouble occurs in the service brakes. The two types of transmission brakes in common use are contracting and disk.

b. Contracting. (1) A typical contracting transmission brake is shown in figure 314. The drum is splined on the transmission mainshaft. The brake must be designed for either forward or backward motion of the car. For this reason the brake band is anchored at a point just opposite that at which the operating force is applied. The halves of the brake band then wrap against the drum, preventing rotation in either direction.

(2) The mechanism for operating this brake is usually a simple bell crank arrangement controlled by the hand lever. A spring disengages

the brake band lining when the actuating pressure is released. Various other mechanisms are employed for operating contracting transmission brakes.

c. DISK. The disk brake is generally mounted on the rear of the transmission case or on a cross member of the frame. It is designed to dissipate rapidly the heat generated in braking. The rotating member of the brake (fig. 315) consists of a specially designed steel disk splined to the transmission mainshaft. This disk has two faces which act as the

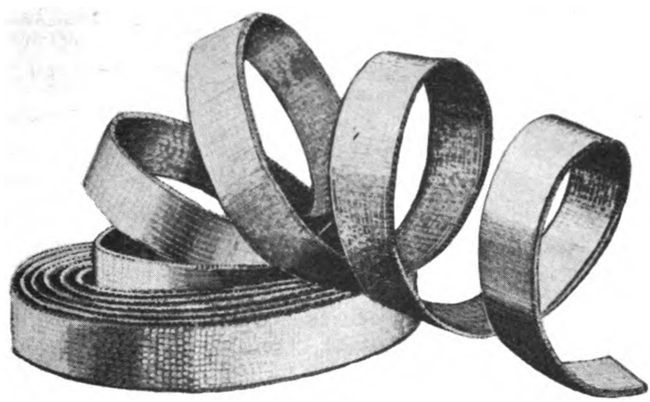


Figure 313. Woven Brake Lining.

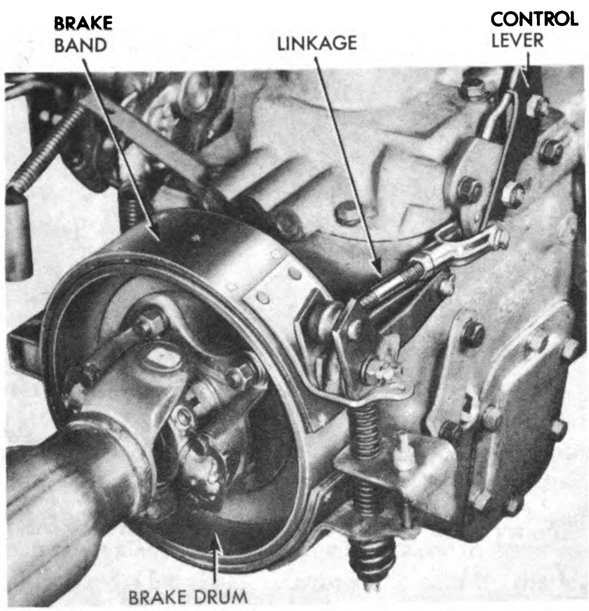


Figure 314. Contracting Transmission or Propeller Shaft Brake.

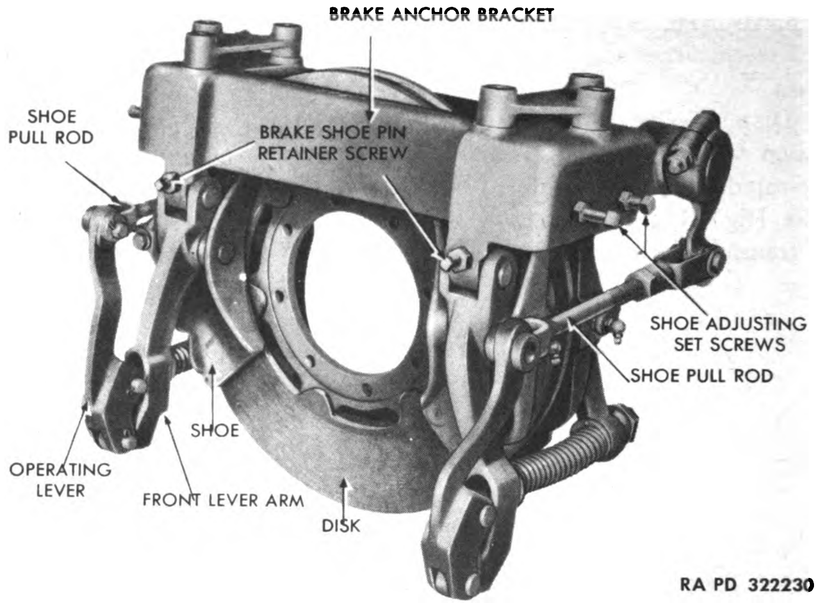


Figure 315a. Disk Transmission Brake—Front View.

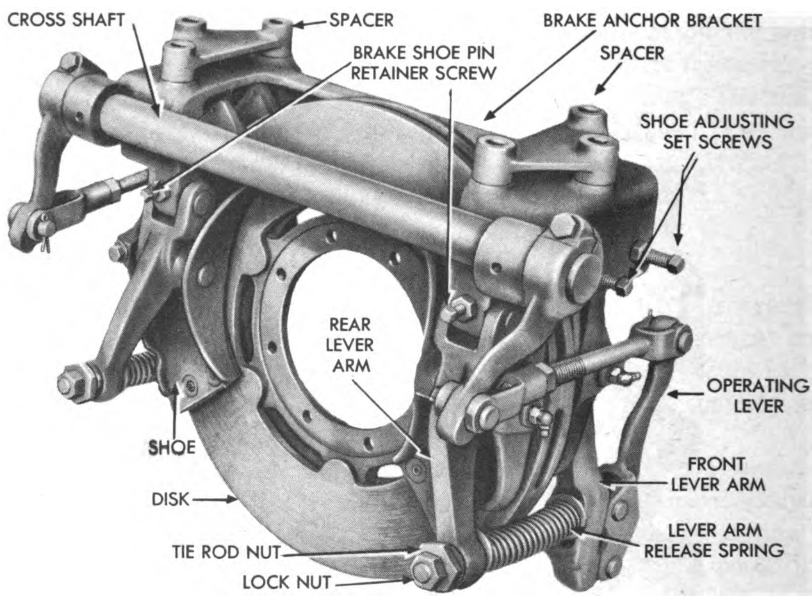


Figure 315b. Disk Transmission Brake—Rear View.

rotating braking surface. Between them are air passages so arranged that a large volume of air passes through them to cool the braking surface when the disk is rotating. One brake shoe covers ¼ of each disk face. The shoes are supported on swinging brackets and are clamped against the disk faces by means of a camlever arrangement. A spring removes the shoes from the disk faces when the hand lever is released.

d. PARKING BRAKE. The parking brake is operated by a hand lever in the driver's compartment and is used to keep the vehicle stationary when no driver is present. It may act on the wheels but usually acts on the transmission and is located immediately behind the transmission or transfer assembly.

e. ADVANTAGES AND DISADVANTAGES OF TRANSMISSION BRAKES. Transmission and transfer assembly brakes are theoretically more efficient than wheel brakes, since the braking effort is multiplied by the final-drive ratio, and their braking action is perfectly equalized through the differential. Practically, however, they cannot be made as powerful as wheel brakes. In the first place, they put a severe strain on the power-transmission system; in the second place, they are not positive in action for they do not prevent differential action from taking place in the drive axle. Thus, under some conditions the vehicle can move while the brake is applied.

243. Wheel Brake

a. The wheel or service brakes used for retarding and stopping modern motor vehicles operate on all four wheels. Early motor vehicles had wheel brakes on the two rear wheels only, but this practice is obsolete. Four-wheel brakes give increased braking effect and also make possible a much smoother, more even braking action, thereby reducing the tendency to skid. Wheel or service brakes are interconnected so that they may be adjusted to operate together from one control.

b. Mounting of rotating and nonrotating units of the brake on the wheel is shown in figure 316. The brake drum is mounted directly on to the wheel and provides the rotating braking surface. The brake shield, sometimes called the backing plate or dust shield, is mounted on some fixed structure such as the axle housing, and forms a support for the nonrotating braking surface and its operating mechanism.

c. The brake shoes may be anchored to the brake shield by separate pins or by the same pin. Conical springs usually are used to keep the shoes in position close to the brake shield. A fairly strong retracting spring is hooked between the shoes to pull them away from the drum when the brakes are released (fig. 317). With a mechanical hook-up, pressure can be applied to the brake shoes by means of a cam, toggle, or double lever arrangement. A cam turned by a small lever is the method most frequently used (fig. 310). Turning the cam by the lever tends to spread the brake shoes and push them outward against the drum. The

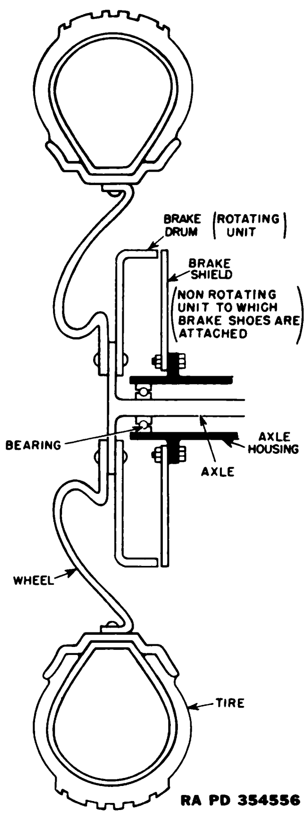


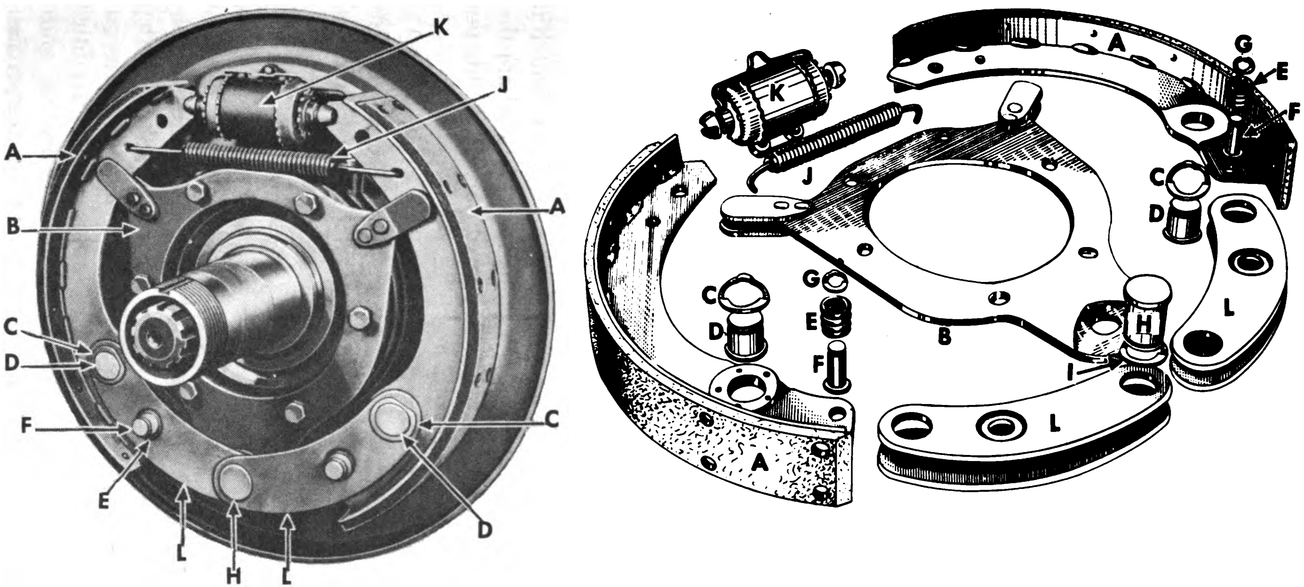
Figure 316. Wheel Brake Mounting.

material of the wearing surfaces against which the cam bears must be able to withstand considerable pressure, since lubrication at this point is difficult and since some road grit is certain to find its way into the brake drum. With a hydraulic system, pressure is applied to the brake shoes by means of a wheel cylinder.

244. Self-energizing Action

a. The brake-operating linkage alone does not provide sufficient mechanical advantage for positive braking. Some means of supplementing the physical application of the braking system has to be used to increase pressure on the brake shoes. A self-energizing action is very helpful in accomplishing this, once setting of the shoes is started by physical effort. While there are variations of this action, it is always obtained by the shoes themselves which tend to revolve with the revolving drum.

b. When the brake shoe is anchored as shown in figure 318, and the drum revolves in the direction shown, the shoe will try to revolve with the drum when it is forced against the drum. As a result the shoe will exert considerable pressure against the anchor pin. Since the pin is fixed



A BRAKE SHOE AND LINING
B FRONT BRAKE SHOE ANCHOR PLATE ASSEMBLY
C FRONT BRAKE SHOE LINK PIN LOCK
D FRONT BRAKE SHOE LINK PIN
E PIN SPRING
F PIN
G PIN LOCK
H ANCHOR PIN
I ANCHOR PIN LOCK
J FRONT BRAKE SHOE RETURN SPRING
K FRONT BRAKE SHOE WHEEL CYLINDER
L FRONT BRAKE SHOE LINK

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Figure 317. Articulating Link Wheel Brake.

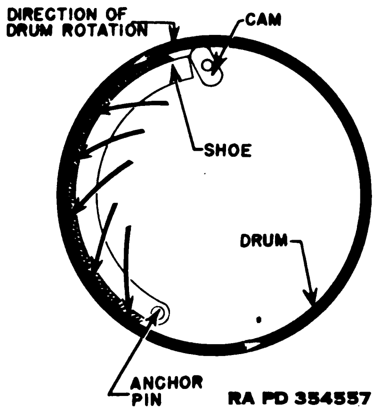

Figure 318. Brake Shoe Self-energizing Action.

to the brake shield, this pressure will tend to wedge the shoe tightly in between the pin and the drum as shown. As the initial braking pressure is increased on the cam, the wedging action increases and the shoe is forced still more tightly against the drum to increase the friction. This self-energizing results in more braking action than could be obtained with the actuating pressure alone. Brakes making use of this principle to increase pressures on the braking surfaces are known as self-energizing (servo) brakes.

c. It is most important that the operator control the total braking action at all times; therefore, the self-energizing action should increase only upon application of additional actuating pressure at the brake pedal. The amount of self-energizing action available depends mainly on location of the anchor pin. As the pin is moved toward the center of the drum, wedging action increases until a point is reached where the shoe will automatically lock. The pin must be located outside of this point so that the operator can control the braking.

d. When two shoes are anchored on the bottom of the brake shield, as shown in figure 310, self-energizing action is effective on only one shoe. The other shoe tends to revolve away from its pivot which reduces its braking action. When the wheel is revolving in the opposite direction, the self-energizing action is produced on the opposite shoe.

e. Two shoes are usually mounted so that self-energizing action is effective on both. This is accomplished by pivoting the shoes to each other and leaving the pivot free of the brake shield. The only physical effort required is for operating the first or primary shoe. Both shoes then apply additional pressure to the braking surfaces with no increase in the pressure on the operating linkage. The anchor pins are fitted into slots in the free ends of the brake shoes. This method of anchoring allows the movement of the shoes necessary to expand against the drum when the shoes are forced against the drum, the self-energizing action

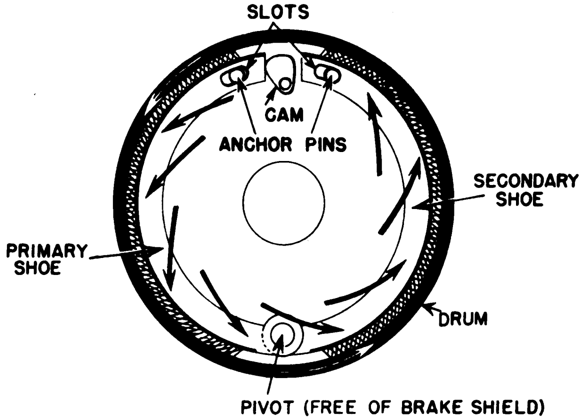

Figure 319. Mounting for Two Self-energizing Brake Shoes.

of the primary shoe is transmitted through the pivot to the secondary shoe, as shown in figure 319. Both shoes will tend to revolve with the drum and will be wedged against the drum by the one anchor pin. The other anchor pin will cause a similar action when the wheel is revolving in the opposite direction. Hence both shoes are self-energizing in either direction.

f. Another type of brake shoe mounting (fig. 317) consists of two links anchored together on the brake shield with the end of each link pivoted to one of the brake shoes. This articulated mounting allows more even application of the braking surfaces because of the freedom of movement of the brake shoes. Each shoe is self-energizing in opposite directions. The amount of self-energization and the degree of control by the operator depend on the anchor position of the links.

Section III. MECHANICAL SYSTEM

245. Means of Actuation

a. The energy supplied by the operator's foot in pushing down on the brake pedal is transferred to the brake mechanism on the wheels by various means. A mechanical hook-up has been used since the earliest motor vehicles, but hydraulic pressure is most extensively used at the present time. Mechanically-operated braking systems are practically obsolete. However, mechanical hook-ups are used for a portion of the braking systems in many vehicles.

b. Power-operated brakes have come into widespread use on heavy-duty vehicles. The power medium acts as a booster to assist the operator in applying the brakes. Air, vacuum, and electric systems are employed to obtain power operation of the brakes. These systems are discussed in section V.

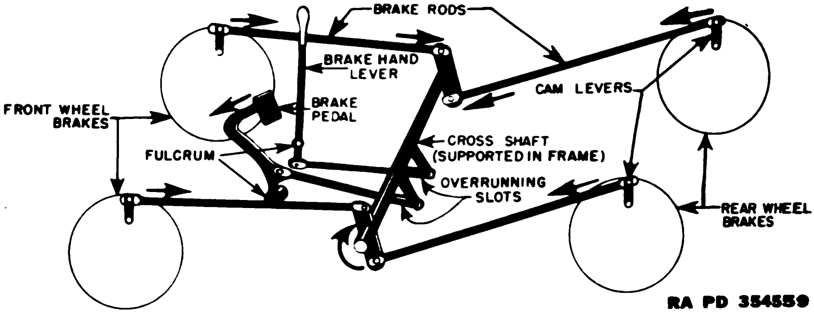

Figure 320. Mechanical Brake System with Single Cross Shaft.

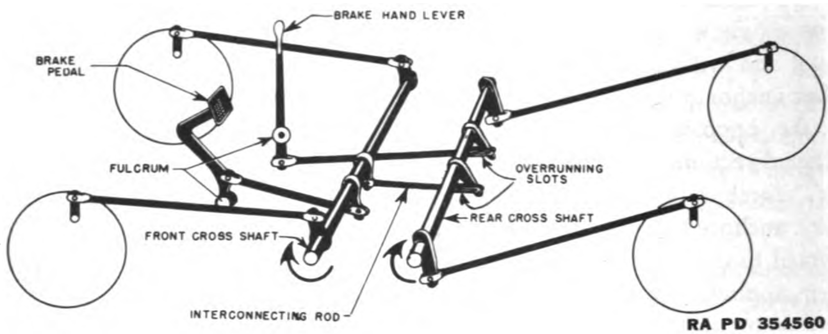

Figure 321. Mechanical Brake System with Two Cross Shafts.

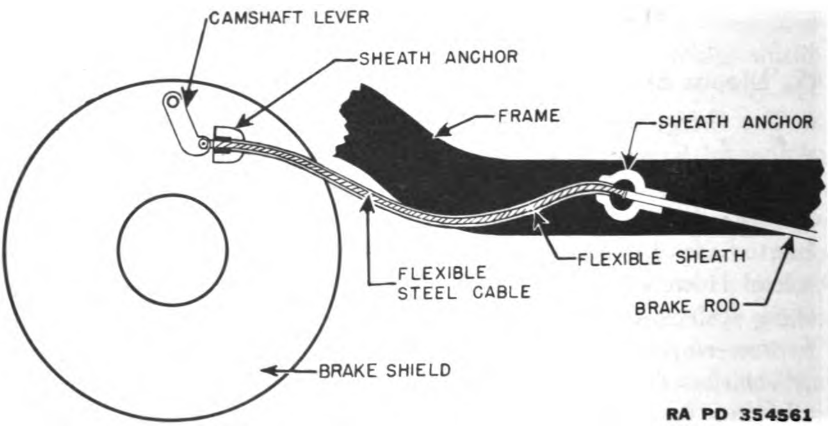

Figure 322. Brake Operating Flexible Steel Cable.

246. Hook-up

a. CROSS SHAFT. (1) In a mechanical braking system the force applied to the pedal is transmitted to the brakes by means of rods and cables. The mechanical linkage may be arranged in various ways but its operation is essentially the same. In order to have all the wheel brakes applied uniformly, a cross shaft is provided near the center of the vehicle frame on which are mounted the levers connected to the rods and cables leading to the wheel brakes. The brade pedal is also connected to a lever on the cross shaft, as shown in figure 320.

(2) When the pedal is depressed, the cross shaft shown in figure 320 is turned so that the levers on the top of the shaft are turned backward and those on the bottom of the shaft forward. Thus by connecting the front brake rods to the levers on the top of the shaft and the rear brake rods to the levers on the bottom of the shaft, all the brake rods are pulled together and the four wheel brakes are applied at the same time.

(3) The usual practice in mechanical systems has been to link the handbrake to the footbrake so that both operate the same braking units. With such an arrangement the handbrake linkage incorporates an overrunning slot in the handbrake pull rod where it is connected to a lever on the cross shaft. This allows the pedal linkage to operate without interference from the hand lever. Both controls may be independely operated by also incorporating an overrunning slot in the footbrake linkage.

b. TWO CROSS SHAFTS. In some mechanical brake arrangements two cross shafts are provided so that the handbrake is applied to the shoes on the rear wheels only (fig. 321). The front and rear cross shafts are connected together by an interconnecting rod joined to a lever on each shaft. An overrunning slot must be provided on the interconnecting rod and the handbrake pull rod as shown in figure 321, if only the rear wheel brakes are to be applied by the brake hand lever. Some braking systems incorporate additional shoes on the rear wheels for the handbrake, in which case the handbrake has its own cross shaft and hook-up and is in no way connected with the foot or service brakes.

247. Front-wheel Control

The hook-up of the brake rods to the front wheels must be designed to allow the wheels to turn without locking in any position. If the front wheels lock, steering is destroyed. One means of controlling the front wheels is the use of the brake rod attached to a camshaft with a small universal joint above the steering knuckle pivot. A more popular and satisfactory method employes a flexible steel cable connecting the end of the brake rod to the brake camshaft lever (fig. 322). Because of the flexibility of the cable and its sheath, motion of the wheel does not affect tension on the cable. Flexible steel cables may also be used advantageously on the rear wheels because of the vibration of the wheels when traveling over the road. On some braking systems the pressure on the wheel brakes

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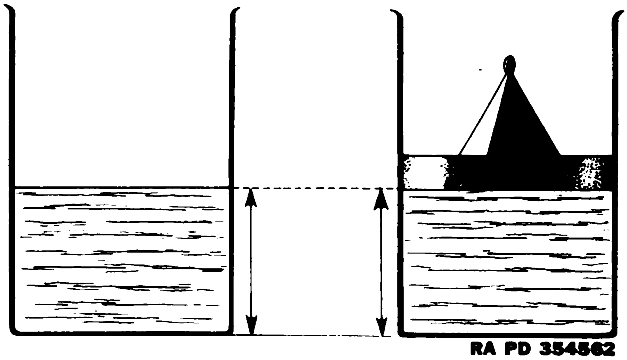

Figure 323. Non-compressibility of Liquids.

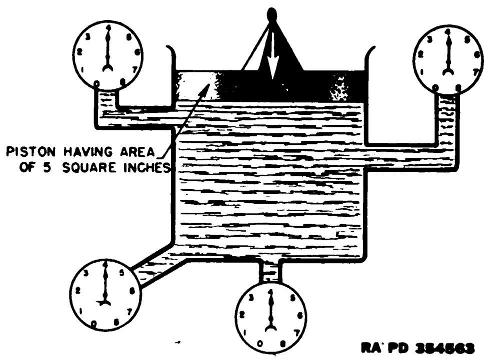

Figure 324. Equal Distribution of Force Upon Confined Liquid.

is evenly distributed by various types of equalizers. Equalizers are designed to take up all the slack in the hook-up to each brake so that all brakes will be applied at the same time. This prevents the possibility of too much pressure being applied to any one brake which would lock that wheel and probably make the vehicle skid. One of the main reasons why the mechanical braking system is being supplanted is the difficulty of maintaining equal pressure on all brakes.

Section IV. HYDRAULIC SYSTEM

248. Principles

a. In hydraulic braking systems, pressure applied at the brake pedal is transmitted to the brake mechanism by a liquid. To understand how pressure is transmitted by a hydraulic braking system, it is necessary to understand the fundamentals and principles of hydraulics. Hydraulics

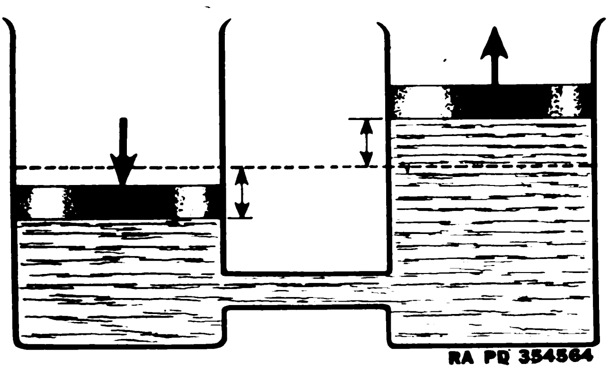

Figure 325. Jars of Same Diameter Interconnected.

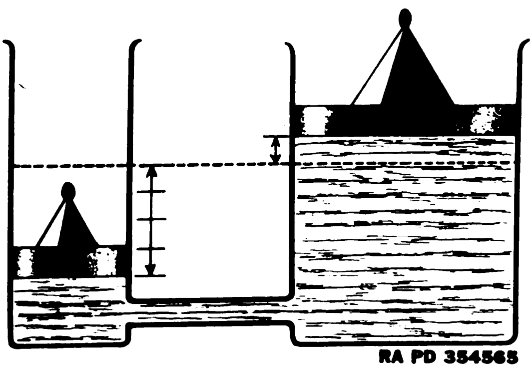

Figure 326. Jars of Different Diameters Interconnected.

is the study of liquids in motion or the pressure exerted by liquids conveyed in pipes or conduits.

b. One well-known hydraulic principle is that liquids cannot be compressed under ordinary pressures. This may be demonstrated by placing a weight on top of a piston fitted to a jar as shown in figure 323. The force of the weight does not change the level of the liquid, hence it does not diminish the volume or compress the liquid.

c. Another well-known hydraulic principle is that force exerted at any point upon a confined liquid is distributed equally through the liquid in all directions. That is, if a total force of 20 lb, including piston and weight, is placed upon liquid and if the piston in the jar has an area of 5 sq in., then the unit hydraulic pressure is increased by $20/5 = 4$ pounds per square inch, or psi (fig. 324). A gage inserted at any point in the jar will indicate an additional pressure of 4 psi since the liquid transmits the pressure equally throughout the jar.

d. Use of these hydraulic principles may be illustrated by interconnecting two jars of the same diameter containing liquid, as shown in

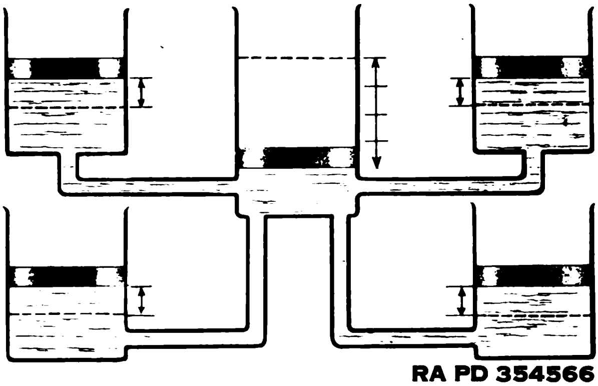

Figure 327. Four Jars Connected to a Central Jar.

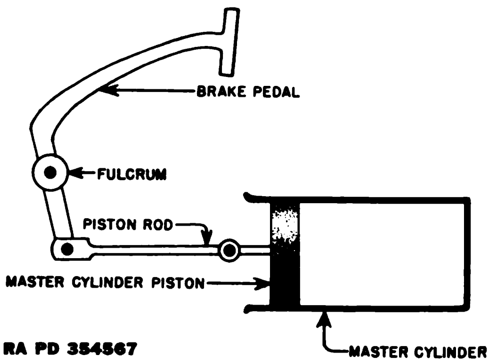

Figure 328. Foot Pedal Linkage to Piston in Master Cylinder.

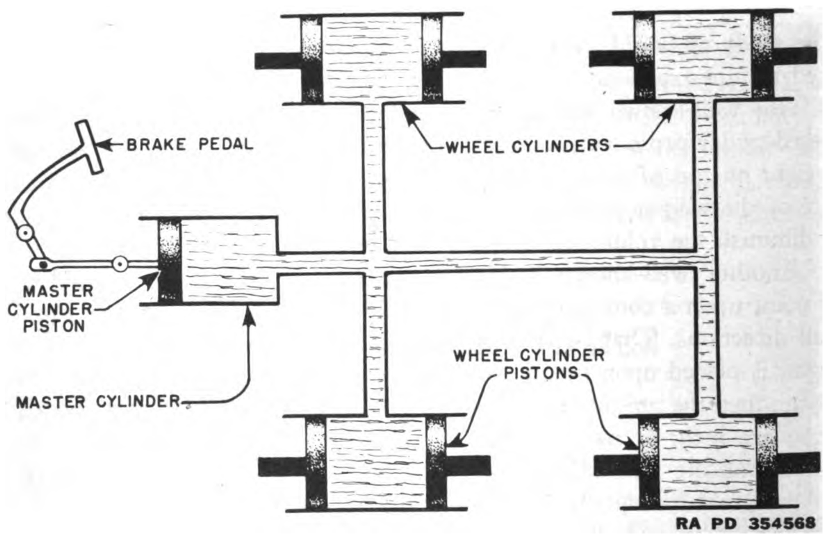

Figure 329. Diagram of Hydraulic Brake System.

figure 325. If a force is exerted on a piston in one jar (the left jar in fig. 325), a piston placed in the other jar will receive the same amount of force due to the transmission of pressure by the liquid. When the areas of the two pistons are equal, moving one piston produces identical movement in the other piston since the liquid is not compressible and maintains the same volume.

e. By connecting one jar with another jar which has twice the diameter and therefore four times the area of the first jar (fig. 326), the results are somewhat different, although the same basic facts apply. When a force is exerted on the piston in the small jar, the piston in the large jar will receive four times as much force because the hydraulic pressure acts on four times the area. Since the liquid will always occupy the same volume, the large piston will move ¼ as far as the small piston. Thus a mechanical advantage is obtained very similar to that obtained from a simple lever.

f. With four jars connected to a central jar, all of the same diameter, as shown in figure 327, an approximation of the action in four-wheel brakes is obtained. A force exerted on the piston in the central jar will be transmitted to each of the other jars so that the piston in each will receive an identical force but will move only ¼ as far as the central piston.

g. If the four jars have a larger diameter than the central jar, then the total pressure on each of the four pistons is greater than that applied to the central one, and each of the four pistons moves less than ¼ as far as the central piston. Hydraulic brake systems operate in such a manner.

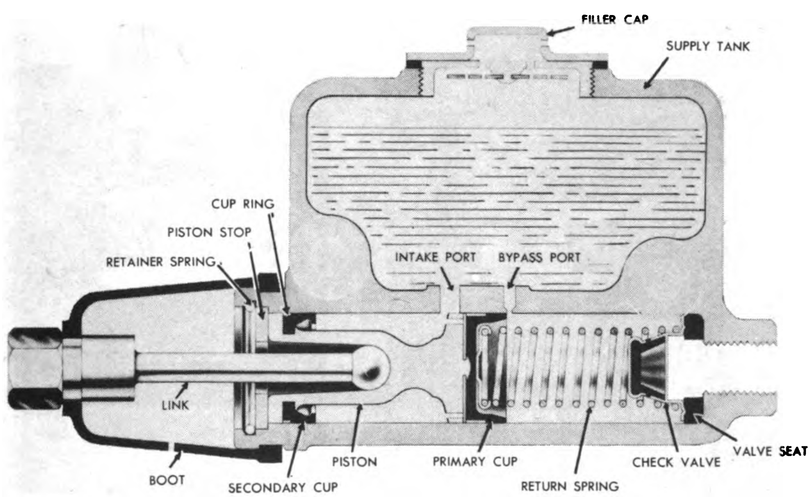

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Figure 330. Master Hydraulic Brake Cylinder Cross Section.

249. Operation

a. In a hydraulic brake system, force is applied to a piston in a master cylinder that corresponds to the central jar in figure 327. The brake pedal operates the piston by a linkage as shown in figure 328. Each wheel brake is provided with a cylinder fitted with opposed pistons connected to the brake shoes.

b. The brake pedal when depressed moves the piston within the master cylinder, thus forcing the brake liquid or fluid from the master cylinder through tubing and flexible hose into the four wheel cylinders. A diagram of a hydraulic brake system is shown in figure 329.

c. The brake fluid enters each of the wheel cylinders between opposed pistons, making the pistons move the brake shoes outward against the brake drum. As pressure on the pedal is increased, greater hydraulic pressure is built up within the wheel cylinders, and consequently greater force is exerted against the ends of the shoes.

d. When pressure on the pedal is released, retracting springs on the brake shoes return the wheel cylinder pistons to their release position, thus forcing the brake fluid back through the flexible hose and tubing to the master cylinder.

250. Master Cylinder

a. General. The master cylinder housing is an iron casting incorporating a large reservoir for the brake fluid (fig. 330). The cylinder is

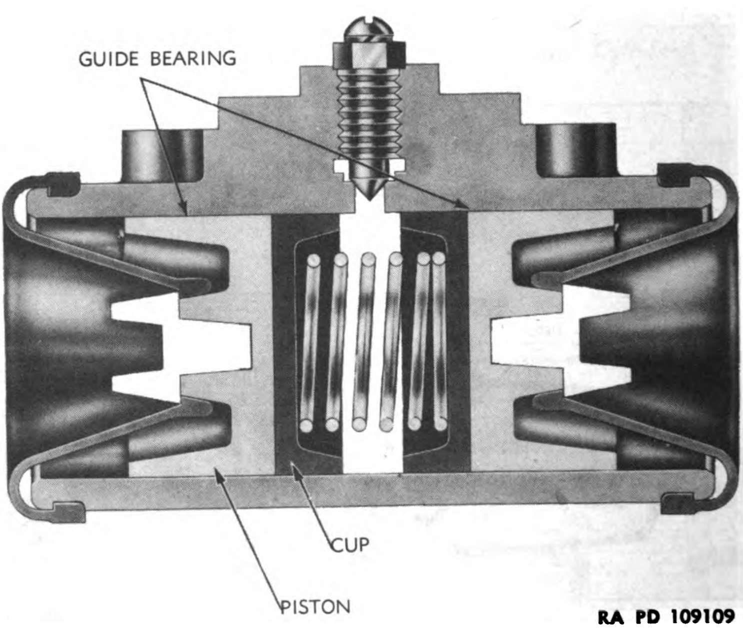

Figure 331. Wheel Cylinder Cross Section.

sometimes a unit by itself, in which case a supply tank is provided to feed the fluid to the master cylinder by gravity. The reservoir carries sufficient reserve fluid to insure proper operation of the braking system. It is filled through a hole at the top which is well sealed by a removable filler cap containing a vent. The cylinder is connected to the reservoir by two drilled ports, a large breather port and a small compensating port.

b. PISTON. The piston is a long, spool-like member with a rubber seal at the outer end and a rubber primary cup which acts against the brake liquid just ahead of the inner end. This primary cup is kept against the end of the piston by a return spring. A steel stop disk, held in the outer end of the cylinder by a ring retainer, acts as a piston stop. A rubber boot covers the piston end of the master cylinder to prevent dust and other foreign matter from entering it. This boot is vented to prevent air from being compressed within it.

c. CHECK VALVE. In the head of the master cylinder is a combination inlet and outlet check valve held in place by the piston return spring. The valve shown in figure 330 consists of a rubber valve cup incased in a steel valve cage which seats on a rubber valve seat that fits in the end of the cylinder. In some designs, the check valve consists of a spring-operated outlet valve seated on a valve cage rather than a rubber cup outlet valve. The principle of operation is the same. The piston return spring normally holds the valve cage against the rubber valve seat to seal the brake fluid in the brake line.

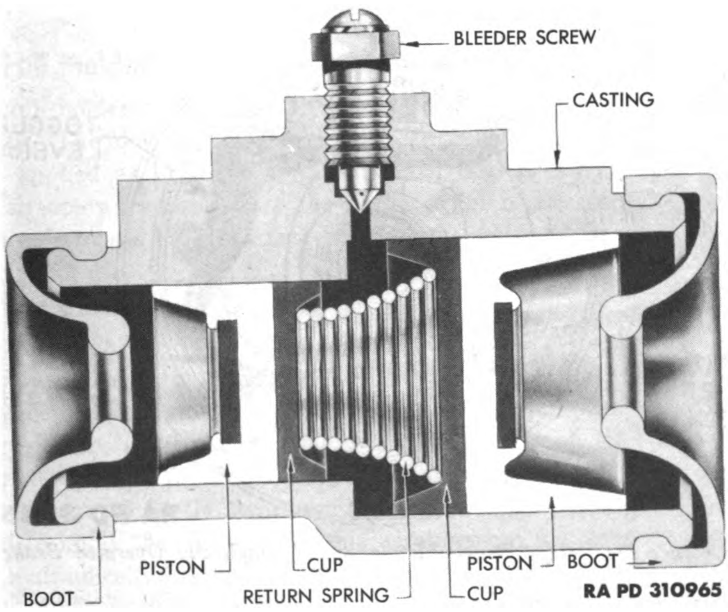

Figure 332. Stepped Wheel Cylinder Cross Section.

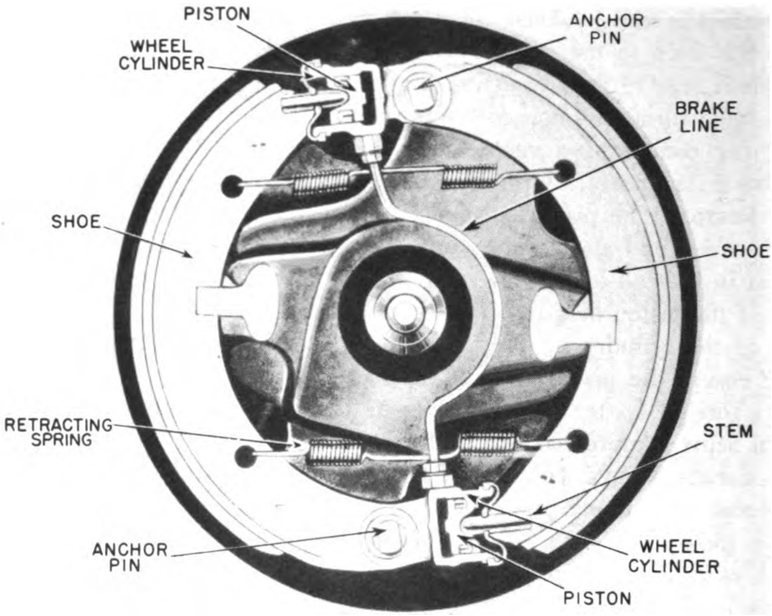

Figure 333. Two Single Piston Cylinder Mounting.

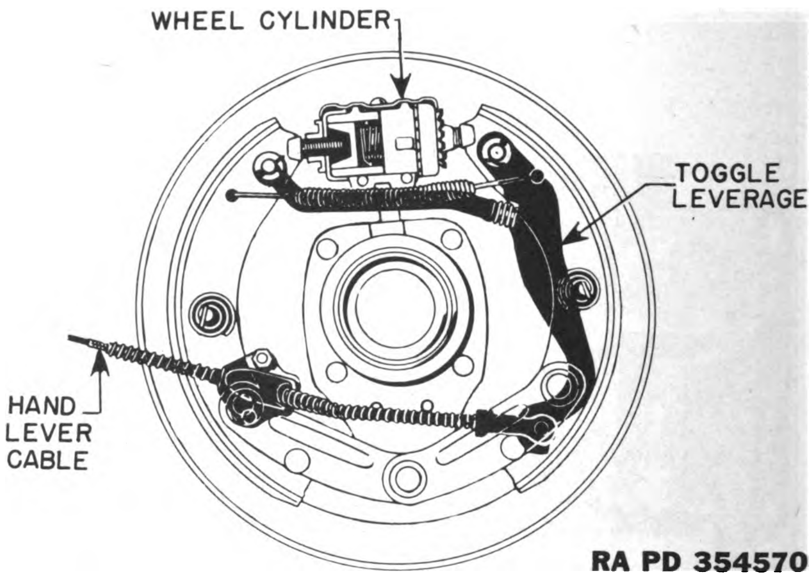

Figure 334. Hand Brake Linkage on Hydraulically Operated Brake.

251. Wheel Cylinder

a. The wheel cylinder changes hydraulic pressure to the mechanical force that actually pushes the brake shoes against the drums. The wheel cylinder housing is a casting mounted on the brake backing plate. Inside the cylinder (fig. 331) are two pistons that are moved in opposite directions by hydraulic pressure and at the same time they push the shoes against the drum. The pistons or piston stems are connected directly to the shoes. Rubber piston cups fit tightly in the cylinder bore against each piston to prevent the escape of brake liquid. There is a light spring between the cups to keep them in position against the pistons. The open ends of the cylinder are fitted with rubber boots to keep out foreign matter. Brake fluid enters the cylinder from the brake line connection between the pistons. At the top of the cylinder between the pistons is a bleeder hole through which air is released when the system is filled with brake fluid.

b. Variation in Arrangement. A stepped wheel cylinder is used to compensate for faster rate of wear on the front shoe than on the rear shoe due to self-energizing action. By using a larger piston for the rear shoe, the shoe receives more pressure to offset the self-energizing action on the front shoe. This requires a stepped wheel cylinder with two bore sizes (fig. 332). If it is desired that both shoes be independently self-energizing, especially, on front wheels, it is necessary to have two wheel cylinders, one for each shoe. Each cylinder has a single piston and is mounted on the opposite side of the brake backing plate from the other cylinder (fig. 333).

252. Hill Holder

The hill holder provides greater ease of vehicular control on hills and in traffic. The device is connected to the clutch pedal and keeps the brakes applied as long as the clutch pedal is depressed when the car is on an upgrade, even after the brake pedal is released. The driver is then able to use his right foot for the accelerator pedal.

253. Handbrake and Dual Brake System

a. The handbrake in vehicles with a hydraulic system operates mechanically either on a transmission brake or on the brake shoes of the rear wheels. The transmission brake, entirely independent of the hydraulic system, is of the type described in paragraph 242. When the handbrake operates on the wheels, it is usually linked to the same shoes that are operated by the hydraulic pistons. A toggle leverage (fig. 334) is used to apply the shoes. With this arrangement the shoes are applied either hydraulically by the brake pedal or mechanically by the hand lever.

b. In addition to the hydraulic system some cars are fitted with a mechanical device designed to act on rear wheel brakes after the brake pedal has traveled a predetermined distance toward the toeboard. In normal operation, braking action is wholly one of hydraulic force, the mechanical hook-up working in connection with the hydraulic system. With the correct quantity of fluid in the lines and brakes properly set, the mechanical hook-up is inactive; however, if the hydraulic system fails, the mechanical linkage acts as a safeguard. This mechanical hook-up serves a further use as it may be connected to the handbrake lever for parking.

254. Brake Fluid

The liquid used for hydraulic braking is termed "brake fluid." It is composed chiefly of equal parts of alcohol and castor oil. This combination forms a liquid that does not freeze or boil at the temperatures encountered in year-around operation of motor vehicles.

a. Brake Lines. The brake lines which transmit the fluid from the master cylinder to the wheel cylinders are made of tubing and flexible hose. Connections are tight so that no liquid can escape from the system. Tubing and flexible hose must be able to withstand hydraulic pressure developed when the brakes are fully applied.

b. Bleeding. Air enters the hydraulic brake lines and wheel cylinders if fluid level is too low, if fluid leaks out, or if any part of the system is disconnected. Since air seriously affects braking efficiency, the hydraulic system is usually bled whenever brakes are adjusted. All wheel cylinders must be separately bled to make sure that all air is removed.

Section V. POWER-OPERATED BRAKES

255. General

Heavy motor vehicles and their towed loads require, in general, more powerful braking effect than can be exerted by the unaided efforts of the operator. There have been three systems developed in which the operator simply controls a valve or switch which releases stored energy as needed to produce braking action of the desired intensity. The actuating force is produced by compressed air, vacuum, or electricity.

256. Air System

a. General. The fundamental characteristics of this system is that the brakes, although controlled by the driver, are applied by pressure of compressed air. Compressed air provides sufficient braking force to control even the heaviest vehicles.

b. Compressed-air Principle. Unlike liquids, gases are easily compressed. If a gas such as air is confined and a force applied to it, it is compressed and has less volume. Such a force may be exerted by placing a weight on a piston that fits into a container as shown in figure 335.

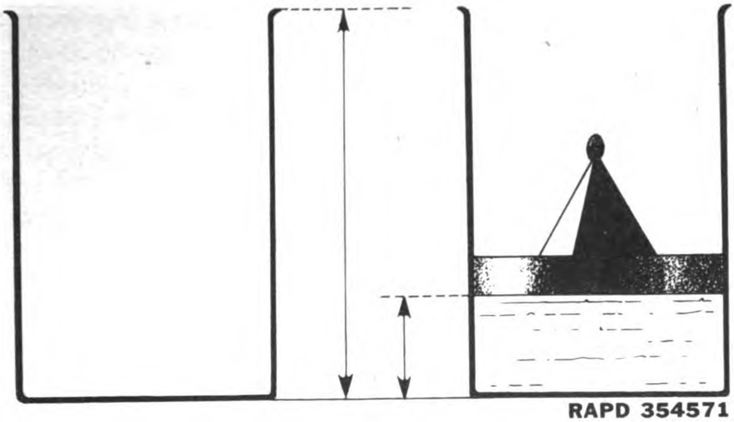

Figure 335. Compressibility of Gas.

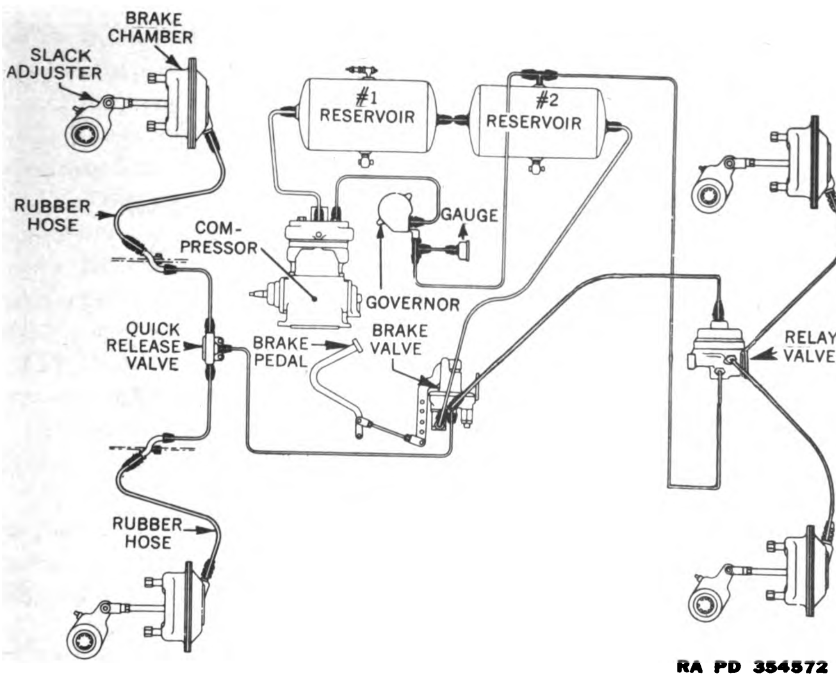

Figure 336. Diagram of Typical Air Brake System.

The air that originally filled the entire container as shown in figure 335 (left) is pressed into only a portion of the container due to the force of the weight upon it as shown in figure 335 (right). The pressure of the compressed air due to the force exerted upon it by the weight will be equally distributed in all directions just as it is in a liquid. Compressed air may be conveniently stored under pressure and made available for the power application of brakes.

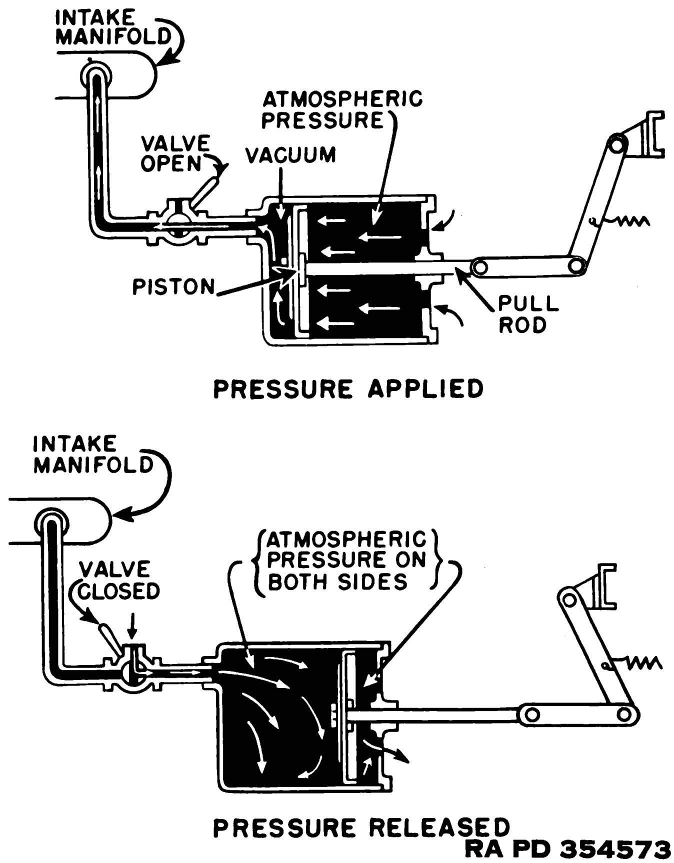

Figure 337. Action of Vacuum Power Brake Cylinder.

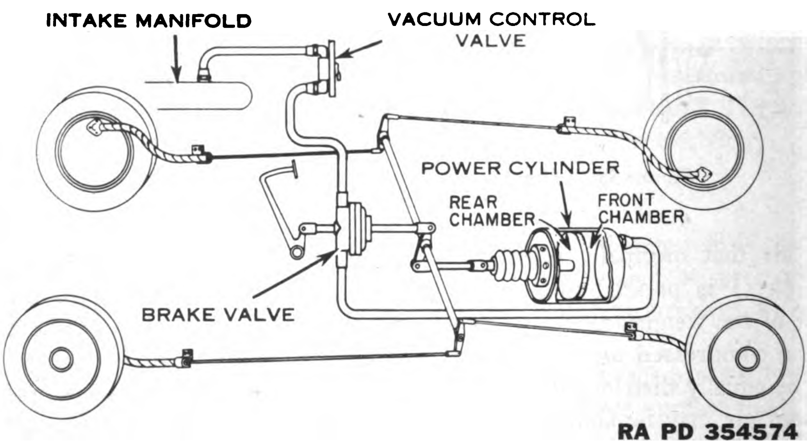

Figure 338. Atmospheric Suspended Brake System.

c. ESSENTIAL ACTION. An air pump or compressor driven by the engine is used to compress air and force it into a reservoir where it is stored under pressure and made available for operating the brakes. Air under presure in the reservoir is released to the brake lines by an air valve operated by the brake pedal. This released air goes to brake chambers located close to the wheel brakes which contain a flexible diaphragm. Against this diaphragm is a plate which is directly connected by linkage to the mechanism on the wheel brakes. The force of the compressed air admitted to the chamber causes the diaphragm to move the plate and operate the brake shoes through the linkage. Considerable force is available for braking since operating air pressure may be as high as 100 psi. All brakes on a vehicle, and on a trailer when one is used, are operated together by means of special regulating valves. Operation of trailer brake systems is described in chapter 24.

d. FUNDAMENTAL UNITS. A diagram of a typical air brake system used on a motor vehicle is shown in figure 336. The fundamental units and their functions are:

(1) Compressor, driven directly from engine crankshaft or from one of auxiliary shafts to furnish compressed air for brake operation.

(2) Governor, to limit pressure produced by compressor within a predetermined range.

(3) Reservoir, to receive air from compressor and store it for use in the braking system. Two reservoirs are usually used.

(4) Brake valve, to control brake operation by directing flow of air from reservoir to brake chambers when brakes are applied, and from brake chambers to atmosphere when brakes are released.

(5) Brake chambers, one for each wheel, to convert pressure of compressed air into mechanical force for applying brakes.

(6) Quick release valve, to speed up exhaust of brake chambers not close to brake valve so all the brakes may be quickly released.

(7) Relay valve, used on trailers and trucks with long wheel bases to speed operation of rear wheel brakes. On trucks with short wheel bases the shorter length of brake lines permits rapid rear brake action without aid of a relay valve.

257. Vacuum System

a. PRINCIPLE. (1) In order to understand the principle on which the vacuum system operates, it is necessary to know what a vacuum is and how it can be used. For practical purposes a vacuum may be defined as a space from which air or gas has been partly exhausted.

(2) Air, like all matter, has weight. Since air extends upward from sea level for several hundred miles, the weight of this air exerts a pressure, termed "atmospheric pressure," at sea level of about 15 psi, 14.7 psi to be exact. This pressure is equally distributed in all directions upon all objects of the earth's surface.

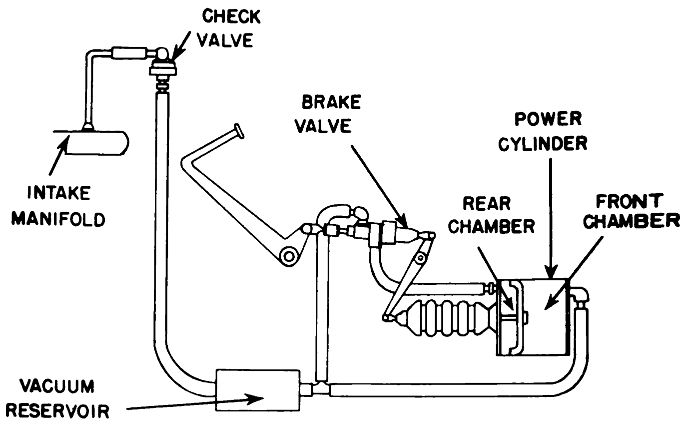

Figure 339a. Vacuum Suspended Brake System.

(3) Atmospheric pressure may be used to operate brakes by the creation of a vacuum. Since a vacuum is created by removing air, the pressure within a vacuum is less than that of the atmosphere. A perfect vacuum from which all matter has been removed has no weight or pressure whatsoever. A perfect vacuum is never obtainable although it can be closely approached. Hence, the full force of 15 psi atmospheric pressure can never be utilized. If air in a container has been pumped out or evacuated until only 5 psi pressure remain, the 10 psi differential existing between vacuum pressure and atmospheric pressure may be used to perform work.

(4) Vacuum is created in the intake manifold of an internal combustion engine by the pumping action of the pistons. When the vehicle is coasting in high gear with the carburetor throttle fully closed, very little air is admitted into the intake manifold so that the pumping action of the pistons reduces the pressure to about 5 psi in the manifold. The driver's foot is taken off the accelerator pedal when he applies the brakes so that about 10 psi difference between the vacuum pressure (5 psi) and atmospheric pressure (15 psi) are available to operate the brakes.

b. Power Cylinder. (1) Any chamber connected to the intake manifold will have air exhausted from it when the engine is running. The power cylinder, which contains a piston, depends upon this fact for its operation. A valve operated by the brake pedal is inserted between the cylinder and manifold, as shown in figure 337, to control the operation of the power cylinder. When the valve is opened air is exhausted from the chamber ahead of the piston. Atmospheric pressure acts on the other side of the piston to exert a powerful pull on the rod attached to the piston. The amount of pull depends upon the area of the piston on which the pressure acts.

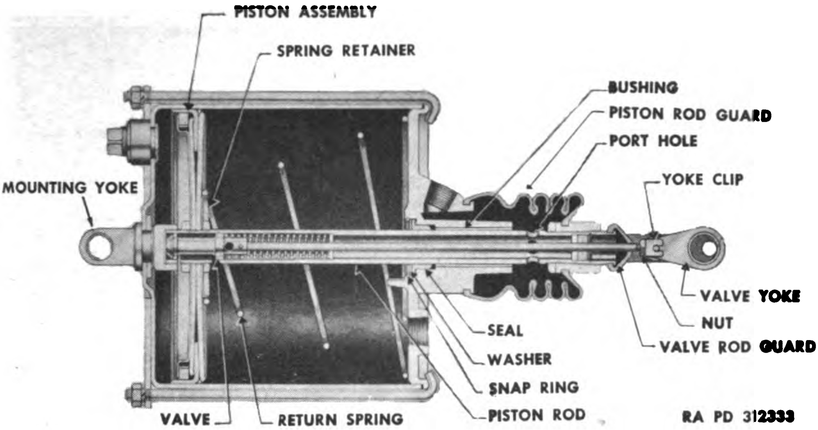

Figure 339b. Slide Valve Reactionary Internal Valve Brake Power Unit.

(2) When the valve is closed, the chamber ahead of the piston is shut off from the intake manifold and connected to the atmosphere. Air enters this chamber through the valve and raises the pressure on the front side of the piston to that of the atmosphere, as shown in the lower illustration of figure 337. The pressure is then the same on both sides of the piston so that no pull is exerted on the pull rod and it remains in the release position. The operating principle of the brake valve in a vacuum brake system is similar to that shown in figure 337, although the internal construction and operation are quite different.

c. Atmospheric Suspended System. (1) In the power cylinder shown in figure 337, atmospheric pressure exists on both sides of the piston when the valve is closed. A braking system with the power cylinder operated in this manner is known as an atmospheric suspended system (fig. 338). Depressing the brake pedal opens the brake valve, giving a free passage from the front chamber of the power cylinder to the intake manifold. (The piston pull rod end of the cylinder is designated as "rear" and the opposite end as "front.") The power of a vacuum cylinder may be applied to either mechanical or hydraulic brake systems.

(2) The vacuum power cylinder supplies a considerable force to augment or "boost" the force of the driver's foot. For this reason the vacuum power brake is often called a booster brake. If the vacuum power system fails, direct physical operation of the brakes is always possible.

d. Vacuum Suspended System. (1) In order to apply the brakes faster and to take advantage of the vacuum available for operating the brakes, a vacuum system has been developed in which vacuum is present on both sides of the piston when the engine is running and brakes are released. Such a vacuum system of power braking, known as a vacuum suspended system, is shown in figure 339.

(2) A check valve maintains a vacuum within the system even after

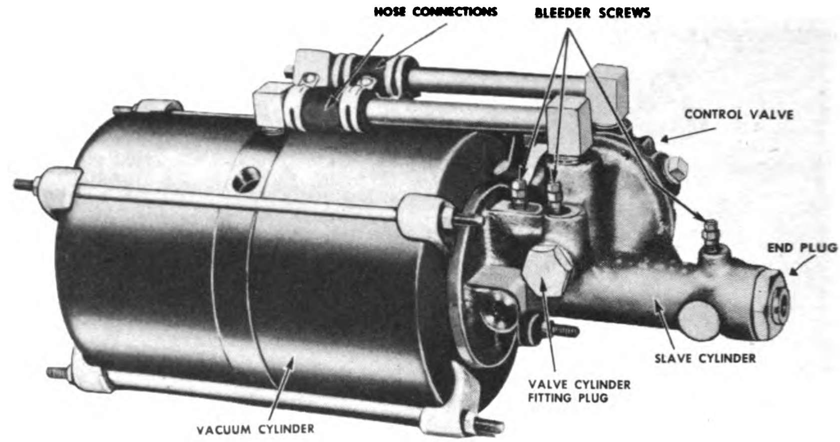

Figure 339c. Hydrovac Vacuum Power Brake Cylinder.

the engine is stopped by closing the intake manifold when pressure in the manifold rises above the vacuum pressure within the system. A vacuum reservoir is usually required so that a substantial source of vacuum is available. Once air is pumped out of the reservoir through the intake manifold, the resulting vacuum is diminished only by operating the power cylinder.

(3) With the brake pedal in the release position, there is a passage through the brake valve from the vacuum reservoir to the rear chamber of the power cylinder (fig. 339). Since the front chamber is connected to the vacuum reservoir at all times, the piston is suspended in a vacuum when it is in the release position.

(4) When the brake pedal is depressed to apply the brakes, the brake valve closes the vacuum passage to the rear chamber, and open a passage to the atmosphere through the brake valve. Air is admitted only to the rear chamber, which is the pressure chamber in this illustration. The piston is thus forced to the front of the cylinder to apply power to the braking system. With the vacuum suspended system, the brakes may be applied without admitting a charge of air to the reservoir so that the available vacuum is not reduced.

(5) When the brake pedal is released, the air in the rear chamber of the power cylinder is drawn into the reservoir through a passage opened in the brake valve, equalizing pressure on each side of the piston and permitting the brakes to be released by their retracting springs.

(6) All force applied to the brake pedal is transmitted directly to the brake system since the brake valve is contained within the pull rods that operate the brake mechanism. The entire valve may be moved with the pull rods to apply the brakes by physical effort when the power cylinder becomes inoperative.

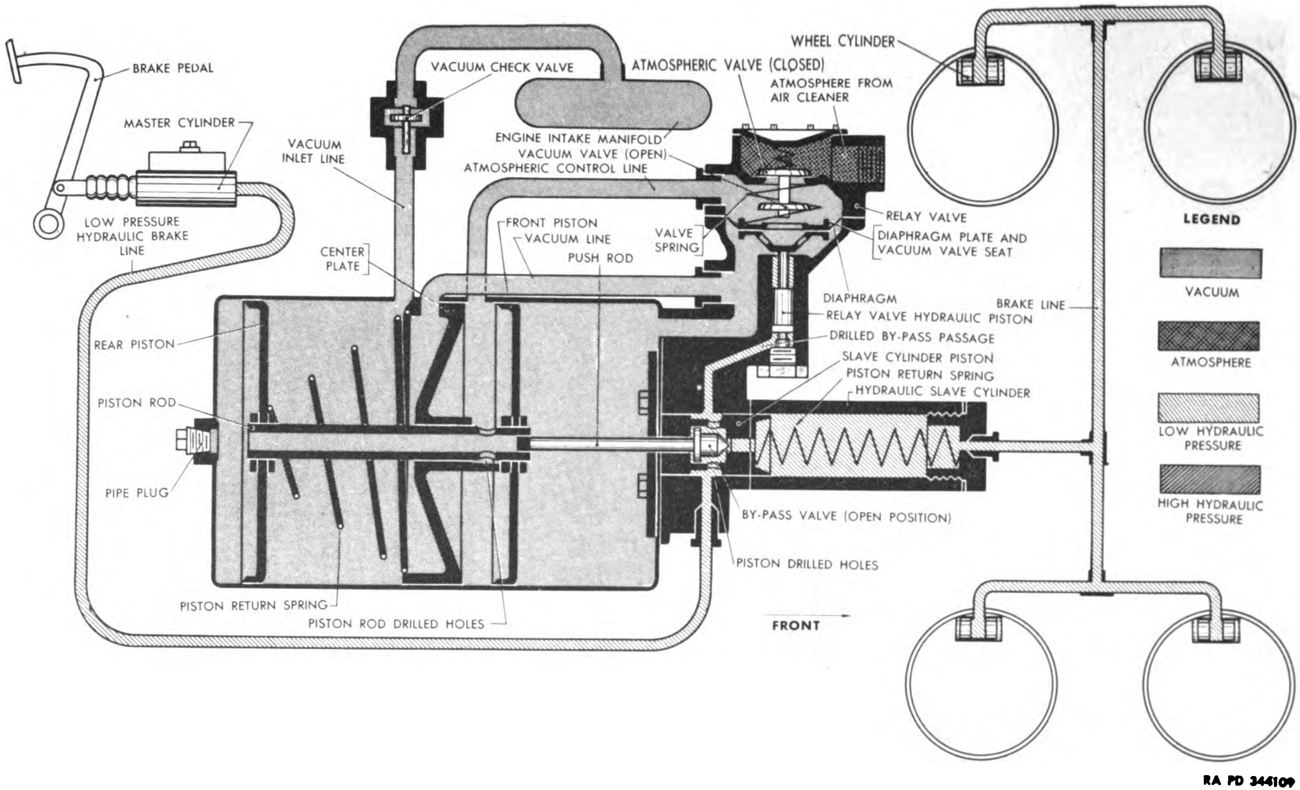

Figure 339d. Hydrovac Operation—Released Position.

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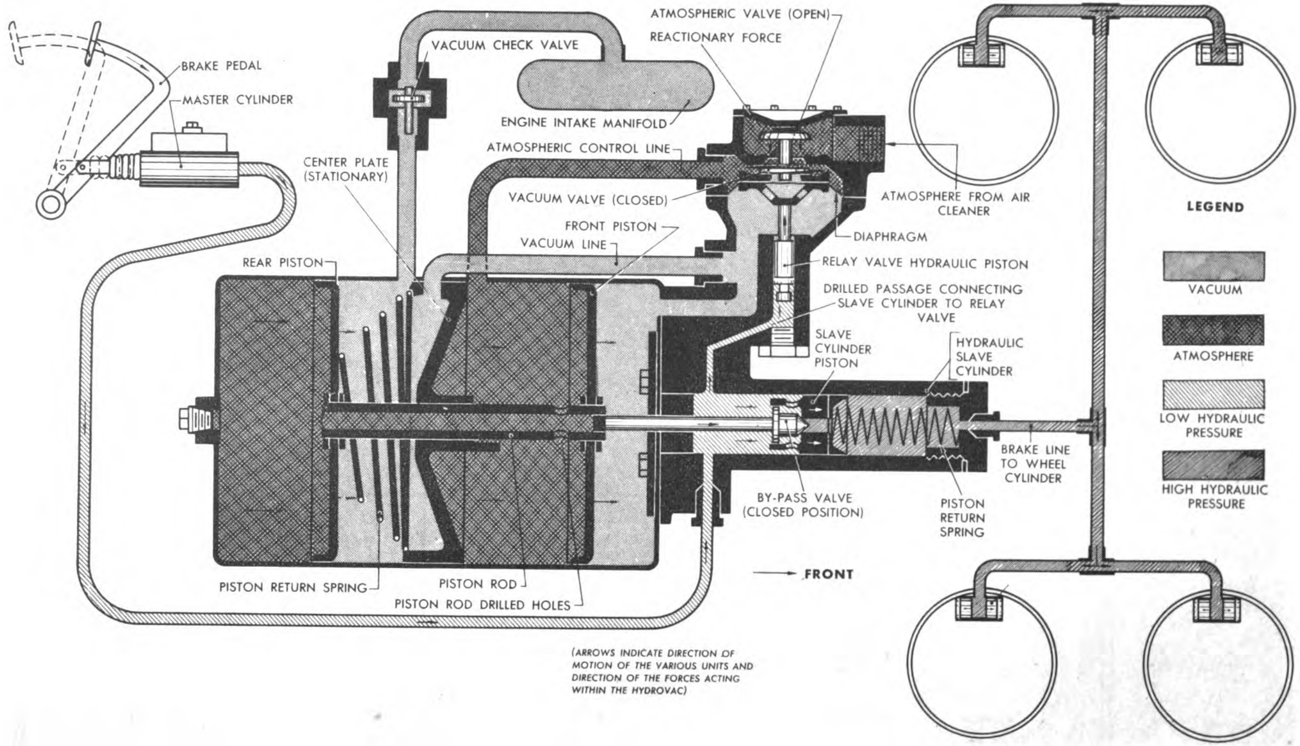


Figure 339e. Hydrovac Operation—Applied Position.

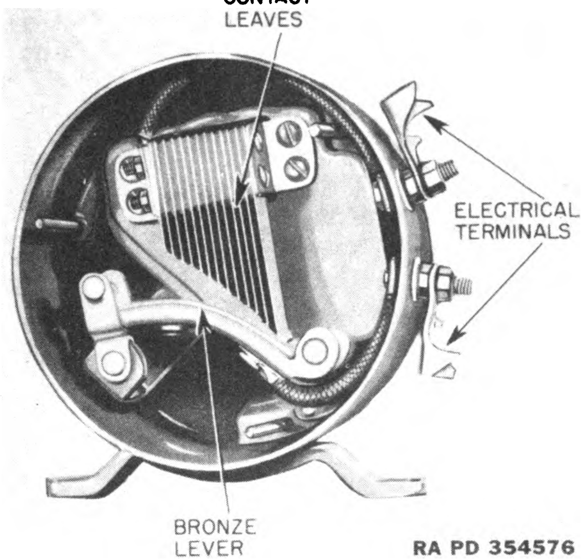


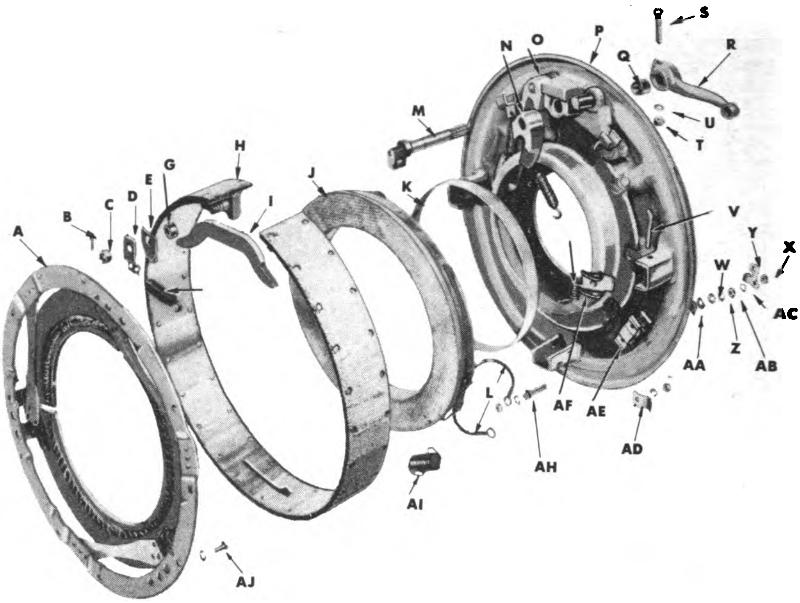
Figure 340a. Controller for Electric Brake.

258. Electric System

a. GENERAL. A brake which is set into operation electrically is sometimes used. The lay-out of the electric brake system which operates from the storage battery or the electrical system is quite simple. Wiring replaces the rods, cables, and tubings used in other types of brakes.

b. CONTROLLER. A bronze lever within the controller connected by linkage to the brake pedal (fig. 340) acts as a rheostat switch. The controller is provided with electrical terminals to convert it in the electric brake circuit. As the brake pedal is depressed the bronze lever comes in contact with leaves of varying lengths and completes the electric circuit from the battery to an electromagnet in the brake. Electric current is then supplied to the electromagnet, the amount depending on the number of leaves contacted by the bronze lever. When the brake is fully depressed all the leaves are in contact with the bronze lever and the maximum amount of current flows to the brake.

c. ELECTRIC BRAKE. (1) The armature revolves with the brake drum and is kept in constant contact with the electromagnet by means of flat springs (fig. 340). When the brake pedal is depressed the current flows from the controller to the brake and through a coil of copper wire in the magnet, setting up a magnetic field and causing the magnet to attract the armature. The farther the footpedal is depressed, the greater is the amount of current that reaches the magnet and the tighter the magnet clings to the armature. This attraction of the magnet to the armature



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A—ARMATURE ASSEMBLY
B—COTTER PIN
C—SLOTTED NUT
D—SPRING CLIP
E—RETAINER WASHER
F—BAND RETURN SPRING
G—ROLLER
H—BAND AND LINING ASSEMBLY
I—PARKING TRUST LEVER
J—MAGNET ASSEMBLY
K—MAGNET BUSHING
L—MAGNET WIRE
M—PARKING CAMSHAFT LEVER
N—LEFT HAND CAM
O—RIGHT HAND CAM
P—BACKING PLATE ASSEMBLY
Q—BUSHING
R—PARKING CAMSHAFT LEVER
S—BOLT
T—NUT
U—LOCK WASHER
V—COTTER PIN
W—BRASS WASHER
X—NUT
Y—TERMINAL
Z—LOCK WASHER
AA—FIBER BUSHING
AB—NUT
AC—LOCK WASHER
AD—WIRE CLAMP
AE—INSIDE CONTACT INSULATOR
AF—MAGNET HOLD-DOWN BAR
AG—MAGNET HOLD-DOWN SPRING
AH—STUD
AI—MAGNET RETURN SPRING
AJ—SCREW

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Figure 340b. Electric Brake Disassembled.

causes the magnet, which can revolve within a limited arc, to start turning with the armature. As the magnet turns, it engages a cam lever which in turn expands the brake band evenly against the brake drum in the conventional way.

(2) When the current is cut off by removing pressure from the brake pedal, the magnet in each brake is demagnetized and remains stationary. The brake return springs release the brake bands from contact with the brake drums.

(3) The principle of the electric brake permits use of a self-adjusting feature to compensate for lining wear. As the brake band wears, the electromagnet moves a little further to drive the brake lining against the surface of the drum. An automatic stop on the brake band prevents the rivets from coming into contact with the drum after excessive wear, eliminating danger of scoring of the drum.

(4) If the vehicle is standing still and the current turned on, there is no action of the brakes. If the wheel revolves in the slightest degree, however, the brake is operated.

CHAPTER 22

HULLS AND FRAMES

259. Frames, General

The frame is a base to which the body and other units of the chassis are attached. The most essential requirement of frames is stiffness sufficient to withstand unusual twisting under load, to absorb road shocks, and to keep the attached units in correct alinement. The plan and construction of a frame depends upon the type of vehicle and the service for which the vehicle is intended. Passenger car frames can be comparatively light because the frame receives approximately two thirds of its rigidity from the body structure, which in most cases is made of steel. The metal covering the bodies of some passenger cars, delivery trucks, and busses is given a special skin stressing process; thus metal covering and the body framework are substituted for the vehicle frame. Attempts to strengthen the vehicle frame by increasing the size of the members is effective to only a minor degree; using the same amount of metal in strengthening the body structure is of considerable benefit. In military vehicles standard frames ordinarily are used, and also in these vehicles the body plays an important part in adding strength and rigidity to the frame. In tanks and certain amphibian vehicles, the hull itself serves as the frame.

260. Passenger Car Frames

Passenger car frames are built of side rails, cross members, and gussets, riveted or welded together into some form of A, X, Y, or K construction to secure stiffness with light weight. (Gussets are angular pieces of metal for strengthening angles or corners.) Frames are usually not more than 30 inches wide in front, to permit the use of a short turning radius, and may be widened at the rear to 48 inches for increased body stability. Kickups may be provided over the axles to lower the center of gravity of the vehicle.

261. Truck Frames

Trucks of up to one-ton capacity have frames similar to those of passenger cars. For larger trucks the frames are simple, rugged, channel-iron constructions. The side rails are usually parallel to each other at standardized SAE widths to permit the mounting of stock transmissions, transfer assemblies, rear axles, and the like. Trucks which are to be used as prime movers have an additional reinforcement of the side rails and rear cross members to compensate for the added towing stresses.

262. Brackets and Hangers

Frame members serve as supports to which springs, independent suspensions, radiators, transmissions, and the like may be attached. Additional brackets, outriggers, engine supports, and horns are added for the mounting of running boards, longitudinal springs, bumpers, engines, towing hooks, shock absorbers, gas tanks, and spare tires.

263. Hulls of Tanks and Armored Cars

A tank hull or body, welded into an assembly from heavy armor plate, serves not only as a frame but to house and protect the crew and equipment. Removable sections are provided for service operations; a circular opening in the top, for the installation of the turret; openings in the front end for the installation of the power train; and other openings for escape hatches, vision devices and gun mountings. The interior of the hull is divided into an engine compartment and fighting compartment by a lateral bulkhead which also strengthens the unit. The hull of an armored car is constructed in a similar manner although of lighter weight plate and, also, it serves as a frame for the vehicle.

264. Hulls of Cargo Carriers

Both amphibian and non-amphibian cargo carriers utilize the hull as a frame. In both vehicles the hull consists of a sheet steel welded structure, except for various covers which are easily removed to facilitate inspection and maintenance operations. On the amphibian version, bow and stern cells of reinforced and welded sheet steel are added to the basic hull in order to float the vehicle.

265. Hulls of Tracked Landing Vehicles

For the tracked landing vehicles the hull is defined as the framework of the vehicle together with all inside and outside plating but exclusive of equipment. It is the main or central section that runs from front to rear and consists of the cab, cargo compartment, and engine room. Technically a part of the hull, are the pontons which are welded to each side of it. Engines, controls, armament and driving assemblies are housed in or mounted on the main hull.

266. Hulls of Amphibian Trucks

Amphibian trucks, unlike the two tracked vehicles mentioned above, have both a hull and a frame. Designed to provide buoyancy necessary for flotation, the basic hull assembly is of all-steel, watertight, welded construction, with reinforcements to add to its rigidity. It is built to accept the chassis frame and power plant. The frame, similar to a conventional truck frame, is installed inside and bolted to the hull. The power plant and power train are supported by the frame; running gear, underneath the hull, is attached to both hull and frame.

PART SIX

SPECIAL EQUIPMENT UNITS

CHAPTER 23

ACCESSORIES

267. Power Take-off

a. This is an attachment for connecting the engine to power driven auxiliary machinery when its use is required. It is attached to the transmission, auxiliary transmission, or transfer case. A power take-off installed at the left side of a transmission is shown in figure 341. It is used to drive a winch, located at the front of the truck, through the universal joint and propeller shaft.

b. The simplest type of transmission power take-off is the single-gear, single-speed type shown in figure 342. This unit is bolted over an opening provided for the purpose at the side of the transmission case. This opening is closed by a cover plate when no power take-off is used. The opening in the transmission case and the power take-off gear meshes with a gear on the transmission countershaft. As shown in figure 342, the gear slides on the splined mainshaft off which the power is taken. The shifter shaft, controlled by a lever in the driver's cab, slides the gear in and out of mesh with the countershaft gear. Since it is driven by the countershaft, the power take-off shaft rotates in the same direction as the engine crankshaft.

c. Transmission power take-offs are available in several different designs: a single-speed, two-gear model in which the rotation of the power take-off shaft is opposite to that of the engine; a model having a single speed forward and reverse; and a model having two speeds forward and one reverse. Several different mountings are also available.

d. The same types of power take-offs are also applied to auxiliary transmissions. Figure 343 shows a winch driven off an auxiliary transmission.

e. Power is sometimes taken off a transfer case as shown in figure 343. The transfer case drive shaft, which is connected to the transmission, extends through the case and the power take-off shaft is engaged

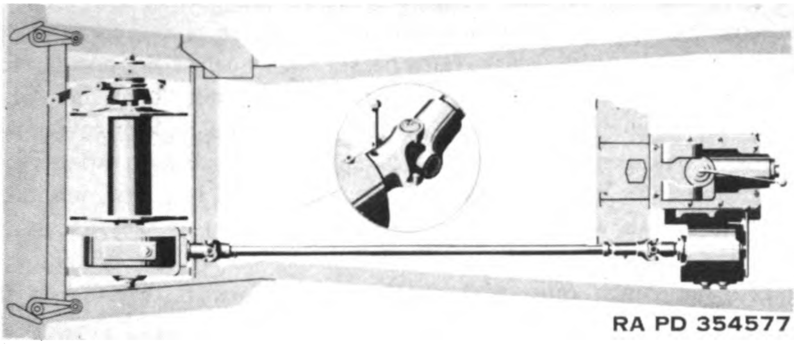


Figure 341. Winch and Power Take-off Installation.

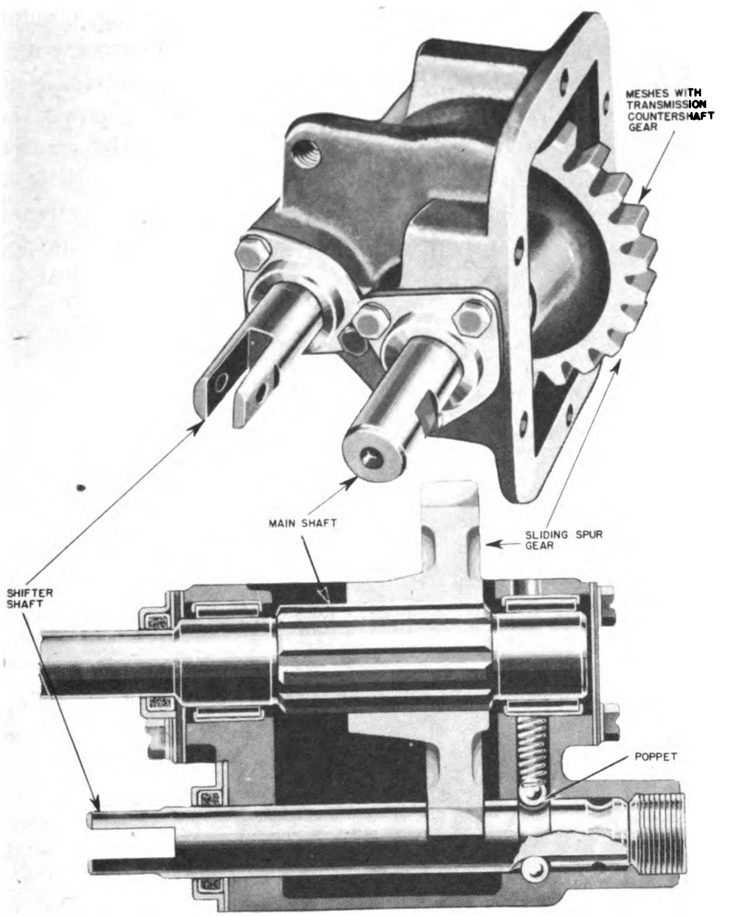


Figure 342a. Single-speed, Single-gear Power Take-off.

to it by a dog clutch. This transfer case has two speeds and a neutral position. It is necessary to put the transfer case sliding gear in the neutral position if the vehicle is to be stationary while the power take-off is in use. If the power take-off is needed while the vehicle is in motion, the transfer case may be shifted either into high or low range. With this arrangement, the power take-off will work on any speed of the transmission. The positions of all the cab control levers of one model of vehicle are shown diagrammatically in figure 344 as they are placed on the instruction plate in the cab. When the power take-off clutch is engaged the winch capstan operates; but the winch drum does not rotate until the winch clutch is engaged.

f. The several types of power take-offs have been described as operating winches, but their uses for operating various kinds of hoists, pumps, and other auxiliary power-driven machinery is essentially the same.

268. Winches

a. Purpose. Using its winch and some type of rigging, a vehicle can pull itself or another vehicle through such an obstacle as very muddy or very rough terrain. This is the primary reason for providing winches on standard military vehicles. The winch in this case is powered by the engine of the vehicle through a power take-off from the transmission. Field expedients, of course, may utilize the winch for such devices as simple cranes in a field shop. However, on special equipment and vehicles, winches are furnished for special purposes such as powering

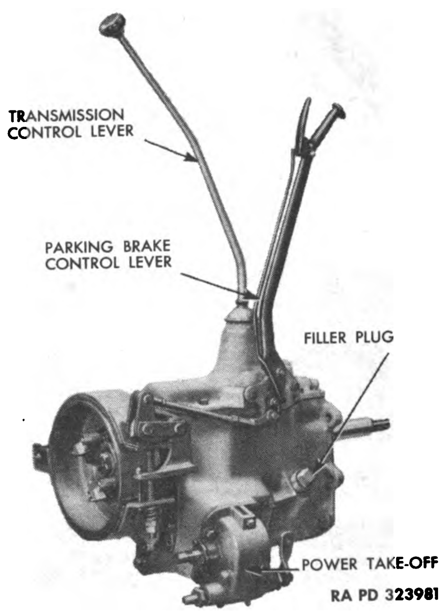


Figure 342b. Single-speed, Single-gear Power Take-off Installed.

the crane of a wrecker. Some of these latter winches are powered by separate gasoline engines.

b. MOUNTING. Generally, the winch is mounted behind the front bumper and is secured to the front cross member of the frame or between the two side frame rails. It may be mounted, however, behind the cab. The tandem winch assembly, for example, which consists of a front (upper) and rear (lower) winch is secured to a mounting assembly fastened to the chassis frame at the rear of the cab.

c. OPERATION. The typical front-mounted winch is a jaw-clutch worm-gear type. The winch consists of a worm and shaft which drives a worm gear that is keyed to a shaft (fig. 345). A bushed drum is mounted on

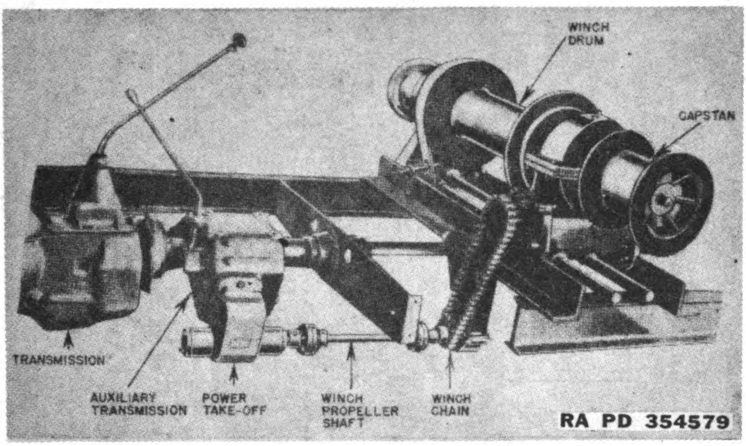


Figure 343. Auxiliary Transmission Power Take-off Driving Winch.

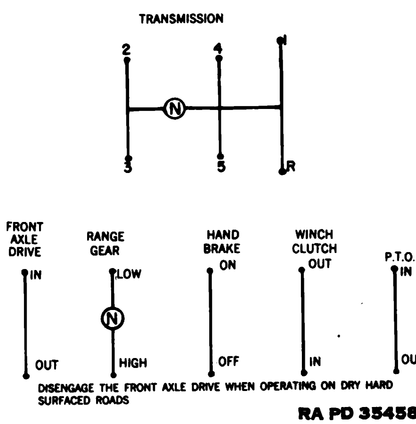


Figure 344. Typical Shift Positions of Transfer and Power Take-off Control Levers for 2-Speed Transfer Assembly with Power Take-off.

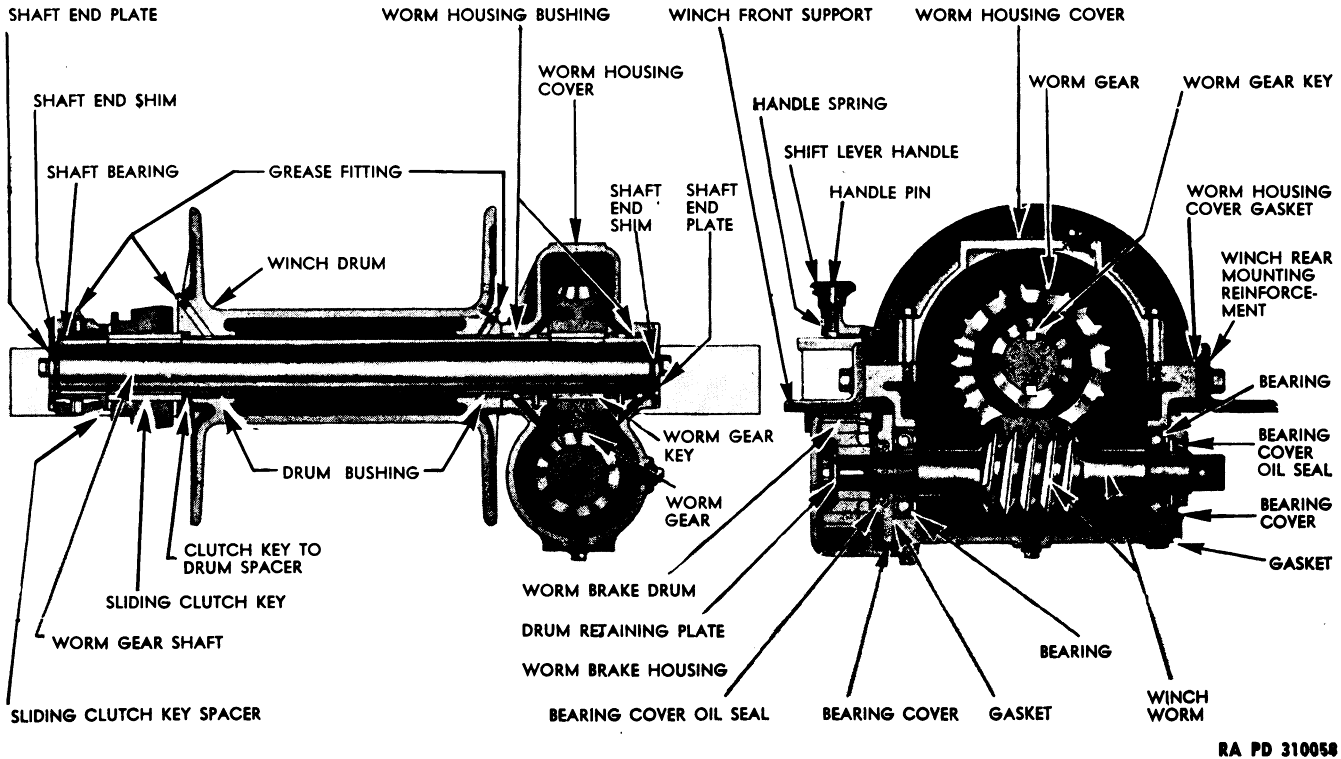


Figure 345. Jaw-clutch Worm Gear Type Winch.

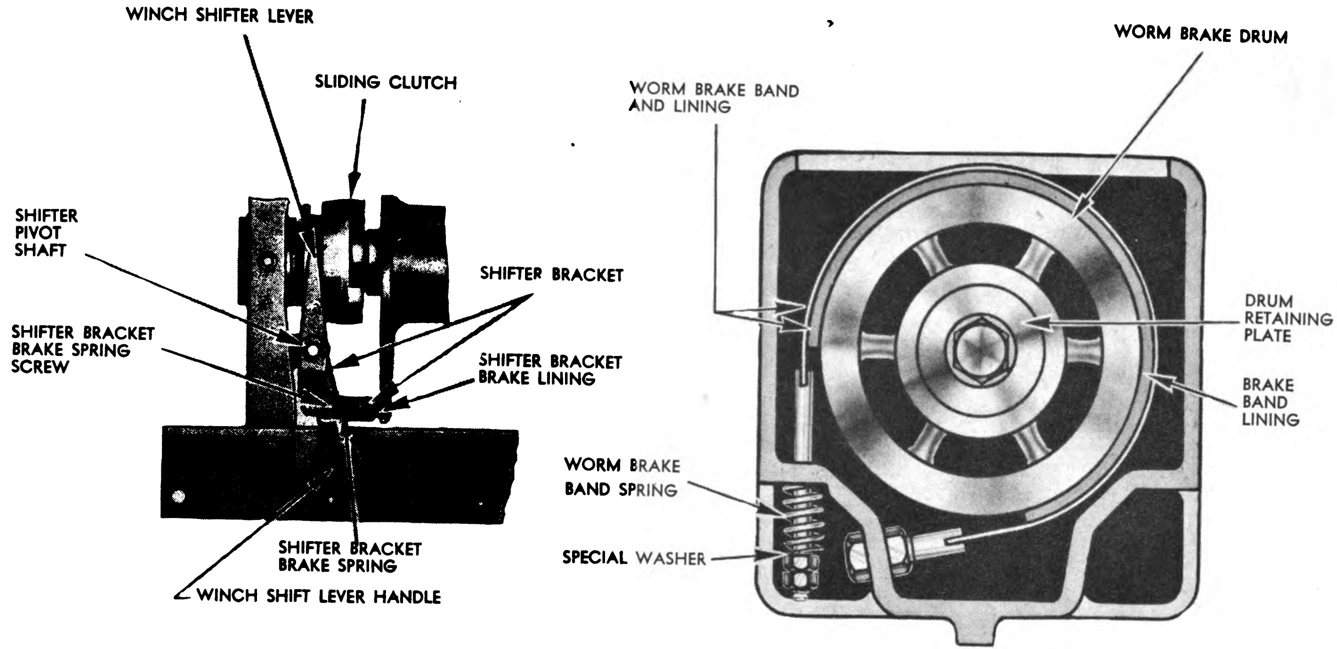
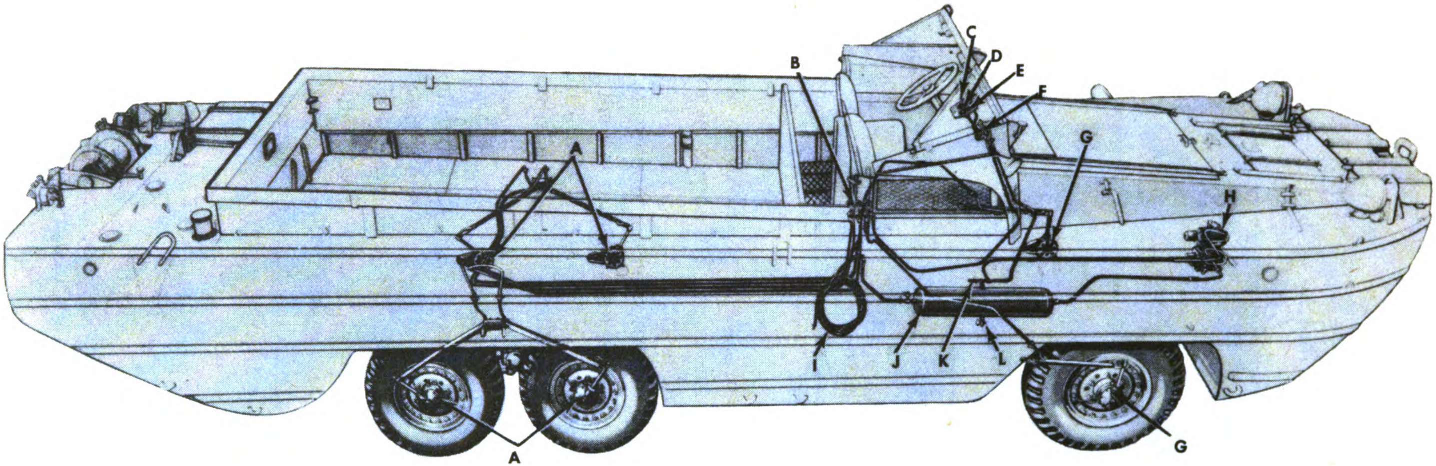


Figure 346. Winch Clutch and Brake.



A REAR TIRE INFLATING DEVICES
B AIR LINE MANIFOLD AND VALVES ASSEMBLY
C TIRE INFLATING CONTROL LEVER
D TANK PRESSURE AIR GAGE
E TIRE PRESSURE AIR GAGE
F TIRE INFLATION AND DEFLATION CONTROL VALVES
G FRONT TIRE INFLATING DEVICES
H TIRE PUMP
I TIRE INFLATING HOSE
J AIR TANK
K SAFETY VALVE
L DRAIN COCK

RA PD 333220

Figure 347. Location of Central Tire Pressure Control System Components.

the worm gear shaft which is controlled by a sliding clutch. The worm shaft is driven by a drive shaft connected to a power take-off unit mounted on the transmission. The hand-operated sliding clutch is keyed to the worm gear shaft outside of the winch drum, and must be engaged with the jaws on the side of the winch drum when the winch is to be operated. Disengagement of the sliding clutch permits the drum to turn on the worm gear shaft. Two brakes are provided to control the winch drum. The worm shaft brake prevents the winch drum from rotating under load, when the power take-off is disengaged. The shifter bracket brake prevents the drum over-running the cable when the cable is being unreeled (fig. 346). A shear pin on the worm drive shaft prevents damage from overloading. The power take-off is controlled by a shift lever located in the driver's compartment.

269. Tire Inflation System

a. Amphibian trucks are equipped with a central tire pressure control system, by means of which the tires may be inflated or deflated to meet various conditions encountered by the vehicle. When operating on sand the tires are deflated to obtain adequate flotation; then, to travel on a hard surface, the tires are inflated.

b. Location of each component of the system is shown in figure 347. A two-cylinder, water-cooled, self-lubricated pump with a capacity of 9 cubic feet per minute is mounted in the front compartment and driven directly by the engine crankshaft. This maintains pressure in the air tank, and is controlled by a governor that stops the pump when maximum allowable pressure is attained and automatically starts the pump when pressure in the tank drops below a prescribed limit. Air pressure is piped from the tank to the inflation and deflation control valves assembly. When the control valve lever is placed in the INFLATE position, air passes through the valve to the air line manifold and valves, thence to each tire through individual air lines and tire inflating devices. A safety valve is located in the system. The tire inflating device, or hub device, is mounted on each wheel hub. It is an airtight rotary joint which provides a connection between the air supply line and the tire. The inner part rotates with the wheel hub, while the outer part is held stationary by a swivel-ended strut attached to the hull.

CHAPTER 24

TRAILERS

270. General

a. A motor vehicle can pull a heavier load than it can safely carry. This fact is put to use in motor transportation by using trailers. A trailer is a cargo vehicle with no motive power of its own, towed by a motor vehicle. Motor vehicles specially designed for towing trailers are known as tractors.

b. Considerable time must be spent in loading and unloading certain types of cargoes. In such cases trailers are useful because they can be left at the loading and unloading points while the tractor tows other loads.

c. Trailer spring suspension is the same as that employed on motor vehicles. Auxiliary springs are often used. Radius rods are usually used to maintain axle alinement and to transmit braking and pulling action between the trailer axle and frame. The wheels are usually slightly cambered.

d. Air, vacuum, or electric braking systems are used with trailers. The trailer braking system is coupled to that of the towing vehicle by a flexible hose and detachable couplings or cables. The trailer braking system is usually designed so that the brakes are applied and keep the trailer in place when these couplings are disconnected. However, when the trailer is detached from the towing vehicle, the trailer brakes will hold for only a limited time. For this reason wheel blocks are usually used to keep the trailer in place when it is to be idle for some time. Provisions are often made for carrying wheel blocks on a trailer.

e. Trailers are of three general types, depending on the manner in which their weight is supported: the semitrailer, the three-quarter trailer, and the full trailer. A large proportion of the semitrailer weight is supported by its connection to the towing vehicle and the remainder is supported by the wheels of the semitrailer. The weight of a three-quarter trailer is mostly balanced on and supported by the trailer wheels, and any unbalanced weight is supported by the connection to the towing vehicle. The entire weight of a full trailer is supported by the trailer wheels.

f. Trailers are made in many sizes and equipped with various body styles depending upon the service for which they are intended. The connections between towing vehicles and trailers differ according to the type of trailer involved. Two main types are used: the fifth wheel (semitrailers), and the pintle hook connection (three-quarter and full trailers).

271. Semitrailers

a. A typical semitrailer chassis (fig. 348) consists mainly of a frame, spring suspension, axle, fifth wheel connection, and a landing gear. It resembles the conventional truck chassis in that its frame is made of two pressed-steel side members with several cross members, laminated leaf spring suspension, and wheels and tires that are interchangeable with the tractor used for hauling the trailer. Figure 349 illustrates a trailer chassis with tandem axles for carrying heavy trailer loads.

b. Early semitrailer frames were built of straight side members, which meant that the rear of a level trailer body had to be at a considerable height above the ground to clear the rear wheels of the tractor. Such a high frame is objectionable because it heightens the center of gravity, making it easier to overturn the trailer. A kick-up in the semitrailer frame (fig. 348) permits a lower center of gravity without reducing the necessary clearance space above the rear wheels of the motor vehicle.

c. Cross members are located where the greatest strains occur to the trailer frame. They may be tubular, channel, or box shaped, with gusset plates riveted or welded to the side members to make a rigid, strong frame.

d. Another type of semitrailer with a variable wheelbase is the "pole" trailer used for transporting long or irregularly shaped goods, such as poles, pipes, or structural members. In this case the "pole" or "boom" forms the trailer frame. The pole is attached to a turntable mounted on

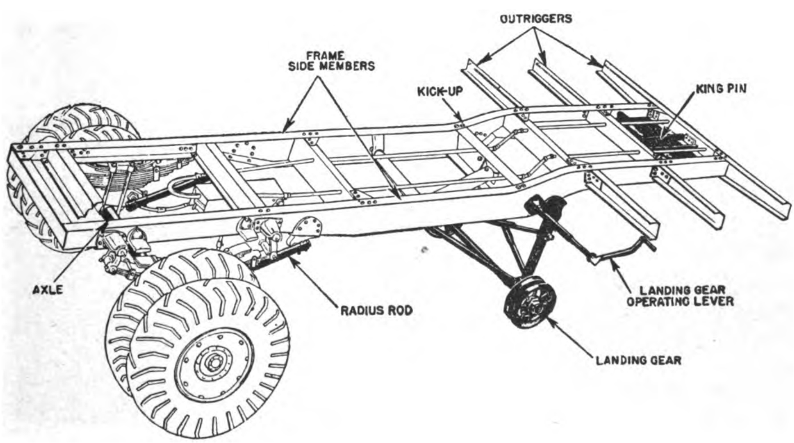


Figure 348. Semitrailer Chassis.

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the tractor in much the same manner as a fifth wheel. The trailer axle unit is attached by adjustable clamps to the other end of the pole.

e. A tractor used to haul a semitrailer must be especially designed. Its wheelbase is shorter than that of a standard truck, and the engine and transmission units are designed to produce the necessary power for pulling a loaded semitrailer. Tractors may be of the cab over engine or conventional truck design with either single or dual rear axles. The flexible hose connecting the brake system of the tractor to the trailer is clearly shown at the rear of the tractor cab (fig. 350).

272. Landing Gear

a. The landing gear (fig. 351) is a retractable support under the front end of a semitrailer to hold it up when it is uncoupled from the tractor. The two leg members of the landing gear are usually attached to the under side of the trailer chassis by pivot pins. These leg members are connected together by cross braces to resist any side strains. Two small steel wheels mounted on the ends of these leg members facilitate moving the trailer about when it is uncoupled from the tractor. Bracing members connect the lower end of the leg members to a movable bracket containing a nut which rides on a worm shaft located lengthwise between the side members of the trailer frame. Rotation of the worm shaft moves the bracket forward or backward (depending on the direction of rotation) and consequently lowers or raises the landing gear wheels. The landing gear is shown in its lowered position (trailer uncoupled from tractor) in figure 351.

b. The worm shaft is supported by bearings in a housing mounted on the under side of the trailer chassis. It is rotated by means of a set of bevel gears at the forward end of the housing. These gears are turned by a hand-operated lever at the end of a shaft which extends out to the side of the trailer.

c. The height which the landing gear lifts the front end of the trailer above the ground can be varied by adjustable clamps at the top of the

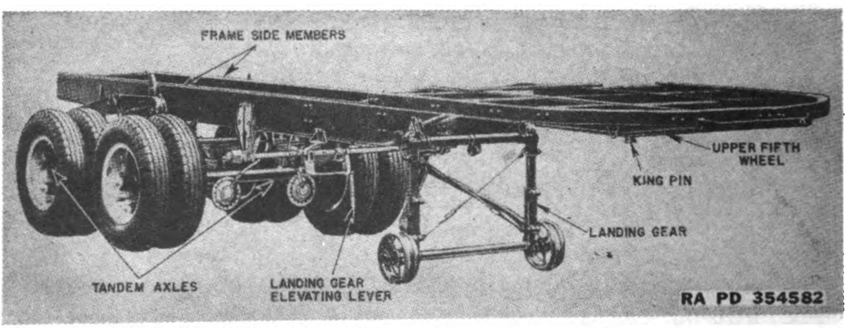

Figure 349. Semitrailer Chassis with Tandem Axles.

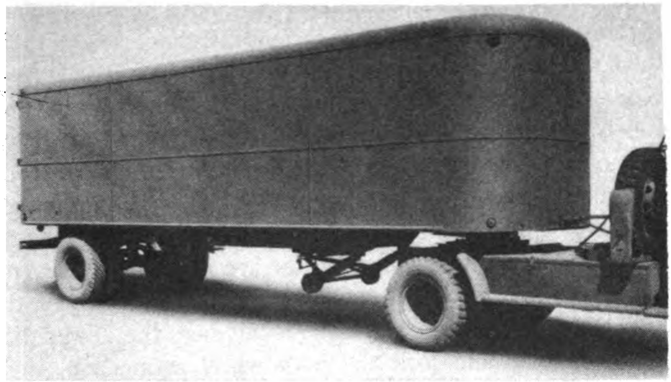

Figure 350a. Tractor and Semitrailer Combination.

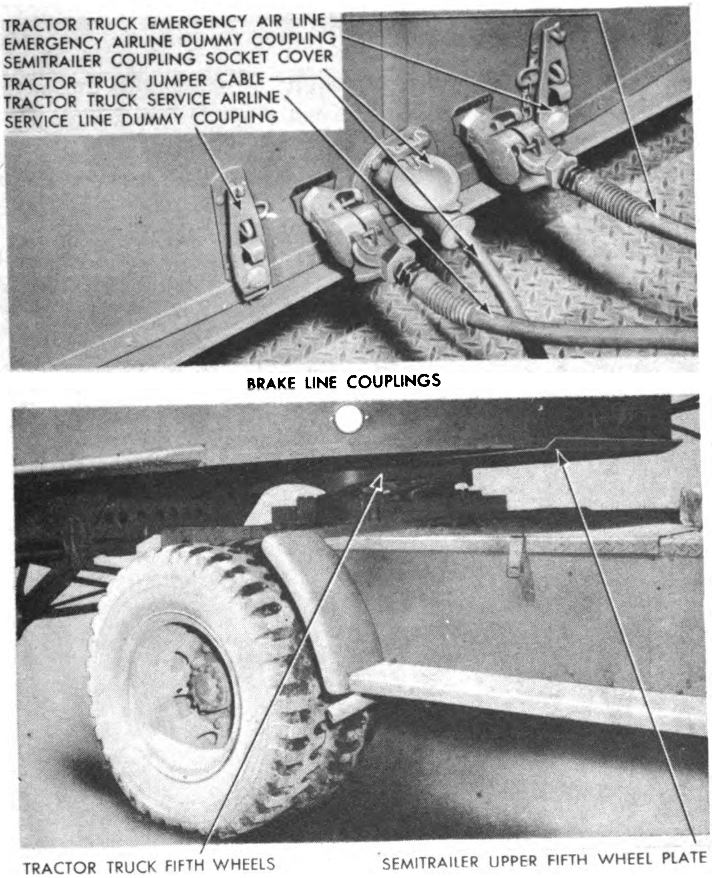

Figure 350b. Tractor and Semitrailer Combination.

two leg members. This adjustment is necessary if the trailer is to be used with tractors having different rear end heights.

d. When semitrailers are coupled and uncoupled, it is important that the landing gear be coordinated with the fifth wheel lock. If the landing gear is elevated before the fifth wheel connection is fully locked, the front end of the trailer will drop to the ground when the tractor is driven away, with the possibility of damaging both the load and the semitrailer. Before the semitrailer is uncoupled, the brake coupling should be disconnected so that the semitrailer brakes are applied to prevent it from moving. Automatic controls are sometimes used to coordinate the desired features. Auxiliary locking pins strike against the lower fifth wheel plate on the tractor and lock the fifth wheel connection, thereby preventing the trailer from being separated until the landing gear is fully lowered. These auxiliary locking pins are connected by an actuating rod in such a way that they cannot be raised to unlock the fifth wheel connection until the landing gear is fully lowered and the trailer brakes applied.

273. Fifth Wheel

a. The standard method of connecting the tractor to the semitrailer is by means of a fifth wheel. A heavy steel plate, known as the upper

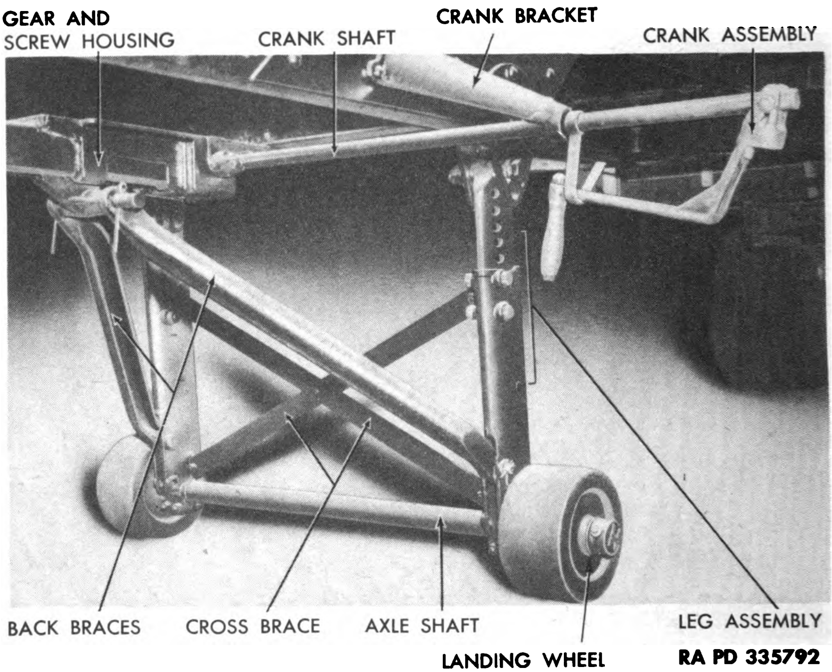

Figure 351. Semitrailer Landing Gear.

fifth wheel plate, is securely attached to the under side of the front end of the semitrailer frame (fig. 352). This plate serves as the bearing or front end support of the semitrailer when it is coupled to a tractor. The front edge of the plate is turned up approximately 45° to form a skid which slides on the lower fifth wheel plate (mounted on the tractor) when the semitrailer is being hitched to the tractor. In the center of the upper fifth wheel plate is a permanently attached king pin by which the tractor pulls the semitrailer.

b. The lower fifth wheel (fig. 353) contains the movable parts of the fifth wheel assembly and supports the semitrailer load thrust on the tractor. The circular portion of the heavy cast steel plate is the bearing surface upon which the upper plate of the semitrailer rides. The circular grooves in the lower plate are grease retainers for lubricating the rub-

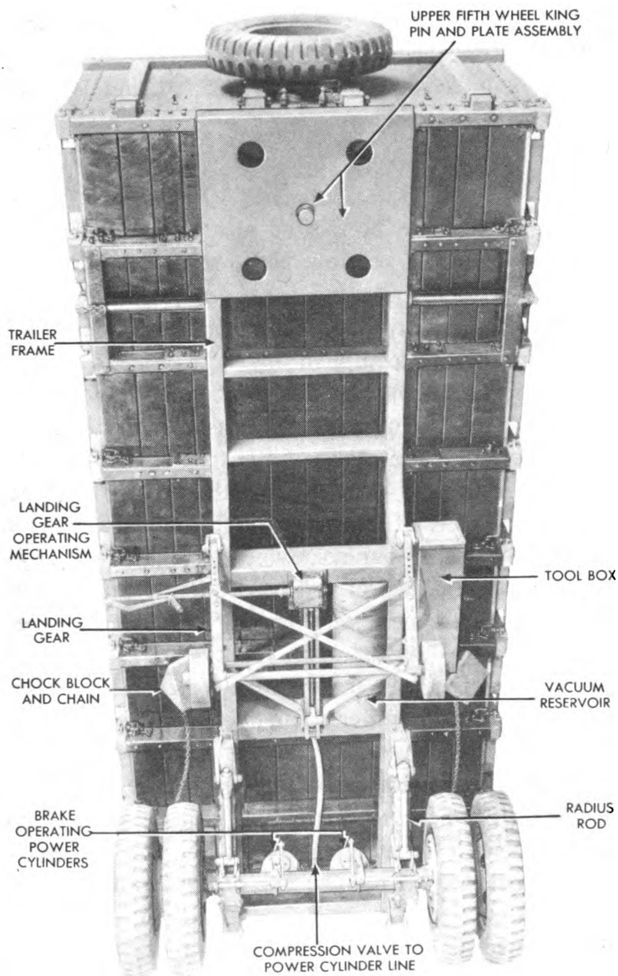

Figure 352. Underside of Semitrailer Showing Upper Fifth Wheel.

bing surfaces of the upper and lower plates. The sloping ramps aid in picking up the upper plate of the semitrailer. The wide open space between the ramps guides the king pin into place. The lower plate is pivoted on a rocker pin crosswise to the tractor, providing a free swinging movement between the semitrailer and tractor. The outer ends of the rocker pin are supported in pillow blocks bolted to a bedplate which is mounted on the frame of the tractor.

c. There are three types of fifth wheel couplings: permanent, semiautomatic, and automatic. In a permanent fifth wheel coupling the king pin is made part of the lower fifth wheel plate, and once locked in position the tractor is operated with the same semitrailer at all times. In semiautomatic and automatic fifth wheel couplings, the king pin is contained on the upper fifth wheel plate. The king pin is locked in position by a king pin lock which is a ring on the lower fifth wheel that clamps around the king pin. In the semiautomatic coupling, which is the most popular type, the kin pin lock is operated by a hand lever that extends to the side of the lower fifth wheel (fig. 353). The automatic coupling is locked in a similar manner, except that it is controlled by the operator from the tractor cab.

274. Load Distribution

a. The fifth wheel should be located at a point on the tractor chassis that will best distribute the portion of the semitrailer load thrust on the tractor. The ideal load distribution for a tractor and semitrailer combination is illustrated in figure 354. The fifth wheel should be well ahead of the tractor rear axle to accomplish this.

b. Another important factor in the location of the fifth wheel is that of safety in hilly or mountainous country. When climbing hills the load thrust will act at a point back of the tractor rear wheels (fig. 354), if the fifth wheel is located directly over the rear wheels, and will tend to raise the front wheels of the tractor off the road. This will cause a dangerous loss of steering control, which is aggravated by each bump in the road. With the fifth wheel and consequently the load center located well ahead of the rear wheels, this hazard is avoided as the load thrust will always fall ahead of the driving axle.

c. Another danger from an incorrectly located fifth wheel is that due to the momentum of the trailer. The momentum of the trailer has a tendency to push the rear end of the tractor off the road when on a sharp turn (jackknifing), especially if the road is wet or covered with ice or snow. With the fifth wheel located well ahead of the tractor rear wheels, the load thrust is placed between the tractor axles and offers additional resistance to the momentum of the trailer when it tends to jackknife.

d. Clearance beween the rear of the tractor cab and the front of the semitrailer body should always be at least 1 foot.

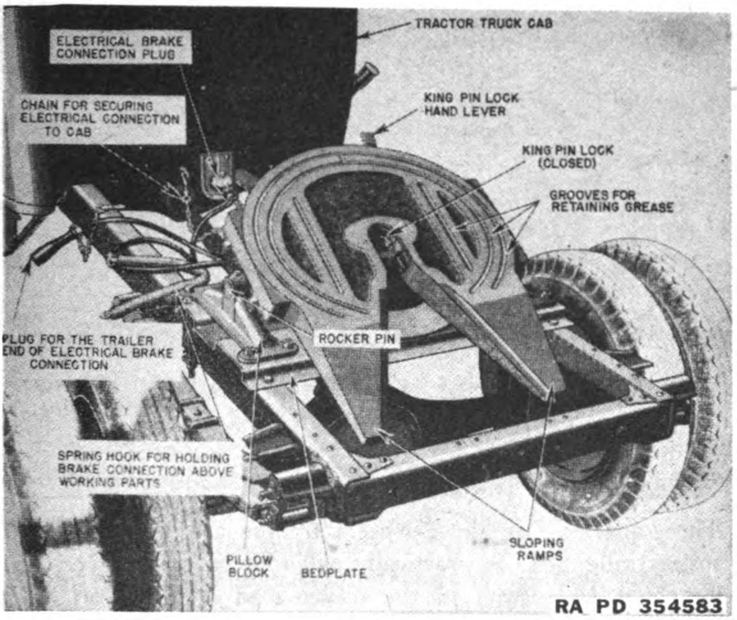

Figure 353. Lower Fifth Wheel Mounted on Tractor (Semi-automatic Coupling).

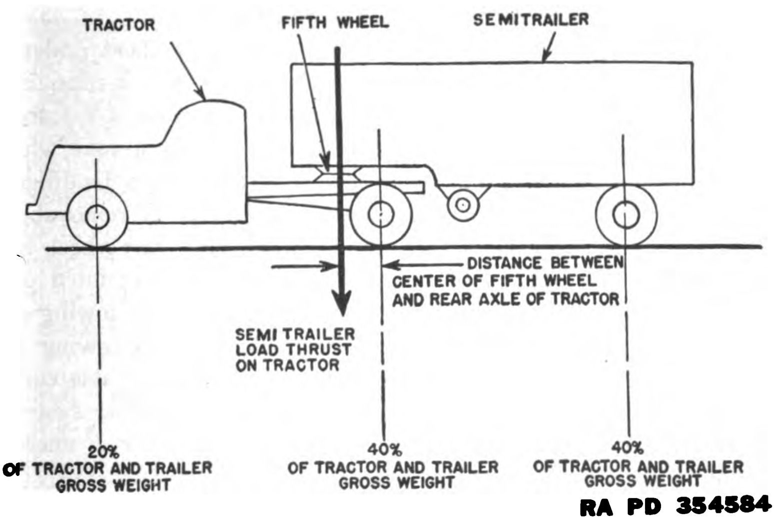

Figure 354. Ideal Locd Distribution for Tractor and Semitrailer Combination.

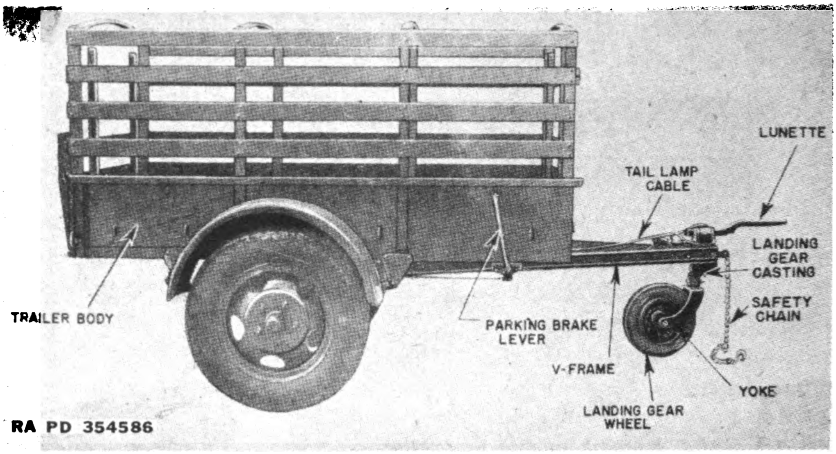

Figure 355. 1-Ton, 2-Wheel Trailer.

275. Three-quarter Trailers

a. Three-quarter (usually 2-wheel) trailers are used for light loads. The entire trailer load is practically balanced on the trailer suspension. Usually about 15 percent of the trailer load is thrust on the tractor connection. Three-quarter trailers are built in many sizes and fitted with various forms of bodies ranging from the general pick-up and tank (fuel and water) to the more elaborate house trailers used as hospital and recruiting vehicles. In some of the heavier types, tandem axles are employed to carry the load.

b. A 1-ton standard 2-wheel trailer is illustrated in figure 355. The frame and body form an integral unit. The cross members underneath the body reinforce the floor board and form the rear section of the frame. The front end of the trailer body rests directly on a V-frame.

c. The landing gear wheel rotates on a shaft held by a yoke which is free to turn horizontally. The yoke is also pivoted to a landing gear casting so that the wheel may be raised or lowered. A removable pin can be placed in various holes of the yoke to hold the wheel at the desired height (fig. 356). The lunette (towing hook), mounted on top of the landing gear, is connected to the pintle hook of the towing motor vehicle. A short safety chain connects the trailer and the towing motor vehicle to prevent the trailer breaking loose. A tail lamp cable connects the trailer tail lamp to the towing motor vehicle electrical system. A simple mechanical parking brake is used when the trailer is uncoupled from the motor vehicle. It is operated by a hand lever (fig. 355).

d. A house trailer equipped with tandem axles is illustrated in figure 357. It is hitched to the towing vehicle by a standard SAE No. 2 ball and socket coupler (fig. 358). Its landing gear consists of an upright worm shaft with a small caster wheel clamped to its bottom end. When

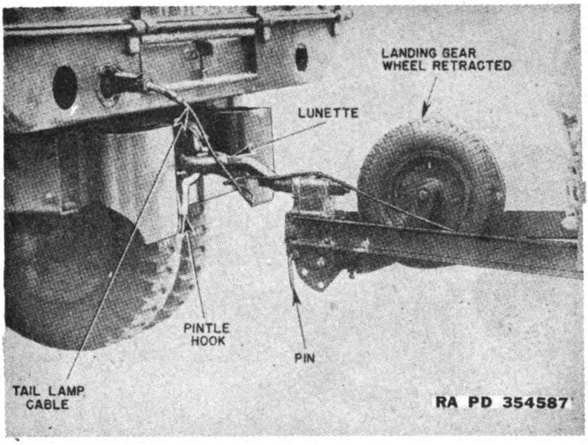

Figure 356. Pintle Hook Connection to a 1-Ton, 2-Wheel Trailer

the trailer is being towed, the caster wheel is removed by loosening a thumbscrew and the worm shaft is raised by a hand crank.

e. Safety towing chains are connected between the trailer and the towing motor vehicle. Another safety feature is the short chain fastened by a snap hook to the towing motor vehicle and by an open loop spring hook which fits around a pin on the trailer brake safety switch. If the trailer breaks loose, the towing motor vehicle will jerk the chain away from the pin, which is thereby released to operate the switch which immediately applies the brakes of the trailer. An electrical lead connects the trailer brakes to the electrical brake connection on the towing motor vehicle.

f. Six screw jacks are used for supports when the trailer is parked. These jacks are placed underneath the frame on both sides at the front, center, and rear and permit the trailer to be leveled and its load to be supported when parked.

g. House trailers in comparison to other types of trailers are lightly built to reduce weight and to allow the use of soft springs. They are usually designed for use with soft spring passenger vehicles. If they are coupled to vehicles having stiff springs, the towing connection will be jarred considerably.

276. Full Trailers

a. Full trailers, which support their entire load, may be connected directly behind the towing motor vehicle to a semitrailer, or to another full trailer. They are independent and fully contained vehicles without motive power.

b. Early full trailers were equipped with knuckle or Ackerman steering used on motor vehicles, but all full trailers now use fifth wheel steering.

Figure 357. House Trailer with Tandem Axles.

Many full trailers are constructed with a simple type of fifth wheel consisting of two large steel plates and a king pin. In a heavily loaded trailer, considerable binding between the fifth wheel plates hinders free steering, so when the driver steers the motor vhicle to the right or left, the binding fifth wheel resists the turning effort and tends to keep the motor vehicle traveling straight ahead. This is readily apparent to the driver when operating on slippery roads and makes steering not only difficult but dangerous. To overcome this, there is a tendency toward more refined fifth wheel designs that will turn freely under heavy loads by the use of bearings.

c. Full trailers may be classified as nonreversible, reversible, and converted semitrailers. A nonreversible full trailer can be towed and steered from one end only. Its frame (fig. 359) is supported by front and rear 2-wheel trucks which consist of a square frame made of channel sections containing the spring hangers The rear truck is bolted to the trailer frame and forms an integral part of the chassis. A lower fifth wheel ring, mounted on top of the front truck, fits together with an upper fifth wheel ring attached underneath the front end of the trailer frame. The front truck, therefore, turns about the fifth wheel which allows the trailer to be steered. A towing tongue is pivoted to the front truck, and the other end contains a lunette which connects with the pintle hook of the towing vehicle. The trailer chassis illustrated in figure 359 is equipped with air-brake and electrical connections which are hooked up to the towing motor vehicle. A safety chain is provided to prevent the trailer from running away should the pintle hook connection break loose.

d. A reversible full trailer may be towed and steered from either end. It is similar to the nonreversible trailer in construction and appearance, except that both front and rear trucks are mounted by fifth wheels. The towing tongue is detachable and may be used with either truck. Both trucks are provided with locks so that one may be prevented from turning when the other is connected to the towing ends, increasing the operating flexibility of the trailer.

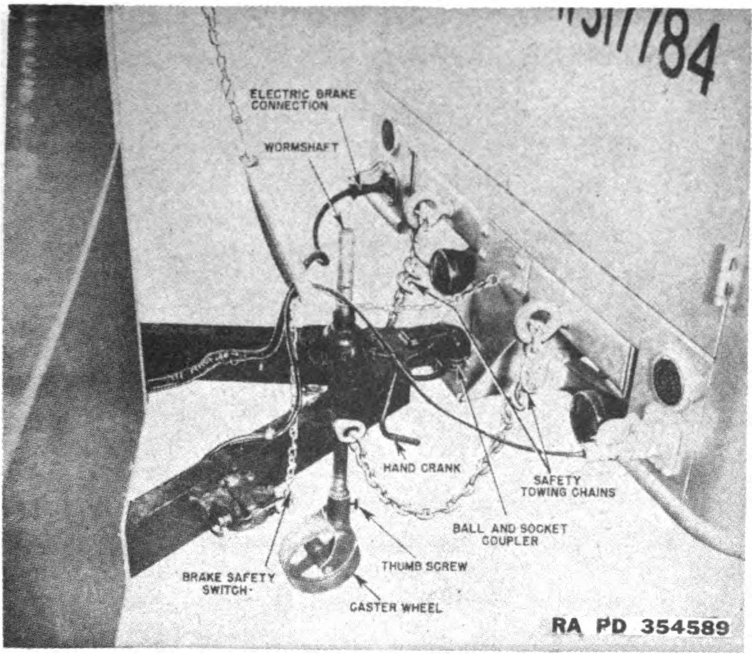

Figure 358. Ball and Socket Connection to a House Trailer.

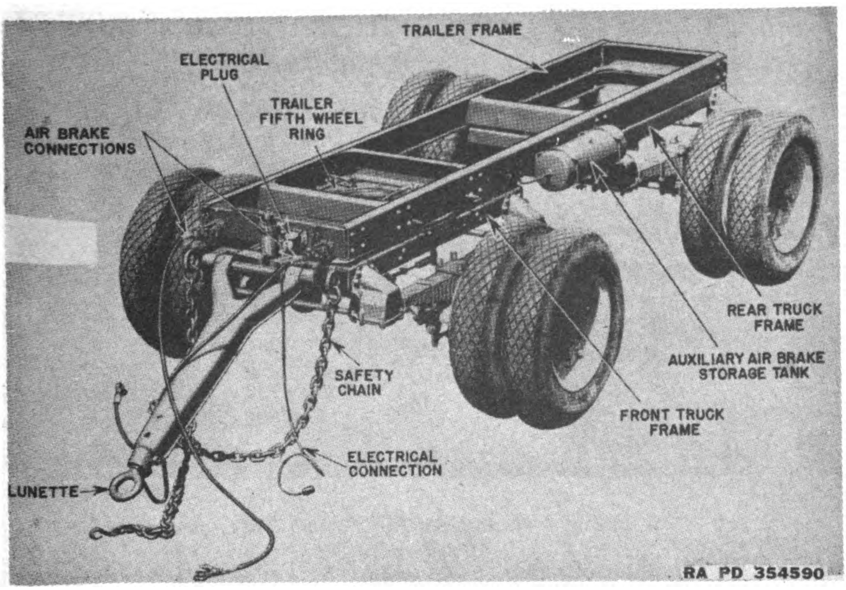

Figure 359. Non-reversible Full Trailer Chassis.

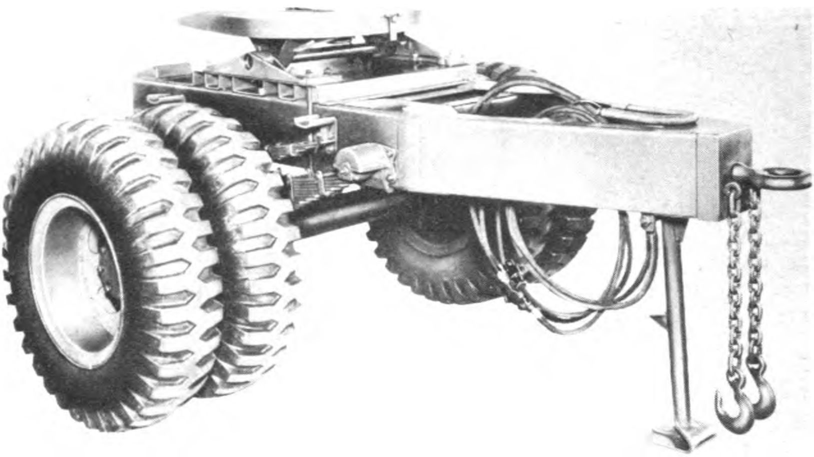

Figure 360. Dolly for Converting a Semitrailer to a Full Trailer.

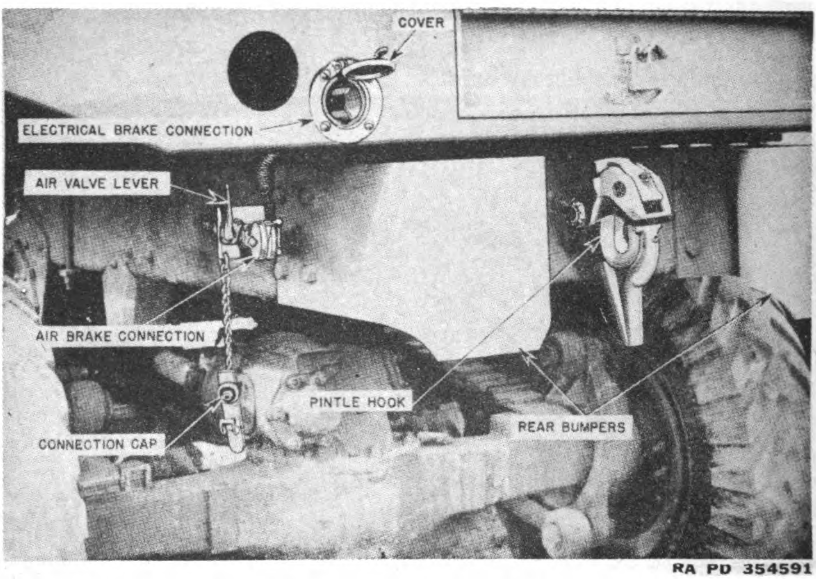

Figure 361. Rear End of Vehicle Used for Towing Three-quarter and Full Trailers.

e. A semitrailer may be converted into a full trailer by mounting the fifth wheel on a dolly (fig. 360) and using the dolly in place of a tractor as the semitrailer front end support. Such a combination is known as a converted semitrailer. The dolly is merely a short 2-wheel trailer chassis with a standard lower fifth wheel mounted on its frame. The front end of its frame is tapered to receive a bracket that contains a lunette for towing the trailer by a pintle hook. A retractable landing gear supports the front end of the dolly when not in use. The open hooks on either side at the front end of the frame are used for joining the towing vehicle and the trailer with safety chains.

f. The rear end view (fig. 361) of a heavy duty motor vehicle used for towing three-quarter and full trailers illustrates the pintle hook. The rear bumpers protect the frame of the motor vehicle and guide the trailer lunette (towing hook) into the pintle hook during the trailer coupling operation. The electrical brake lead of the trailer is plugged into the electrical brake connection, shown with the cover open. The air-brake connections enable the air-braking system of the towing vehicle to be joined to that of the trailer when the trailer is equipped with air brakes. The air-brake connection is shown with its cap removed as it would appear when ready for coupling.

APPENDIX

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