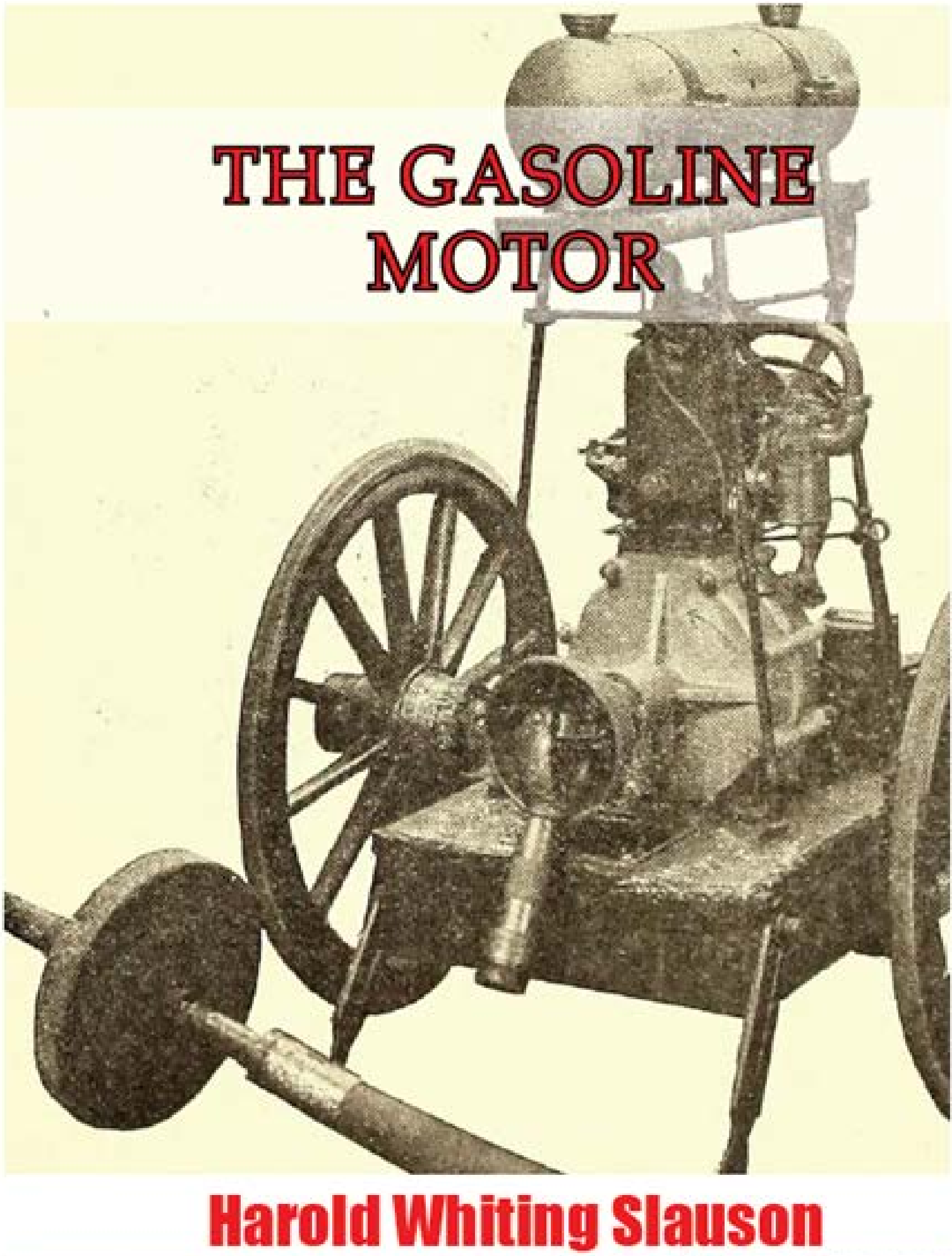
THE GASOLINE MOTOR



Harold Whiting Slauson

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By

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CHAPTER I

Types of Motors

There are certain events that must happen in a gasoline motor before the engine will run of its own accord. For instance, to obtain successive power impulses, the charge must first be admitted to the cylinder and compressed; it must then be ignited to form the explosion that creates the force at the flywheel; and the burned gases resulting from this explosion must be ejected in order to clear the cylinder for the new charge. To accomplish this series of events, some motors require four strokes, while others do the business in two. These are popularly called four-cycle and two-cycle motors, respectively.

A cycle, of course, can be any round of events, such as a cycle of years—at the end of which time the previous happenings are scheduled to repeat themselves. But in gas engine parlance a cycle is taken to mean the round of events from, say, the explosion of one charge to the ignition of the next. Thus, it will be seen that the four-cycle motor requires four strokes of the piston to accomplish its round of events, and is, properly, a four-*stroke* cycle motor. Likewise, the so-called two-cycle motor requires two strokes to complete its cycle and should therefore be termed a two-*stroke* cycle motor.

If this longer terminology could be adhered to, there would be less misunderstanding of the meanings of two- and four-cycle, for when taken literally, these abbreviated forms signify absolutely nothing. Usage seems to have made them acceptable, however, and if the reader will but remember that four-cycle, for instance, means four *strokes per cycle*, the term becomes almost as simple as does "four-cylinder."

It is evident that there are two strokes for each revolution of the flywheel—one when the crank is forced down and the other when the crank moves up. As the piston is attached to the crank through the medium of the connecting rod, the strokes are measured by the motion of the piston. Thus, since it requires four strokes of the piston to complete the round of events in the four-cycle motor, the explosions occur only at every second revolution of the flywheel. In this connection it must be remembered that we are dealing with but one cylinder at a time, for a four-cycle engine is practically a collection of four single-cylinder units.

But even though the explosion in a four-cycle motor occurs only every other revolution, the engine is by no means idle during the interval between these power impulses, for each stroke has its own work to do. The explosion exerts a force similar to a "hammer blow" of several tons on the piston, and the latter is pushed down, thus forming the first stroke of the cycle. The momentum of the flywheel carries the piston back again to the top of its travel, and during this second stroke all of the burned, or exhaust, gases are forced out and the cylinder is cleaned, or "scavenged." The piston is then carried down on its third stroke, which tends to create a partial vacuum and sucks in the charge for the next explosion.

On the fourth, and final, stroke of the cycle the piston, still actuated by the momentum of the flywheel, is pushed up against the recently-admitted charge and compresses this to a point five or six times greater than that of the atmosphere. At the extreme top of this last stroke, the spark is formed, causing the next explosion, and the events of this cycle are repeated.

Now, inasmuch as on one up-stroke of the piston the charge must be held tightly in place in order that it may be compressed, and on the next up-stroke a free passage must be offered so that the exhaust gases may be forced out, it is evident that a valve must be used as a sentry placed at the openings to restrain the desirable gas from escaping and also to facilitate the retreat of the objectionable exhaust. Likewise, the force of the explosion must be confined to the piston on one down-stroke in order that all of the energy may be concentrated at the crank, while on the succeeding down-stroke a free passage must be afforded to the charge so that it may be sucked in through the carburetor. Consequently a second valve must be used to control the inlet passage on the down-strokes and prevent the escape of the force of the explosion through an opening that was intended as an entrance for the fresh charge. Thus valves are a necessity on all motors in which successive similar strokes of the piston do not perform the same operations.

As quadrupeds and bipeds form the two great divisions of the animal kingdom, so is the motor separated into the two main classes of four-cycle and two-cycle engines. Even though to all exterior appearances, the two types of motors may be identical, the distinction, to the engineer, at least, is as marked as is the difference between a stork and an elephant. The difference is somewhat reversed, however, in that, while the elephant has double the number of legs of the stork, the four-cycle motor has but one-half the number of power impulses of its two-cycle cousin at the same speed.

In other words, there is an explosion in each cylinder of the two-cycle motor with every revolution of the flywheel,—instead of with alternate revolutions, as is the case with the four-cycle type. But the number of events necessary to produce each explosion must be the same in both types of motors, and consequently it is only by "doubling up" and performing several operations with each stroke that the two-cycle motor can obtain a power impulse with each revolution of the flywheel.

Starting with the ignition of the charge, as in the four-cycle motor, let us see how the events are combined in the two-cycle type so that all will occur within the allotted two strokes. Directly after the explosion there is but one event that can happen if this force has been properly harnessed, and that is the violent downward travel of the piston. Just before the bottom of this downward stroke is reached, however, an opening is uncovered through which the exhaust gases can expend the remainder of their energy—which by this time has become greatly reduced. Immediately after this another passage is uncovered and the charge is forced into the cylinder under pressure, thus helping to clear the cylinder of the remainder of the exhaust gases.

All of this takes place near the end of the down-stroke; and at the beginning of its return, the piston closes the openings previously uncovered for the passage of the exhaust gases and incoming charge, and then compresses the mixture during the remainder of its up-stroke. Thus the suction stroke and the "scavenging" stroke of the four-cycle motor are dispensed with in the two-cycle type and every downward thrust of the piston is a power stroke.

The two-cycle motor has been used in several notable instances with great success on motor cars, but by far the larger majority of automobile power plants are of the four-cycle type. In view of the wonderful simplicity of the two-cycle motor, its small number of moving parts, and its more frequent power impulses, it may well be asked: "Why is this not in more popular use on the motor car?" The four-cycle motor has but one power stroke out of every four, while only alternate strokes of the two-cycle motor consume power without producing any.

This would seem to indicate that, for equal sizes and weights, the two-cycle motor would produce twice as much power as the four-cycle type—and this is true theoretically. But the four-cycle motor devotes an entire stroke to forcing out the exhaust gases, or scavenging, and another entire stroke to drawing in a fresh charge, and it is evident that these operations can be done much more effectively in this manner than when combined with several other events following each other in such rapid succession as is the case with the two-cycle motor. In the two-cycle motor the incoming charge must be diluted to a certain extent with the exhaust gases which have not been entirely expelled, and the intake valve port is uncovered for so short a time that unless there has been very high compression in the base, the cylinder cannot be entirely filled with the explosive mixture at high speeds. This is described in greater detail in the last chapter of this volume. Thus, while admittedly simpler in construction and operation than the four-cycle, the two-cycle motor in its ordinary forms does not obtain quite as high an efficiency from the fuel as does its more complicated cousin. Each type has its distinct use, however, and in many instances in which low initial cost and simplicity of design are more desirable than are economy of fuel and high efficiency of operation, the two-cycle motor stands supreme.

The sentries that stand guard over the passages through which the gases make their entrance and exit may appear in a variety of guises, but they determine the shape of the cylinders of a motor and divide the four-cycle engine into a number of classes. For instance, if the valves controlling the admission of the explosive mixture are placed on one side of the cylinders and those officiating over the exit of the exhaust gases are located on the opposite side, the motor is known as the "T-head" type because of the shape of its cylinders.

All valves that are placed at the side of the cylinder must operate in pockets so as not to interfere with the movement of the piston. These pockets are cast with the cylinder and form a projection at its side near the top. When these projections are cast on opposite sides, a cylinder having the shape of the letter "T" is formed, while if the valves operate on the same side, the single projection forms a cylinder having the shape of the inverted letter "L." Hence cylinders having valves on opposite sides are called "T"-head motors, while "L"-head motor is synonymous for an engine having "valves on the same side."

When the valves are placed in the head, there is no need of separate pockets, for these valves operate from above and do not interfere with the movement of the piston. There may be a combination of these positions, one set of valves being placed in the head and the others at the side. This is known as the "inlet in head, exhaust at side" type—or vice versa, as the case may be.

The valve that has been in almost universal use in motor cars is known as the "poppet" type, as distinguished from the sliding and rotary styles. As evidenced by its name, the poppet valve is pushed or lifted from its seat, and thus the full area of the opening to the passage is made available almost immediately. The poppet valve is lifted by a cam, the shape of which determines the relative speed of operation of the valve, and is returned to its seat by a stiff spring. The nature of the contact that the valve makes with its seat depends upon the condition of the surfaces and is the deciding factor as to whether the joint is completely air-tight or not.

When the exhaust valve is opened, its head is thrust directly in the path of the hot, out-rushing gases; these same gases also swirl around the edge of the seat. The excessive heat and the particles of carbon that are often found in the exhaust gases tend to corrode and build a deposit on the edges of the valve and its seat, thus eventually preventing perfect contact from taking place. This makes necessary the grinding of the valves—an operation that is familiar to the majority of motor car owners and drivers.

While the poppet valve motor is still used on the majority of automobiles, a new and radical type of valve mechanism has been giving successful results. This is known as the sliding sleeve type of motor, and while it has been used for several seasons in Europe, 1912 saw its adoption for the first time in America. The sleeve motor, it must be understood, is of the four-cycle type, the events occurring in the same order as on any ordinary automobile motor, and the only difference lies in the nature of the valves that control the openings of the exhaust and inlet passages. That this difference is great, however, will be realized when it is understood that the valves consist of two concentric shells, in the inner one of which the piston reciprocates. In other words, two hollow cylinders line the interior of the cylinder casting and replace the poppet valves and pockets of the more familiar type of motor.

These sleeves, or shells, or hollow cylinders—or whatever name it is chosen to give them—slide up and down in the same line of action as that of the piston. A port, or slot, is cut near the top on opposite sides of each of the shells. These four ports are so arranged that one set opens directly opposite the intake passage, while the other opens by the exhaust manifold entrance. When it is said that these ports open, it is meant that similar slots in the two sleeves come opposite each other, or "register," so that an unobstructed passage for the gas is offered. The port in one sleeve may be opposite the intake pipe entrance, but if the slot in the other sleeve does not correspond with this, the passage is effectively closed.

Thus it will be seen that the ports are opened and closed by the movement of the sleeves in opposite directions. For example, just before the opening of the intake port, the inner sleeves will be traveling upward while the outer shell moves downward, and the slots in the two shells will be opposite each other at the instant that they pass the inlet pipe. This gives a much quicker opening than would be the case if one shell stood still while the other moved downward, and it is because the slots approach each other from opposite directions that this motor can be run efficiently at high speeds.

Inasmuch as this is a four-cycle motor and the explosions occur in each cylinder but once during every two revolutions of the flywheel, each sleeve makes but one stroke for every two of the piston. The sleeves are operated by eccentrics attached to a shaft driven at a two-to-one speed by the crank shaft of the motor, and as they are well lubricated there is but very little friction generated between them and the piston. In fact, it has been shown that the power required to operate the sleeves, when well lubricated, is considerably less than that consumed by the springs and valve mechanism of the poppet valve motor, for the reason that the former type of valve does not open against the pressure of the exhaust, as is the case with the ordinary gas engine valve.

Besides the two- and four-cycle divisions, a motor is known by the arrangement of its cylinders and is classified as "cylinders cast separately," "cast in pairs," or "triple cast," according to whether there are one, two or three cylinders to a unit. The last-named type is not as common as are the "pair-cast" cylinders and of course can only be used on six-cylinder motors.

When all of the cylinders of a motor are cast in one piece, the engine is known as a "bloc" motor. This is a type that has come into popular use for small and medium-sized power plants during the past few years on account of the simplicity of its construction and the smooth and compact design that is rendered possible. Of course it may be argued that, with such a design, the entire set must be replaced if a single cylinder is damaged, but castings have been so improved that an accident or imperfection requiring the renewal of a cylinder is very rare.

It is evident that, beyond a certain size of cylinder, a bloc casting becomes too bulky to be handled conveniently, and as the entire casting must be removed when it is desired to reach the connecting rods, crank shaft, or piston rings, a motor so designed will seldom be found that develops more than forty or fifty horsepower. This type of casting is found on some six-cylinder cars, however, but it is naturally only the "light sixes" that will use such a motor.

Above six-cylinders, a motor is usually arranged with its power units set at an angle on either side of the vertical, thus forming the V-shaped motor. Several eight-cylinder motors are so constructed, the units being arranged four on a side and each set placed at an angle of about thirty degrees from the vertical. This gives the effect of two four-cylinder motors placed side by side and operating on the same crank shaft.

In order to make the motor as compact as possible, the cylinders are "staggered;" or, in other words, the cylinders of one set are placed opposite the spaces between the units of the other. It will be seen that the V-shaped design of motor shortens the power plant and enables it to be set in a much smaller space under the bonnet than would be the case were the cylinders placed one in front of the other, as in the four- and six-cylinder types.

As a rule, the two-cylinder, four-cycle motor is of a different type from its four- and six-cylinder cousins, and is known as a "horizontal opposed" engine. In such a motor, the cylinders are set lengthwise and the pistons operate opposite each other in such a manner that a "long, narrow, and thin" power plant is obtained that is especially well-suited for a location under the body of the car. In fact, this horizontal motor, which may, of course, be of the four-cylinder type, is the only shape that can well be used under the body or seat of a touring car. In some small runabouts, however, the "double-opposed" motor is used to good advantage under the forward bonnet, as in the "big fellows."

There are, of course, many other features of design that serve to differentiate one automobile power plant from another, but these are details that do not serve to classify the motor, and the man who knows whether his machine is two- or four-cycle; poppet or sleeve valve; separate, pair, or en bloc cylinder castings; and "T"- or "L"-head shape will have at his fingers' ends distinctions that would have "floored" the salesman of a few years ago.

CHAPTER II

Valves

It has been stated in the preceding chapter that the valves of the gasoline motor are the sentinels placed on guard at the entrance to and exit from each cylinder to make certain that the mixture follows its proper course at the proper time.

Therefore, if we accept the definition that a valve is a mechanical appliance for controlling the flow of a liquid or a gas, strictly speaking no such thing as a "valveless" motor exists. Two-cycle motors are sometimes said to be valveless because of the fact that the movement of the piston automatically regulates the flow of the exhaust and intake gases, but in this case the piston is in reality the valve. On the four-cycle motor, however, like events take place only on alternate strokes in the same direction, and consequently some controlling mechanism that operates but once for every four strokes of the piston is needed to time the flow of the gases.

As has been stated in the previous chapter, the most common form of valve is known as the poppet type from the fact that its action is a lifting one. Such a valve may be located in a projection cast on either side of the top of each cylinder, or it may be inverted from this position and placed in the cylinder head. When in the former location, the valve is opened by an upward push on the rod to which it is attached at its center, while a valve placed in the cylinder head is forced down to allow the escape or entrance of the exhaust or intake gases. The ordinary type of poppet valve is somewhat similar in shape to a mushroom, having a very thin and flat head and a slender stem. The disc portion of the valve is known as its head, while the rod forged with the valve and by which the head is raised and lowered is called the stem.

The projections cast in the cylinders of a "T"-head or "L"-head motor, and in which the valves are placed, are known as the valve pockets. Valves so located are lifted by a direct upward push caused by the rotation of a cam and are returned to their closed position by means of the extension of a stiff spiral spring surrounding each valve stem. It is only the outer edge of the lower side of the valve head that comes in contact with the surrounding surfaces of the opening which is closed when the valve is returned to its ordinary position by the spring.

This surface of contact surrounding the opening is known as the valve seat, and it is this, together with the edge of the valve which rests against it, that must be ground smooth in order to insure a tight joint when the valve is closed. On the majority of poppet valves the edge of the head and the seat against which it rests are beveled to an angle of approximately forty degrees in order to conform to the natural direction taken by the gases when they are admitted or expelled. In a few cases, however, the seat angle is ninety degrees, which means that the edge of the head is ground flat, or straight, at right angles to the stem.

One of the chief advantages found in the use of a poppet valve is the fact that a large opening can be obtained after the valve head has been raised but a comparatively short distance. This means that the valve stem need travel only a fraction of an inch between the full open and the full closed position of the valve and that the operating mechanism for obtaining this lift is simple. Practically every poppet valve, therefore, is lifted by means of a cam, which is a thick, irregularly-shaped piece of steel mounted on a shaft known as the cam shaft. If the end of the valve stem, or a rod connected to it, is held against the periphery of the cam while the latter is revolved by its shaft, the valve will be forced up, or away, rather, an amount corresponding to the increase in distance between the periphery of the cam at this point of contact and its axis.

In other words, if the cam were a true circle with its axis passing through its center, there would be no motion of the valve, for all points of the periphery of a circle are at the same distance from the center. Consequently a portion of the periphery of the cam is extended in the shape of a "nose," the projection of this beyond the smallest diameter of the cam being the distance that the valve will be lifted when this point of the cam surface comes in contact with the stem or push rod. The broader, or more blunt, the nose of the cam, the longer will the valve remain open as the cam shaft is revolved, while the "slope" of the sides of the nose determines the rapidity with which the valve will be pushed out and back. Inasmuch as the valve should remain closed throughout two-thirds or three-quarters of every two revolutions of the flywheel, the greater part of the periphery of the cam is circular, or at the same distance from the axis at all points.

As has been mentioned before, the cam serves only to lift the valve, the return of the latter to its seat being obtained by the force from a spring that is coiled around the stem. Thus the spring holds the end of the push rod at all times against the periphery of the cam. This push rod, in some instances, is a small bar of special steel that slides in guides of long-wearing bearing alloy. The upper end of the push rod is in contact with the lower end of the valve stem, while its other extremity is oftentimes designed in the form of a small steel roller that thus serves to create a rolling contact with the periphery of the cam.

In other designs, the lower extremity of the push rod may be in the form of a specially-hardened steel pin with a rounded end, while still a third type consists of a flat disc slightly "offset" on the end of the push rod so that various points of its surface will come in contact with the periphery of the cam and the wear will be evenly distributed. Whatever the particular design, however, the cam is well lubricated and both it and the push rod are intended to last as long as any part of the motor.

Many motors are designed with one valve at the side and the other, usually the intake, in the head. There are also many motors manufactured that have both the intake and the exhaust valves located in the head, in which case the valve pockets, or projections, are eliminated. Such valves may be operated by the same type of cams and cam shaft as those used to open the valves at the side. As the opening of a valve located in the head is downward, however, the motion produced by the cam on the push rod must be reversed in direction. This reversal of motion is obtained by means of a lever mounted at its center and placed in contact with the upper extremity of the push rod at its outer end. The other end of this lever operates in contact with the end of the valve stem, and thus an upward push on the rod is converted into a downward thrust on the stem. This lever that reverses the direction of the push rod motion is known as a rocker arm and is mounted in a yoke cast with the cylinder head.

Inasmuch as a spring is used to keep the valve tightly closed when the cam is not lifting the latter, it is the contact of the valve head with its seat that must form the stop to the motion of the spring. It will be seen that the force of the spring is communicated through the valve stem to the push rod, and thence to the periphery of the cam when the latter is in a position to lift the valve. The push rod should not be forced tightly against the periphery of the cam when the valve is closed, however, for this would prevent perfect contact between the valve and its seat. Consequently there should be a certain amount of "play" between the end of the push rod and valve stem so that it will be certain that the head is forced against the seat with the full power of the spring and without the cam serving as a stop.

On the other hand, this play should not be too great, for the cam and push rod will then move an appreciable distance before the valve is raised. This will cause the opening of the valve to occur late and will reduce the distance that the stem is raised, thus restricting the size of the opening. Furthermore, an undue amount of play between the ends of the push rod and stem will result in a pound or "hammer blow" between the two that is liable to wear the surfaces rapidly.

The "happy medium" that will give the best results may be obtained by properly setting the small valve "tappets" that are secured to the end of the stems or push rods. By turning the nut of the tappet in one direction, the length of the push rod will be reduced, while the reverse operation will increase the length of the rod or stem. This is primarily intended for taking up any wear that may occur at the ends of the push rod or valve stem. In the case of engines having the valves in the head, the long push rod of each valve should be so loose as to move perceptibly when shoved up and down by the thumb and finger.

When the rocker arm is pressed down against the valve stem, the space between the other end of the rocker arm and the push rod should be sufficiently wide to admit a piece of tissue paper. The same test may be made in connection with valves located at the side, after first ascertaining that the end of the short push rod is resting firmly against the periphery of the cam. The play will be apparent, of course, only when the valve is tightly closed, and in order to make certain that their cams are in the "inactive" position, the piston should be set at the beginning of the explosion stroke when testing the intake or exhaust valve. This is at the point of ignition and is the time at which both valves should be tightly closed.

The cam shaft to which the cams that operate the valves are attached is generally placed inside the crank case. If the motor is of the "T"-head type, having valves on opposite sides of the cylinders, the cam shaft operating the exhaust valves will be found on one side of the crank case, while that for opening the inlet valves will be located on the other. If the motor is of the "L"-head type, all the cams will be placed on the one shaft. The cams are sometimes forged with their shaft in a solid piece, while in other designs they are keyed in place, but whatever type is used, the cams and their shaft may be considered as integral with each other.

The cam shafts are generally driven by a gear meshing with a smaller one attached to the front end of the crank shaft of the motor, which forms one of the forward train of gears that are enclosed in an aluminum case. If the cam shaft is driven at the same speed as is the crank shaft of the motor, it will be seen that the valves will open once at every revolution of the flywheel. In a four-cycle motor, however, the explosion and other events occur but once in each cylinder for every two revolutions of the flywheel, and consequently the cam shaft must be driven at one-half the speed of the crank shaft.

To obtain the proper speed ratio, each cam shaft is driven by a "two-to-one" gear, which means that the gear on the end of the crank shaft has but one-half as many teeth as have those attached to the cam shafts. There is thus one revolution of each cam shaft gear for every two of the crank shaft gear, and consequently each cam shaft is driven at the required half speed.

The cam shafts may be driven by a chain, the links of which fit over teeth cut on sprocket wheels, but there must always be a constant relation between the position of the cam shaft and that of the crank shaft. This constant relation is necessary in order that the valves will open and close at the proper points during the travel of the piston. For example, the exhaust valve should open toward the end of the explosion stroke in order to allow the burned gases to be forced out, and the cam for operating this valve should always be in the lifting position at exactly the proper moment.

If the cam shaft is not positively driven, this position may change and the exhaust valve might be opened at the beginning of the ignition of the charge, in which case the force of the explosion would be wasted almost entirely. On the other hand, the inlet valve should open at about the beginning of the suction stroke in order that the fresh charge may be drawn in by the downward travel of the piston; it is evident that this cannot be opened at any other time without a resulting loss in the power developed by the motor.

The proper timing of the action of the valves is consequently one of the most important adjustments of a motor. When the motor is assembled and tested at the factory, the valves are properly timed and there is no possibility that they will require further adjustment in this respect until after the engine is "taken down" for the purpose of cleaning or the renewal of a broken part. If it should ever become necessary to remove one of the cam shafts or any of the gears constituting the forward train, the greatest care should be taken to make certain that all are returned to *exactly* their original position. A difference of one tooth in the relative meshing of the gears may result in a loss of fifty per cent. of the power developed by the motor.

Absolute rules for the proper timing of the valves cannot be given here, for various motors are designed with slightly different positions at which the exhaust and inlet valves should be opened and closed. A cam shaft should never be removed, however, without first marking the intermeshing teeth of its driving gear and those of its companions. This may best be done by means of a small prick punch which, when tapped lightly with a hammer, will make a permanent mark at the desired point on the surface of the gear. If the motor is of the "T"-head type, having its valves operated by two cam shafts, care should be taken to designate the right and left-hand gears so that their positions will not be reversed if both have been removed at the same time.

A safe method to pursue is to indicate the right-hand gear with one punch mark, while two should be used for the gear at the left. Three teeth should be marked on each pair of intermeshing gears. That is, a tooth on one gear should be marked, and then each of the teeth between which it meshes on the other gear. The second cam shaft gear should be marked before the motor is turned.

As has been stated, the cams on many motors are forged integral with their shafts, and there is consequently no possibility of the removal of one from the other. Those cams which are keyed to their shafts are accurately and rigidly set and the keyways so cut that there is slight chance of a mistake in returning a cam that has been removed. It should seldom be necessary to remove a cam from its shaft, however.

Many motors are provided with timing marks on the flywheel to indicate the positions of the latter at which the valves of the various cylinders should open and close. In connection with these marks a pointer attached to the crank case and indicating the top of the flywheel is used. When the line on the flywheel marked, for example, 4 Ex 0, is under the pointer, it indicates that the exhaust valve on the fourth cylinder should be about to open. If the motor is turned but very little beyond this point, a lifting should be felt at the proper push rod or valve stem.

It is well to test the setting of the valves occasionally by means of these marks, for wear at the rocker arms, the push rods, the valve stem, or the cam travelers will result in unevenly-timed valves. It should be remembered that it is the valve itself that should open after the proper mark on the flywheel has been passed, and that the movement of a long push rod is not sufficient evidence that the valve is beginning to leave its seat. There may be so great an amount of lost motion between the push rod, cam, rocker arm, and valve stem that the flywheel may be turned several degrees beyond the proper point before this "play" will be taken up and the valve itself will begin to move.

Although the timing of a motor may be given in inches of piston travel beyond a certain dead center, at which point an exhaust or inlet valve should open or close, it is generally expressed in degrees of flywheel revolution. Suppose, for example, it is said that the inlet valve should open ten degrees after the beginning of the suction stroke. This would indicate that the flywheel should be turned through an arc of ten degrees from the point at which the piston is at its upper dead center before the inlet valve for that particular cylinder should begin to open. Expressed in terms of flywheel revolution, the total travel of the piston during each stroke is 180 degrees, and as in the proximity of its dead centers the piston moves but a short distance in comparison with the size of the arc through which the flywheel swings, valves may be set very accurately by this method.

Not all cam shafts for operating the valves are located in the crank case. On several designs of motors the cam shaft extends along the top of the cylinders and is driven by a vertical shaft and two sets of bevel gears. On such motors both inlet and exhaust valves are located in the cylinder heads, and owing to the proximity of the cam shaft, but short push rods and valve stems are needed. The valves are sometimes operated by means of a bell crank or rocker arm that acts directly against the cam surface and end of the valve stem.

On some designs a double cam is used which serves to operate both the inlet and exhaust valves of the cylinder. The bearings and cams of such a shaft are generally enclosed in oil and dustproof casing screwed to the top of the cylinders. Such a cam shaft should never be dismounted without first marking intermeshing teeth of all spur and bevel gears that are concerned in its operation.

All poppet valves must be accessible and readily removable for the purpose of cleaning and grinding the contact surfaces of the head and seat. The pockets in which the valves placed at the side of a cylinder are located are generally provided with large screw plugs at the top. Such a plug may be removed with a heavy wrench, and as the opening which it fills is larger than the head of the valve, the latter may be removed after first loosening the spiral spring surrounding its stem. It is not necessary to remove the valve entirely from its pocket in order to grind its surfaces, but the pin holding the spring stop in place must be withdrawn so that the tension of the spring on the valve will not be so great as to prevent the latter from being lifted to permit the introduction of the abrasive and turning the head with the grinding tool.

Valves located in the head of the cylinder must be removed entirely before their surfaces can be ground. This, however, is not a difficult operation, as the valve and its seat are generally placed in a removable "cage" that either screws in place or is held firmly in position by means of a clamp or like device. Inasmuch as the seat is contained in this removable cage in which the valve operates, the grinding may be done at a work bench or on the bed of any convenient tool, independently of the location of the motor.

If a valve seems sluggish in its action at high speeds of the motor, it is possible that its spring has become somewhat weakened. These springs are designed to be exceedingly stiff and heavy, some of them requiring a pressure of two hundred and fifty pounds to compress the coils one inch. With such a spring, a special tool is required to compress it sufficiently to enable the valve to be removed. A spiral spring that has become weakened may sometimes be strengthened by "stretching," but it is not to be supposed that this would be of great avail in the case of a spring as heavy as those used on some valves. If, however, a flat tool is introduced between the various coils and each is separated slightly so that the ultimate length of the entire spring is greater than it was formerly, it will exert a more powerful force on the valve when it is returned to its place surrounding the stem.

Stiffening the spring, however, will be of but little help if the stem or push rod is tight in the guides through which it slides. These guides are often made of a special bearing bronze and are designed to withstand a large amount of wear, but the friction surfaces must be lubricated if satisfactory service is to be obtained. The lower guide is generally lubricated by the oil from the cams, while the guide near the valve may receive its oil from the engine cylinder. It is not necessary that these guides shall be packed or that they shall be particularly tight, as they are not called upon to retain any gas or air pressure, but they must hold the stem and rod sufficiently rigid to prevent any perceptible side motion and thus cause imperfect seating of the valve. In replacing valve stems and push rods, it should be made certain that each works freely in its guide before the spring is installed. If there is a slight tendency for the guide to grip the rod or stem, the latter should be smoothed with emery paper at the point at which it comes in contact with the guide and plenty of oil applied until the surfaces are well "worked down." As the distance that the rods and stems travel through the guides is comparatively short, the wear is slight and only a small amount of lubricant is needed, provided the rubbing surfaces are smooth and well-fitted to each other.

The mechanism of a sleeve valve motor is slightly different from that of the poppet valve type. Each sleeve is operated by a connecting rod and eccentric mounted on a shaft driven by a chain or gears from the crank shaft of the motor. The eccentric replaces the cams of the poppet valve motor, and as it must maintain a certain relation with the position of the piston in order that the operation of the valves shall be timed correctly, the same care must be observed in replacing the eccentric shaft with the proper teeth of the sprocket or gear in mesh as has already been described in connection with the cam shaft of the poppet valve motor.

CHAPTER III

Bearings

In the general meaning of the term, a bearing is any part that carries weight or pressure and at the same time rubs over another surface. According to this definition, the portion of the cylinder walls traversed by the pistons are bearings, and that is in reality the case, but the term has come to be applied more specifically to the part of the machine in which another part *revolves*, either continuously or intermittently. Thus the portions of the crank shaft on which it is supported and the parts of metal in which they revolve combine to form the crank shaft bearings. The shaft or stud on which a gear or wheel is mounted and on which it revolves is the bearing of that gear or wheel.

Although they are concealed, as some six-cylinder motors may be provided with as many as three dozen, or more, bearings—if we consider those on which the cam, pump, and magneto shafts and the gears are mounted— but what descriptions, rules, and precautions apply to all hold true in the largest sense when the crank shaft, connecting rod, and wrist pin bearings only are considered. It is on this latter class that the greatest wear of the motor is concentrated, and the owner who understands and inspects these need fear no trouble from the cam shaft and gear bearings.

The expert will judge of the condition of a motor by the wear that has occurred in the bearings rather than by any exhibition of temporary power that it may develop in a short test, and it is for this reason that the "general public" runs a risk whenever it buys a second-hand car that has not been thoroughly overhauled by a reputable factory or inspected by a competent engineer. The bearings are in reality the vitals of the motor, and when these are worn beyond the point of easy adjustment or renewal, the repairs necessary to place the machine in good condition would oftentimes cost more than the entire engine is worth. But even in a badly-worn motor, the bearings may be "taken up" and "doctored" so that, for a while at least, the engine will seem to run perfectly and develop its full power. This will not be for long, however, and soon the motor will begin to pound, knock, and rattle until an examination will bring to light the true condition of the bearings.

In no machine are the bearings subjected to more severe usage than in the automobile motor. In order that the motor car power plant shall be light in weight and occupy but a small amount of space, the power must be transmitted at high speeds. In many an automobile motor, the pressure imparted to a single bearing during a certain portion of its revolution may frequently be well over two tons, and in this same bearing, the "speed of rubbing" may approach eight or nine hundred feet per minute. In other words, at normal speeds of the motor, about a sixth of a mile of steel surface will rub over a certain point in each crank shaft bearing during every minute that the engine is running.

When properly lubricated, an iron or steel shaft will run in almost any kind of a metal bearing that is sufficiently strong to carry the weights and pressures imposed upon the shaft. The friction generated between two different metals that rub against each other, however, varies according to the composition of those metals, and consequently it is advisable to employ some material for a bearing that will offer a minimum resistance to the turning of the shaft. Friction must be reduced between all moving surfaces in order that the mechanical efficiency of the machine shall be high, and it is in the bearings that a large amount of power may be absorbed.

But even between the best-lubricated surfaces, employing the most efficient metal as a bearing, some wear is bound to occur. The crank shaft of a four- or a six-cylinder motor is forged or sawed from one piece of steel, and with the accurate machining, finishing, and grinding to which it is subjected, it becomes an expensive part of the engine. Consequently it is advisable that the wear of bearings of such parts shall be restricted to the "boxes" or surrounding stationary metal in which the shaft revolves at these points. In order that all wear shall occur here, rather than in the shaft, the boxes are made of or lined with a softer metal. If the crank shaft is of hard steel, the bearing metal may be of brass or bronze, but it has been found that babbitt metals give the most satisfactory service for such conditions—particularly as a sufficiently hard crank shaft is difficult to produce commercially.

Not only is a babbitt metal softer than the steel of the shaft and consequently receives practically all the wear of the bearing, but it has the added advantage of melting at comparatively low temperatures. At first thought, this may seem like a doubtful advantage, but in case of a failure of the oil supply to that bearing, this characteristic may be the means of saving the crank shaft, and possibly the crank case, cylinders, and connecting rods, from rack and ruin.

The purpose of lubrication is to reduce friction between the two surfaces in contact. Friction generates heat, and consequently the temperature of a bearing to which a sufficient supply of oil is not delivered will be raised to a very high point. This high temperature will cause both parts of the bearing to expand, with the result that the fit becomes very tight and the shaft binds or "seizes" in its box. This is the familiar "hot box," so often the bane of railroad men, and if the shaft is still run under these conditions, the bearing material will be torn out and the surface of the shaft, axle, or whatever the revolving portion happens to be, will be cut and abraded, oftentimes beyond the possibility of repair. It is such accidents as these that are prevented by the use of an easily-melted babbitt metal.

If the oil supply becomes insufficient so that the temperature of the bearing is raised above a certain point, the babbitt metal will be melted and will run out of its container before any damage can be done to the shaft. Efficient running cannot, of course, be obtained with the bearing "burned out" in this manner, but the babbitt is quickly and easily renewed and serves as a sort of fusible safety valve that saves many an expensive crank shaft replacement.

Babbitt metals may be of various compositions and proportions and many contain lead, but those which have been found to give the best results for use on the crank shafts of automobile motors are composed only of tin, antimony, and copper. If lead is used at all for this purpose, it should not appear in proportions above one per cent of the total composition. Inasmuch as a babbitt metal will fuse at a comparatively low temperature and is much softer than steel, it is obvious that such a material will not withstand heavy pressures unless reinforced and is unsuited for structural purposes. Consequently the babbitt is placed in the bearing box in the form of a thin lining within which the shaft revolves.

When the shaft is "lined up" in the box, the hot babbitt metal may be poured in until the space is entirely filled. When the babbitt cools, the shaft may be turned, and when lubricant has been introduced in the oil grooves which should have been provided for the purpose, the new bearing will be ready for use. It is not to be expected that the majority of motor car owners will rebabbitt the crank shaft bearings themselves, but it is necessary to understand the general principles of such bearing design in order to inspect the motor intelligently and to determine upon the repairs needed.

The above method of renewing "burned out" bearings applies to babbitts in general, but the severe usage that automobile engine crank shaft and connecting rod bearings are called upon to withstand necessitates the exercise of a certain amount of additional care. It is necessary that the box shall fit the shaft perfectly, so that there can be no "play," and yet the shaft must be allowed to turn easily within its surrounding babbitt metal.

As was stated above, the shaft may be easily loosened from the babbitt metal after the latter has cooled, and this would form a satisfactory type of bearing were it not advisable that some means be supplied by which the wear could be taken up without renewing the entire babbitt lining. The bearing boxes of the crank shaft are each made in two halves, the lower portion being cast integral with the crank case, while the upper half is in the form of a separate cap that may be held in place by two or four bolts. In this case, it is necessary that the boxes shall be in two sections, for the shape of the crank shaft prevents it from being slid into place lengthwise, and consequently it must be placed on its bearing from the top. In some designs of motors the bearing caps form the lower half of the box, but as in this case the base of the motor must be inverted in order to remove the crank shaft, the caps will still be considered as the "top" halves of the boxes.

There may be dove-tail grooves cut in the inside of the halves of the boxes to retain the babbitt metal after it has been poured in place. Consequently, in order to remove the cap after renewing the babbitt lining, the babbitt metal must be cut in two at the joint between the two halves of the box. The two halves of the box, instead of fitting closely together, are separated by thin strips of copper or fiber known as "shims" that serve to relieve the shaft from the pressure of the bolts when the bearing cap is screwed in place. In other words, the two halves of the box must be held tightly in place by means of the bolts and nuts, but none of this pressure should rest on the revolving shaft, as this would bind it and prevent it from turning easily. Consequently by "building up" the space between the two halves with these thin shims the proper adjustment may be obtained.

These shims provide the method of taking up the wear in the babbitt that will eventually result. By loosening the box retaining bolts and removing the required number of shims, the halves of the box will be brought closer together. When the bearing cap is screwed securely in place, the shaft should be able to revolve freely without binding, and yet the fit should be sufficiently tight to prevent any "play" at right angles to the length of the shaft.

The pressure of a shaft should not be concentrated in one place, but should be distributed over as large a surface of the babbitt metal as is possible. A few years ago, when renewing or repairing a bearing, it was considered sufficient to pour in the molten metal or to remove the proper number of shims—and the bearing was then said to be ready for its work. But even though no play was apparent, it was possible that the shaft rested on only a few portions of the bearing surface; and the increased attention that is now paid to the details of automobile construction is no better exemplified than in the fact that nearly all bearings are "scraped" in. This operation is simple and consists merely in removing any slight excess babbitt metal so that the lining fits the shaft throughout its entire length and circumference. The babbitt is sufficiently soft to enable it to be peeled or scraped with a sharp tool provided for the purpose, and no great degree of skill is necessary in obtaining the required fit.

In order to determine at exactly what portions of the babbitt lining the pressure is too great, a dye or paint known as "blueing" is used. The bearing portion of the crank shaft is painted with this, and the cap is then screwed in place. If the crank shaft is then turned and the cap removed, it will be found that the blueing has been transferred from the bearing to the portions of the babbitt metal on which the pressure is the greatest. These portions should then be shaved with the tool mentioned above, and the same test repeated. As the excess metal is removed, it will be found that the blueing gradually is deposited over a larger area of the babbitt, but it is not to be supposed that the fit can be made so perfect that the color will be distributed evenly over the entire surface. Care should be taken to screw the bearing cap onto the shims as tightly as possible each time the blueing test is to be made.

There is nothing that will heat a bearing so quickly as a poor alignment of the shaft supported by it. For this reason gasoline engine crank shafts are made exceptionally strong and heavy, especially those that are supported only at their extremities, or at these points and in the center of their length. A shaft that is bent or twisted to even the slightest degree will soon "burn out" all of its bearings, regardless of the amount of oil that may be fed to them. This is because of the unequal pressures on the different sides of the bearing that allow no room for the admission of the film of oil or other lubricant that is necessary in all cases to prevent a "hot box."

On the other hand, the bearings must all be in perfect alignment, for to set one slightly "off" would produce the same result as though the shaft were bent. It will be seen that the use of babbitt produces a "self-aligning" bearing, for the straight shaft may be set in its proper position and the molten metal poured around the interior of the boxes.

As it is highly important that the cap screws or nuts holding the bearing cap in place should remain set as tightly as possible, precautions must be taken to prevent any of these from working loose. This may be done by means of a cotter pin that passes through a hole in each bolt and through a pair of corresponding notches cut in the top of opposite faces of the nut. A notch is generally cut in the top of each face of the nut in order that the latter may be held securely in place in any position. A continuous wire passing through all of the bolts and nuts is sometimes used instead of the individual cotter pins.

Many modern automobile motors are designed with the crank shaft running in ball bearings. The type generally used consists of a row of balls set between the inner and outer edges of two concentric rings. The inside of the outer and the outside of the inner ring are grooved, constituting the ball "race" which forms the surface upon which the balls roll and which, at the same time, serves to hold them in place. Each ball of the same bearing must be made of exactly the same size as its companions—or at least within one or two ten-thousandths of an inch—and each one must be large enough and of sufficient strength to withstand, by itself, the entire pressure in that bearing. The inner ring slips over the bearing portion of the shaft with a comparatively tight fit, while the outer ring remains stationary in its bed in the crank case.

The inner ring turns with the shaft, thus causing the balls to roll in their race. Each ball rolls about its own axis, and the entire series describes a circular motion in the same direction as that taken by the shaft, but considerably slower. Consequently there is no rubbing in such a bearing, all the motion being of the rolling type, and as this reduces friction to a minimum, the balls may be run without oil, although lubrication of the proper kind would certainly not harm the bearing. Ball bearings are adapted only for a two-bearing crank shaft, for inasmuch as the rings must be slipped over the shaft, it would be manifestly impossible to provide a ball bearing in the center, or in any other portion beyond a crank.

Next in importance to the main bearings of a crank shaft are those by which the connecting rods communicate their motion to the cranks. These are known as the crank pin bearings or the "big end" of the connecting rod bearings. But inasmuch as the upper, or smaller, end of the connecting rods are termed the wrist-pin bearings, the other end may be called simply the connecting rod bearing.

The connecting rod bearings are similar to the main bearings described in the foregoing pages and are renewed and adjusted in the same manner. It is probable, however, that these receive a greater amount of wear than do the main bearings, inasmuch as the former obtain the direct impact of the force of each explosion. Furthermore, the box of the connecting rod bearing describes a complete circle with each revolution of the crank shaft, in addition to the "internal rotation" of the crank, while an alternate push and pull is delivered to it by the connecting rod on its various strokes.

Consequently it is the connecting rod bearings that will become loose and require "taking up" before any attention need be bestowed on the main bearings. The wear will increase in the connecting rod bearing as the play becomes greater, and if matters are not remedied, the box may eventually be broken, with the result that the end of the connecting rod thus freed will start on the "rampage" and will punch several pieces out of the bottom of the crank case.

Brass or bronze bearings may be used at the big end of the connecting rods, but the large majority of motor car engines are provided with babbitted bearings at these points. It is especially necessary that these bearings should be scraped to a perfect fit and that the shims should be adjusted properly so that no side play will be apparent when the connecting rod is moved transversely to the length of the crank shaft. When renewing the babbitts of connecting rod bearings care should be taken to allow the connecting rod to swing free before the molten metal is poured in. If this is not done, the connecting rod may be forced slightly to one side or the other and will be held permanently in this position when the babbitt cools. This will induce a slight side thrust in the connecting rod, which will be communicated to the piston, with the result that the side of the latter and of the portion of the cylinder wall against which it moves will be scored and worn unduly.

Inasmuch as the connecting rod bearings are subjected to such a variety of strains, and as looseness at these points will result in serious wear, it is doubly necessary that the nuts and bolts holding the bearing caps in place should be securely wired or held tightly by means of the previously-mentioned cotter pins. It is evident that the base of the large end of the connecting rod forms the upper half of the bearing box, while the cap constitutes the lower end and is attached from the bottom.

The connecting rod bearings on some motors are hinged at one side so that the cap may be turned away from the crank shaft when it is desired to remove the connecting rod. In this case the hinge replaces the one or two bolts or nuts on one side of the box and is held in the proper position by those on the other side. While it may be easier to adjust a bearing provided with such a cap, the results obtained can hardly be expected to be as satisfactory for high-grade service, as is the case when the shims may be used on both sides of the two halves of the bearing.

The wrist-pin bearing is located at the upper, or small, end of each connecting rod, and, although it also carries the full force of each explosion, it is not subjected to as great wear as is the bearing at the other end of the connecting rod. The reason for this is that this bearing does not revolve and its friction surface is reduced to the comparatively small arc through which the connecting rod swings. Wear can occur here, however, and because this bearing is more inaccessible than is the crank shaft or connecting rod bearing, trouble at the wrist pin is often overlooked.

The wrist pin can only be reached by the removal of the piston and connecting rod. In the majority of designs the wrist pin is placed in the sides of the piston and is held stationary by small keys or by set screws. In this case, the bearing surface is formed by the wrist pin and the small end of the connecting rod, at which point the greatest wear occurs. This bearing is never babbitted, but in order to reduce the wear on the wrist pin—which is generally made of hardened steel—the circular opening in the upper end of the connecting rod is lined with a bronze or brass bushing that forms a bearing fit over the wrist pin. It is this lining, or bushing, that will wear rather than the hardened steel wrist pin, but as the former is easily removed and is not expensive to replace, the renewal of this bearing is a comparatively simple matter.

In other types of wrist pin bearings, the pin is held stationary in the connecting rod opening and turns with it as the connecting rod swings through its arc on each stroke of the piston. With such a design, the bearing surface is formed by each end of the wrist pin and the openings in the sides of the piston walls in which the wrist pin rests. In order to form an easily-replaced bearing surface, these openings in the piston walls are lined with brass or bronze bushings that receive the major part of the wear, as has been described in connection with the bushings fitted to the opening at the small end of the connecting rod.

There is nothing complicated or mysterious connected with the renewal or repair of bearings, but the man who makes such replacements or adjustments must be an accurate and careful worker, and while he need not be a "born machinist," he must at least possess the "knack" of handling tools properly. And he must, above all, realize that the designers and manufacturers of his motor have been dealing in measurements of the thousandth part of an inch and that too great care cannot be taken in the repair of bearings to obtain a perfect fit.

If he is renewing a connecting rod or a wrist pin bearing, he must also remember that the piston has formerly been traveling over a certain area of cylinder surface that has not varied in length the ten-thousandth part of an inch between one stroke and the next. Consequently, the babbitts or bushings should be so replaced that the piston shall occupy the same position relative to the cylinder walls at the top and bottom of its stroke that it did formerly. In other words, by varying the thickness of the top of the babbitt he is replacing, he may change the "center" of the bearing so that the piston will start on its upward stroke from a different point than was previously the case. Thus, while the length of travel of the piston will be the same, it will traverse a slightly different portion of the cylinder walls under the new conditions, and this will have the effect of changing the compression and, possibly, of wearing the piston and rings unduly.

CHAPTER IV

The Ignition System

It was the application of the electric current to the ignition system of the gasoline engine that first enabled these new forms of power plants to be designed with sufficient compactness and to possess enough flexibility to render their use practical on self-propelled vehicles. Without the electric ignition system, the speed and power of the vehicle could not well be controlled, and the explosions would be uncertain and irregular, at best.

Those of us who are familiar with the electric gas lighters that were in popular use a few years ago are furnished with a convincing demonstration of the operation of the first electric ignition systems. By pulling a chain, a wire, or arm was rubbed across a metal point until the contact thus formed was suddenly broken. This arm and the stationary point formed the two terminals of an electric circuit, which caused a flash of blue flame when the contact was broken as the one was "wiped" across the other. The flame thus formed at the instant the contact was broken contained sufficient heat to ignite the gas escaping from the burner to which the device was attached.

Sparks will be formed in the same manner if we hold two wires, connected to the opposite poles of a set of batteries, in both hands and wipe the bare ends across each other. If an arrangement producing this effect is introduced into the gas engine cylinder at the portion in which the charge is compressed, the flash resulting when the terminals are separated will serve to ignite the explosive mixture. The movable terminal is connected to a rod which passes through the cylinder walls and is attached to a mechanism actuated by a cam revolved by the engine. This mechanism is termed the "make-and-break" ignition system for the reason that contact of these terminals is alternately made and broken to produce the flash of electricity that explodes the surrounding charge.

In order to produce a flash of sufficient size when the contact is broken, the nature of the current, obtained from the dry cells or storage battery is changed somewhat by conducting it through a coil of wire surrounding a bundle of bare copper wires. This is known as a spark coil, and while it is generally used with battery ignition of the make-and-break type, magnetos may be designed which produce the proper kind of current direct, without the aid of the coil.

An ordinary set of six dry cells, connected in series—or like with unlike poles—will produce a current of between twenty and twenty-five amperes at a pressure of about nine volts—assuming each battery, when new, to deliver twenty-five amperes at a pressure of one and one-half volts. The "series" wiring gives the entire set the combined voltage of all with the average amperage of one. For the benefit of those who have forgotten their elementary physics, let it be remembered that the ampere is the measure of current *amount*, or flow, while the voltage is concerned only with the *pressure* of the current. By the use of various arrangements of windings of wires, the voltage may be raised with a corresponding decrease in the amperage—and vice versa. Thus, if a coil is used that doubles the original number of amperes produced by the battery, the voltage will be halved.

The make-and-break type of ignition has been used successfully for many years, but with the perfection of the magneto, it has been largely supplanted, in automobile practice, at least, by the "jump spark," or "high-tension" system. Because of the fact that the latter system is less expensive to construct and is highly efficient, it will be found also on the majority of the older cars not equipped with a magneto.

It was found, after the general adoption of the make-and-break ignition system, that a flame was not necessary for the combustion of a properly-mixed charge in the engine cylinder. In fact, a tiny spark, scarcely one-sixteenth of an inch long and no larger around than a pin, was discovered to be sufficient to produce the ignition of the charge. Although, of small volume, such a spark generates intense heat, and it is upon this quality, rather than upon area, that the charge depends for its ignition—although it is claimed that a large flame will produce more complete, rapid, and consequently more efficient, combustion. But the jump spark possesses the advantage of requiring no moving parts projecting through the cylinder walls into the combustion chamber, and its greater simplicity over that of the make-and-break system has resulted in its almost universal adoption by automobile manufacturers.

It has been stated in a preceding paragraph that the voltage produced by the average battery set will not exceed nine or ten, and even the pressure generated by the ordinary magneto is not greater than this. But air is not a good conductor of electricity and forms a very high resistance to the passage of a current. It is only when the high resistance of an air gap is encountered in its circuit, however, that a spark will be formed by the current, and consequently the form of electricity used in this system must have resistance-overcoming properties. But it is only by raising the voltage of the current that even a short air gap can be bridged by the spark. In fact, a pressure of somewhat over fifty thousand volts is required to produce a spark less than an inch long in the air.

Although only called upon to jump a gap about a sixteenth of an inch across, the ordinary high-tension current is capable of bridging a space eight or ten times this width in order that ample pressure will always be assured for the formation of the spark. Furthermore, the warm gases in which the spark is formed in the cylinder increase the resistance ordinarily encountered and it is consequently necessary to raise the voltage above the amount that would be needed were the plug exposed to the open air.

These conditions make advisable a pressure of from twelve thousand to thirty thousand volts in the ordinary jump spark system, and it is from this voltage that the term "high tension" is obtained. The nine or ten volts delivered by the batteries are transformed to this larger amount by means of an induction coil—or what is more generally termed merely the "coil." This is in reality a "step-up" transformer, since it transforms the current from one of low voltage to another of two or three thousand times its original pressure.

This transformer consists of two coils of wire, one surrounding the other. The inner coil is composed of a comparatively few number of turns of rather coarse wire wound around a soft iron core, and is termed the "primary" winding, since the current from the batteries is led directly through it. The outer coil is composed of many turns of a very fine wire, all of which are thoroughly insulated from each other and from the inner winding. This outer coil is termed the "secondary" winding and is the one from which the high-tension, or transformed, current is taken.

This secondary current is "induced" from the primary winding through which the battery current passes and possesses a voltage that has increased over its original amount in the same proportion that the number of turns in the secondary winding bears to those in the primary. Therefore, if the original battery voltage is ten and there are a thousand times as many turns in the secondary winding as in the primary, the resulting high-tension current will have a pressure of ten thousand volts.

The principle of the coil is dependent entirely upon that peculiar electric property known as "induction." Around every wire through which an electric current passes are invisible "lines of force" similar to those that emanate from an electro-magnet. These lines of force surround the wire throughout its length, and arrange themselves in a spiral formation. Insulation has no effect on these lines of force, and they may be collected from wires which are separated from each other by several thicknesses of current-confining material. It is, of course, necessary to use insulated wires in the construction of these coils, for otherwise the current would merely pass to adjoining turns and would not travel the entire length of the winding—and therefore as great a number of lines could not be collected.

If an additional layer or layers of wire is wound around the first series of turns, the lines of force will be collected, or "induced," by this second coil, and will constitute the secondary current. The induction effect is greatly increased if the primary current is allowed to accumulate, or "pile up," and discharge, alternately, for this surging of the current creates a sort of "overflow" from the original containing wires.

Ohm's Law, which states that the number of amperes in an electric circuit is equal to the voltage divided by the number of ohms of resistance encountered, shows that the current will be changed by its passage through the primary winding. The induced current is further changed, and when collected by the secondary winding and sent through its long coils, we have the high-tension circuit mentioned in the preceding paragraph.

If the reader remembers that it is but one hundred and ten volts that is used to operate our electric lights and that five hundred will run a trolley car, he may wonder why it is not dangerous to handle as great a pressure as the thirty thousand volts that are used in connection with the ignition system of a motor car. But it is the combination of great voltage with high amperage that is dangerous, and if it is remembered that, as the former is increased, the latter is reduced correspondingly, it will be realized that the ordinary high-tension ignition current possesses a *quantity*, or flow, of scarcely one one-hundredth of an ampere.

If we liken the electric current to a flow of water in a pipe, we have the amperes corresponding to the quantity of the flow, or the number of gallons that will be delivered at the outlet in a given time. Continuing this analogy, the voltage of the electric current will be the pressure, or "head" in the water system, and the current from the batteries before the coil is reached will correspond to a moderate flow of water at a comparatively low pressure. After the coil has transformed the current to the high voltage, we have the conditions of a very small opening in the water pipe containing a tremendous pressure. Such a stream will possess but small flow, but its high pressure will enable it to be "squirted" to a far greater distance than would be the case were its volume larger and its "head" less. Although the pressure is high, its quantity is so low that the stream can do but little damage and would scarcely more than tickle the flesh of a person against whom it is directed.

Thus it is with the ignition current. It can "tickle," rather viciously, sometimes, as many persons will aver, but the *amount* of electricity involved is so slight as to render the high pressure harmless. Nevertheless, it is well to avoid allowing the fingers or the arm to become a part of the high-tension circuit, for the result may be startling as well as annoying.

But in order that the high voltage shall be induced in the secondary coil, the primary circuit must be alternately made and broken between one stroke and the next. Consequently proper "piling up," or "surging," of the current will be effected. This is accomplished by means of an "interrupter" that either vibrates rapidly or "snaps" once at the formation of each spark. The former is the more common type used with battery ignition and is known as a vibrating coil. A circuit breaker is generally incorporated in the mechanism of a magneto, and consequently when such an instrument is used, the vibrator on the coil is dispensed with. It is the vibrator on each coil that forms the "buzz" that can be heard whenever the box cover is removed, and that often furnishes a simple test for determining the condition of the ignition system of the particular cylinder with which that coil is connected.

The vibrator is a flat, spring steel piece that rests near one end of the soft iron core around which the primary coil is wound. The springy nature of the vibrator ordinarily holds it against a small, adjustable contact point that should be set about an eighth of an inch from the end of the above-mentioned soft iron core. The primary coil is so wired that its current passes through the vibrator steel and the contact point against which it rests. As soon as the current travels through the coil surrounding the soft iron core, however, the latter becomes magnetized and draws the steel vibrator toward it. This breaks the circuit, the magnetism of the iron core disappears, and the vibrator returns to its original position against its contact point. But this action again forms the circuit, and the same operation is repeated as long as the current is allowed to flow toward the coil.

This is the same principle on which an electric bell is rung, but the vibrator of the coil makes and breaks the circuit much more rapidly on account of the less weight of the moving parts. This vibration of the coil interrupter is so rapid—hundreds a second probably—that the resulting spark is practically continuous and shows no effect of the breaks in the circuit.

Even though it is the primary current, of low voltage, that is interrupted by the vibrator, the frequency of these interruptions causes a slight sparking, or arcing, at the contact points. These are therefore subjected to rather a high degree of heat, as well as a large amount of wear, and it is necessary that they be made of a material that will resist both. Platinum has been found to be unusually suitable for this purpose, but owing to its high cost, only a small amount in the form of two points, or "buttons," is used. One of these points is placed in the vibrator steel, and the other is embedded in the end of the screw against which the first rests. Thus the actual contact is made against these heat-and-wear-resisting platinum points, and it is evident that upon their proper action depends the formation of the spark in the cylinder with which that particular vibrator is connected.

Notwithstanding the fact that platinum possesses high heat-resisting properties, the constant arcing at the contact points will eventually form a sort of corrosion in which minute particles of the material are carried from one point to the other in the direction in which the current flows. If the current is reversed, the corrosion will take place in the other direction, and consequently the platinum point that formerly lost a part of its material will gradually be "built up" again. This corrosive action is known as "pitting," and while it may be reduced to a certain extent by reversing the terminals of the battery, as described, the platinum will occasionally require additional attention.

A coil having badly pitted contact points on the vibrator will "stick" and will cease to form a spark regularly. It is often difficult to distinguish between trouble arising from badly-pitted contact points and that caused by weak or nearly-exhausted batteries, as either ailment produces the same symptoms of irregular running and "jerking" in the motor. For this reason, a volt and ampere meter for measuring the pressure and amount of the current delivered by the batteries should form a part of every automobile owner's tool equipment.

It is the amperage, rather than the voltage, that is reduced through continued use of the batteries, and when this quantity falls below nine or ten, the cells should be discarded—or recharged, in the case of a storage battery. But if the ignition occurs irregularly when the batteries are delivering the proper amount of current, it is probable that the trouble lies in the pitted condition of the platinum contact points of the vibrator of the coil. Fine emery cloth rubbed over the surfaces of contact should serve to remedy matters. It should be made certain that the resulting surfaces on the platinum points are not only rubbed smooth, but level, as well, in order that the entire area of each will rest in contact and the current will not be concentrated at a small portion.

It is probable that there will be a screw adjustment on the vibrator by means of which the force with which the latter rests against its contact point may be regulated. If the vibrator is set too tight, an undue amount of current will be required to magnetize the core of the coil sufficiently to pull the vibrator away from its contact point, and the batteries will soon "run out." On the other hand, the tension of the vibrator should be sufficient to enable it to spring away from the core of the coil as soon as the circuit is broken, for otherwise the vibrator will lag and will not be as "lively" as is necessary to obtain the best results.

The contact screw should be set so that the vibrator rests *about* three-thirty-seconds of an inch from the end of the magnetic core. After the tension of the vibrator has been set to approximately the proper amount, the ear must be trusted for the correct adjustment of the contact screw. When the switch is thrown on and the motor turned until current flows through the coil, the resulting buzz emanating from the vibrator should be decided and forceful. If this buzz is exceedingly high-pitched, it is an indication that the vibrator has been set too tight, and its tension should be loosened if unscrewing the contact point slightly does not lower the tone. It must be remembered that the tension of the vibrator can be changed by turning the contact screw. If this screw is turned down so that it forces the vibrator toward the iron core, the tension will be greater than will be the case if the contact point is turned to the left.

If the buzz of the vibrator is pitched lower than was formerly the case, it is an indication that the contact point should be screwed down, or that the tension of the vibrator should be tightened. It is probable that turning the contact screw to the right will produce the proper result. While these changes in the position of the contact screw are being made, the switch should be left turned on so that the variations in the pitch of the vibrator buzz may be detected. When an evenly-pitched, vigorous buzz has been secured, the switch should be thrown on and off several times to make certain that the response of the vibrator is instant and positive. The switch should then be left on and the vibrator allowed to buzz for several seconds in order that it may be determined whether the pitch of the sound will change, or not. If there is a change noticeable, the contact screw should be readjusted until the pitch of the buzz remains constant as long as the circuit is closed.

The coil and batteries or magneto by no means form the entire ignition system, although the generation of the spark depends entirely upon them. The spark must be regulated to occur at the proper point in the stroke of the piston, as a continuous spark would not only waste the current, but would cause the ignition of the charge during the upward stroke and would result in an impulse in the reverse direction that would prevent the motor from running for more than half a turn.

The device by which the time of the occurrence of the spark is regulated is called the timer. This consists, in its essentials, of a hard rubber disc provided with a copper or brass segment. A metal pin, roller, or ball rests against the outer edge of the disc, and as the latter is revolved, the electrical circuit is completed whenever the two metal portions come in contact with each other. The hard rubber being a non-conductor of electricity, prevents the flow of the current at all other times. The disc of the timer, known as the "commutator," is so geared that it revolves in unison with the motor.

Inasmuch as the explosion occurs in each cylinder only at every second stroke of a four-cycle motor, the commutator on this type of engine is geared to revolve at one-half the speed of the crank shaft. In the two-cycle motor, on the other hand, the explosion occurs in each cylinder at every revolution, and consequently the commutator should turn at crank shaft speed.

Although the spark is intended to occur approximately at the extreme upper end of the compression stroke, a few degrees variation both above and below this point is necessary in order to obtain the desired speed and power flexibility of the gasoline motor. At high speeds, the spark should be timed to occur before the piston reaches the extreme top of its stroke, while at slower revolutions of the motor the ignition should take place, in some instances, just after the piston has started to descend. This variation In timing is obtained by swinging the contact piece of the timer—known as the brush—either forward or backward through an arc corresponding to the range of advance and retard.

If this brush is swung in a direction opposite to that of the revolution of the commutator, the metal portions will meet sooner, with the result that the spark will occur earlier, or will be "advanced." If, however, the brush is swung to a point farther along in the direction of rotation of the commutator, the spark will occur later, or will be "retarded." These variations of position of the brush are generally obtained by means of a lever attached to the steering post or wheel.

It is evident that the current must pass from the brush to the metal segment of the commutator in order to complete the circuit through the timer and thus form the spark. It is the primary current, or low-tension current from the battery or magneto, that passes through the timer, and as this is of low voltage and is therefore easily discouraged, it is necessary that the contact points be kept clean in order that its travel may be made easy. Timers are generally protected from dirt, but the particles that will naturally be worn off from the metal and rubber commutator and brush should be cleaned out before its accumulation becomes deposited on the contact points and interferes with perfect electrical connection.

A few years ago, the majority of battery ignition systems employed a separate coil for each cylinder of the motor. Each coil in this system is connected with an individual brush that operates against the same commutator as do the brushes for the other cylinders. With such a system, the primary circuit leads from one terminal of the battery to the primary winding of the coil, through this and the vibrator to the brush of the timer reserved for that particular coil and cylinder, and thence through the switch to the other terminal of the battery. This order may be reversed, or the timer, switch, and coil may be placed in any consecutive position, provided the current passes through all in its travel from one terminal of the battery to the other. The secondary, or high-tension current is led from the terminal of the secondary winding on the coil to the spark plug of the proper cylinder. There should be a "ground" wire to serve for the return of the secondary current. This may lead from any part of the primary circuit to a clean metal connection on the motor.

The multiple coil system is still used to a large extent, but an elaboration of it will be found on many of the modern cars. This consists of the use of but a single coil for all of the cylinders of the motor. This is done by means of a distributor, which is a sort of "glorified timer" consisting of a commutator provided with as many segments as there are cylinders in the motor. This distributor receives the current from a single coil and delivers it to the proper cylinder as the various connections are made. The timer still performs its function of completing the circuit from the source of current only at the proper instant, and leaves the distributor to serve the purpose of a "switch" to "sidetrack" the current and deliver it at the various cylinders in turn.

If it should ever become necessary to remove any part of the timer, or to change the length of the spark control rods, the greatest care should be taken to make certain that the motor is properly timed when the various portions are replaced. This can best be done by setting the spark lever in its central position, removing a plug from one of the cylinders, and introducing a rod or long screw driver into the opening for the purpose of determining the exact top of the stroke of the piston. When the flywheel is turned, the top of the stroke should be marked on the rod or screw driver as the latter is forced upward by the piston.

If the spark plug is laid with its large nut resting on the cylinder head, and the switch is thrown, the time of the occurrence of the spark can be readily observed as the motor is turned slowly by hand. This spark should occur in this particular plug just as the piston of that cylinder reaches the top of its stroke, as indicated by the change in the direction of the movement of the rod or screw driver. If the spark occurs too soon or too late, the commutator should be moved backward or forward to remedy the respective trouble. Although if the timer is set properly for one cylinder it is probable that the spark in the others is also timed correctly, it is well to test each to make certain that there has been no uneven wear in the contact segments of the commutator or the brush.

CHAPTER V

Magnetos

The perfection of the magneto and its application to cars of all classes and sizes has marked the most important step in gasoline motor ignition since the introduction of the electric spark. The magneto is now considered one of the most vital parts of the car, and while it is possible for the motor to be run for many miles on the batteries that form the auxiliary ignition sources, the mechanical current generator has left the field of the desirable accessories and has become an actual, physical portion of the engine.

The operation of the magneto is simple, its whys and wherefores are logical, and if one investigates the subject, even superficially, he will discover that the much-maligned machine seldom gives trouble, and that when it does, such action, or failure to act, is due to neglect, abuse, or some other perfectly legitimate reason, rather than "pure cussedness" on the part of the instrument itself. If the mere mechanical aspect is considered; if it is realized that the magneto consists mainly of a bundle of wires which, when revolved near the ends of a magnet, collects that magnetism and sends it through the circuit in the form of the electric current, and that consequently the magneto is a converter that changes part of the mechanical energy of the motor into the spark-forming fluid, the chief idea of magneto principles may be more easily grasped.

To be sure, the magneto is delicate, and for that reason it should never be dissected by the amateur, but inasmuch as what few adjustments it has are readily accessible, it is seldom that the machine need to be taken apart. The platinum points of the contact breaker, usually located in the small box on the end of the armature shaft, may need to be smoothed with emery paper occasionally if they have become pitted from excessive sparking, but this is a simple operation and is not greatly different from the care given to the vibrator of the dashboard spark coil, as described in the preceding chapter.

A few drops of oil should be fed to the lubricating cups or holes of the armature shaft as often as the directions call for—usually about once every five hundred miles—but aside from this, the owner can generally forget that he has a magneto, and will only be reminded of the fact by the pleasing absence of ignition trouble. If ignition trouble does occur, it is more than probable that the fault lies with the plugs, timer, or wires, rather than with the magneto.

The man who drives a magneto-equipped car knows that the current producer is run by a gear connected, either directly or through the medium of other gears with the crank shaft of the motor. He knows, then, that the magneto is driven positively and that there is a constant relation between its speed and the number of revolutions of the motor.

But does he know that it is absolutely necessary that a certain position of the armature shall always correspond with a similar position of the crank shaft of the motor, and that consequently the same teeth of the driving gears must always mesh? He will most assuredly be made aware of this if he disconnects his magneto and then fails to replace the gears so that exactly the same teeth are in mesh, for even the difference of a single tooth between the normal positions of the armature and crank shaft will prevent the magneto from delivering a sufficient spark to enable the motor to run.

The reason for this is simple. All of these direct-driven magnetos are of the alternating current type, as this form allows of the simplest construction of armature and windings. The alternating current generator obtains its name from the fact that there are no regularly-defined north and south poles at any part of the circuit, as these keep changing continuously, or alternating.

During each revolution of the armature of the alternating current magneto, there are but two positions at which a current will be formed. Now the spark in any cylinder of a motor is required at about the top of the compression stroke of the piston in that cylinder. Consequently when the piston is at the top of its compression stroke, ready for the spark that will ignite the charge, the armature of the magneto must be in one of its two current-generating positions, and there must therefore be a constant relation between the position of the crank shaft, to which each piston is connected, and that of the revolving part of the magneto.

If, now, the driving gear of the magneto is returned to its place without regard to the teeth of the next gear with which it meshes, it will be seen that the proper relation between the position of the armature and that of the crank shaft will not be maintained. Under these conditions, when the piston is at the top of the compression stroke, ready for the spark, the armature will not be in a position at which a current can be generated, and there can consequently be no spark formed at the plug. Conversely, when the armature has been revolved to the position at which a current will be formed, none of the pistons will be requiring the spark, and this consequent lack of "team work" will prevent the operation of the motor.

In order to maintain this team work between the armature of the magneto and the crank shaft of the motor, the intermeshing teeth of the gears should be marked with a prick punch before they are removed, so that they may be returned to their proper place without trouble. Only in this manner can accurate results be obtained, if it is at any time necessary to remove all or part of the magneto driving gear.

The magnets forming the "fields" of the magneto in which the armature revolves are of the permanent kind; that is, they do not depend upon windings and a separate electric current for their excitation, as is the case with some of the larger generators. These magnets may be considered to be the most faithful part of the machine, for they generally retain their strength under all conditions of rest or work, and it is upon them that the proper operation of the magneto largely depends.

A magneto in which the magnets have become weakened is useless for ignition purposes until the fields can be remagnetized, and as this can only be done at the factory, the machine in its entirety must be removed from the motor. It is a comparatively easy matter to determine whether or not the fields have lost their magnetism by placing a piece of iron or steel within close range of the base or sides of the magneto. An appreciable pull will be exerted by the magnets if they still retain their strength, although it is not to be supposed that the force thus exhibited will be very vigorous from such a small machine.

If the magneto has been disconnected from its driving gear for any reason, the amount of magnetism remaining in the fields will be best determined by turning the armature shaft with the hand. A resistance should be offered to the turning at first until a certain point is reached, after which the armature should exhibit a strong tendency to fly forward to a new position, one hundred and eighty degrees beyond its former normal position of rest. This activity of the armature is one of the best guides to the amount of magnetism remaining in the fields.

Many magnetos that have been installed on old motor cars not previously so equipped are of the friction-driven, direct-current type that produces a uniform spark at any point throughout the armature revolution. Current from these may be used to charge a storage battery for the operation of electric lights or to supply auxiliary ignition current for starting. The positively-driven, alternating-current magneto may also be used to operate electric lights on the car, but this type of current cannot be stored in a battery, and consequently the lights are available only when the motor is running. The magneto, however, is not primarily an electric-lighting outfit, and unless it is especially designed for the double purpose, a separate machine should generally be used for supplying illuminating current.

CHAPTER VI

Carburetors And Their Fuel

Although gasoline is inflammable in its liquid state, its combustion is not sufficiently rapid to approach the *explosive* point necessary to render its energy available in the automobile engine cylinder. The proper proportion of gasoline *vapor* and air, however, forms a mixture that is highly inflammable and that will be entirely consumed in the engine cylinder under ordinary conditions within about one-twentieth of a second after the formation of the spark. This rapid combustion so nearly approaches the instantaneous action of an explosion that it may be considered as such in all ordinary discussions of the gasoline engine. Literally, however, the gasoline engine is not an *explosion* motor, but rather is it an engine of the *internal combustion* type. To obtain this gasoline vapor in an easily-controlled form the carburetor was designed as one of the most important adjuncts of the automobile.

The first form of carburetors, or "vaporizers," as they were called then, employed a flat, woven lamp wick over which the gasoline flowed. This spread the fuel out over a comparatively large surface and rendered evaporation rapid and simple. The chamber containing this wick was placed in the line of the intake pipe of the motor and was connected with the cylinders on the descent of the pistons on the suction stroke through the medium of the various inlet valves. In a four-cycle motor, the piston acts as a suction pump on alternate down-strokes and serves to draw the charge into the cylinder. This suction created the necessary current of air to facilitate evaporation of the gasoline on the wick, and by regulating the size of the passages, the proper proportion of air and gasoline vapor could be obtained.

The modern, high-speed automobile motor, with its varying demands upon the carburetor, created the necessity for a more delicate, flexible, and compact vaporizer than was to be found in the "lamp wick" type. Consequently the wick was replaced by a small, slender, hollow tube having a cone-shaped opening at its upper end through which the gasoline from the feed pipe was made to pass. Fitting into the upper end of this tube, and pointed to the same angle, was a cone-shaped "needle" that could be moved in and out of the opening. If this needle was unscrewed slightly so that it did not form a tight fit with the end of the tube, a small ring would be formed through which the gasoline must pass when sucked by the alternate down strokes of the pistons. This tube and needle constitute, under various guises, the "needle valve" with which practically every modern carburetor is equipped.

When the gasoline, rushing through the small tube, strikes the restricted opening of the needle valve, it is broken up into a fine spray which, under proper conditions, will become vaporized almost as soon as it comes in contact with a current of air. This air current is induced by the same pump-like effect of the pistons as that which sucks the gasoline through the needle valve, and thus it occurs only when the charge is desired in the cylinders.

But the carburetor is not merely to provide a compact device for vaporizing the gasoline, for it must also furnish a means of regulating the proportion of gas to air. Gasoline vapor is only highly inflammable when mixed with the proper quantity of air, and if this proportion is varied above one limit or below another, ignition of the charge will not occur in the cylinders. In fact, the allowable variation in the proportion of gasoline vapor to air is restricted between very narrow limits, and should not change more than four or five per cent. from one extreme to the other. The proportion of gasoline vapor to air by weight is about one to eleven, although this will vary somewhat with the different grades of fuels.

The point to be emphasized, however, is the fact that the proper proportion of air to gasoline vapor, however it may vary with different grades, should be kept constant at all speeds of the motor whenever that particular grade of fuel is used. By volume, about 97½ per cent. of the mixture should be air and the remainder gasoline vapor, and it is the device that will the most nearly maintain this proportion under all conditions of speed, temperature, and air pressure that will prove to be the most delicate and flexible carburetor.

A carburetor may be adjusted for different motors, or for different operating conditions of the same motor, by means of the needle valve. The farther end of the slim rod on which the needle point is mounted terminates in a thread and finger nut that projects through the shell of the carburetor. By turning this nut in one direction, the needle valve is screwed up toward the cone-shaped end of the tube and the orifice through which the gasoline may pass is thus reduced in size. This will decrease the amount of gasoline sprayed into the air passage and will consequently change the composition of the mixture. This, however, should not be confused with throttling the motor. When the needle valve is tightened, the volume of the mixture passing to the cylinders is the same, for it is only the proportion of gasoline vapor in that mixture that is changed.

Throttling consists in restricting the size of the opening through which the *mixture* passes, and thus limits the amount of the charge that reaches the cylinders at each suction stroke of the piston. Throttling is used to reduce the power—and consequently the speed—developed by the motor, while a decrease in the amount of gasoline supplied to the air through the needle valve may serve to increase the power through an improvement in the nature of the mixture.

Since the gasoline vapor, by volume, forms only about three per cent. of the explosive mixture admitted to the cylinders, a slight variation in the size of the needle valve opening will result in a marked change in the composition of the charge and may make all the difference between poor and perfect running of the motor. Consequently the needle valve nut should be moved but the small fraction of a turn for each adjustment. A motor which may refuse absolutely to run at one position of the needle valve may give perfect results if the nut is unscrewed but the eighth of a turn.

In view of the marked difference in the results obtained from the use of mixtures that are "just right," and those which vary but a slight percentage in the proportion of gasoline vapor to air, it may be well to examine, superficially, the effects of "rich" and "weak" charges, and therefrom to obtain a list of "symptoms" which may aid us to diagnose motor trouble properly.

We all know that air—or oxygen—is required to support combustion. "Snuffing" a candle is merely covering its end so that air cannot reach the flame. For the same reason, gasoline in a covered tank cannot burn, no matter how great the heat applied to it. The heat of the electric spark in the cylinder, although intense, does not cover a sufficiently large area to ignite any charge except that composed of the proper proportion of gasoline vapor and air. If there is too much gasoline vapor, making a "rich" mixture, there will not be sufficient air in the charge to support the entire combustion of the gas, and the burning will be slow—if it takes place at all. The same conditions will prevail if there is an insufficient supply of air for a given quantity of gasoline vapor, and consequently a rich mixture may be obtained by reducing the air flow as well as by adding to the amount of gas admitted to the mixing chamber.

A rich mixture will cause irregular explosions in the cylinders, and will often emit a black, pungent smoke at the exhaust. The motor will probably overheat easily, due to the slow-burning properties of the mixture and the resulting fact that a large portion of the cylinder walls uncovered by the pistons will be exposed to the flame. In some instances, the cylinders will miss fire at regular intervals, thus changing the synchronism of the impulses with a well-defined and periodic "skip" in the sound of the explosions.

While these are by no means certain symptoms of a rich mixture, the first test to be made should be to tighten the needle valve adjustment slightly when the motor is running and to note any resulting improvement in the regularity of the explosions. It may sometimes be difficult to distinguish between the symptoms of a rich and a weak mixture, but the readjustment of the needle valve as just described will at least serve to locate the trouble or to eliminate one or the other possibility from consideration.

When a mixture is "starved", or when there is an insufficient supply of gasoline vapor to unite with the air admitted to the cylinders, the charge will not be highly inflammable and may not be ignited by the small spark formed at the plug. Even when ignition does take place, the resulting power impulse will be weak because of the comparatively small amount of pressure-producing gas in the mixture. The explosions may occur regularly for a while, but there will be a marked decrease in the power developed by the motor, and owing to the fact that weak mixtures may be slow-burning, "back-firing" will often result in some engines to which such a charge has been fed.

On the other hand, if a motor will run at all on a weak mixture, it will produce better results than would be the case were the charge too rich in gasoline vapor. Consequently the needle valve should be closed as much as is consistent with smooth running of the motor, but the moment a loss of power or irregular explosions occur, the mixture should be enriched.

At low speeds of the motor, the pumping action of the pistons is not as great as is the case at high revolutions, and consequently the suction drawing the gasoline through the needle valve is diminished. For this reason, the needle valve opening must be made larger or the air passage restricted for slow speeds of the motor, and it was consequently necessary, on the old, non-automatic vaporizers, to *increase* the gasoline supply whenever the revolutions of the motor were to be reduced. The modern carburetor is sufficiently automatic in its action to provide the proper mixture within wide ranges of speed change of the motor, but even nowadays it is often found necessary to increase the gasoline supply or to reduce the amount of air admitted to the intake pipe whenever it is desired to throttle the motor down to a very low number of revolutions per minute.

The automatic action of the ordinary carburetor is obtained by increasing the air supply at higher speeds of the motor. Consequently the motorist will realize that whenever the needle valve is to be set, such regulation should be made when the motor is well throttled, for if an ample gasoline supply is obtained at low speeds, the mixture will certainly be sufficiently rich at increased revolutions. If, on the other hand, the carburetor should be set to supply a proper mixture at high speeds, the mixture would be impoverished when the motor is throttled, and irregular running would result.

The air for the operation of the motor at ordinary speeds is supplied through a fixed opening in the carburetor connected with the chamber into which the gasoline spray is introduced. In addition to this, most carburetors are supplied with an "auxiliary air opening" which serves to furnish the additional air necessary for the mixture at high speeds of the motor. The fixed opening, being restricted in size, cannot admit the increased quantity of air demanded by the higher speeds of the motor. The auxiliary opening is provided with some form of automatic valve which may consist either of a series of ball "checks," a spring-actuated "mushroom valve," or a series of special valves, each of which opens at successively increased speeds of the motor.

All of these devices operate on the same principle, however, and allow the increased suction of the motor to add to the size of the air passage automatically—either by the farther opening of a single valve, or by the successive opening of different valves. Some carburetors are provided with an adjustment by means of which the "delicacy," or ease of opening, of the auxiliary air valve may be regulated. This may be done by means of a nut and screw which will increase or decrease the tension of the controlling spring. If this spring is set with a high tension, the auxiliary valve will act only when the motor is exerting great suction, or at fast speeds.

The regulation of the auxiliary valve is an adjustment that should be made only after the needle valve has been set properly for slow speeds of the motor. When this condition is obtained, the throttle should be opened and the further adjustment of the carburetor for high speeds of the motor should then be made through the auxiliary air valve. In other words, the needle valve should be set so that the motor runs properly at low speeds, while the adjustment of the auxiliary air valve should be made only to secure smooth operation at a high number of revolutions.

It is not to be understood that less gasoline is actually required at high speeds of the motor because the supply often needs to be cut down at the needle valve under these conditions. The actual amount required at high speeds is, of course, greater than is the case at slow, on account of the greater number of explosions in the former instance. But the suction of the motor generally increases the gasoline flow beyond the demands of the cylinders at high speeds, and it is for this reason that the automatic auxiliary air supply is provided to furnish the additional air required to support combustion. In fact, at heavy loads, when the total amount of gasoline consumed must be great, a secondary jet of fuel is brought into action in some carburetors. This is known as the "multiple-jet" type and is found on some of the large engines that must possess a speed and power variation between wide ranges. The action of these various jets is entirely automatic and is dependent upon the speed and fuel requirements of the motor.

Were the gasoline fed directly from the fuel tank to the needle valve of the carburetor it is evident that the rate of flow of the liquid would depend, to a large extent, upon the amount in the tank and upon the position of the car. This would cause each charge to differ in the proportion of gasoline vapor to air, and it is hardly probable that the motor could be run at all under such conditions. In order that the pistons may suck the gasoline from a level that does not vary with the amount of fuel in the tank or the position of the car, a separate compartment is provided in the carburetor. This is known as the "float chamber," and it is from this compartment that the gasoline passes through the needle valve into the vaporizing or mixing chamber.

A cork or hollow metal float is placed in this float chamber and is mounted on a lever connected with a valve located at the end of the gasoline feed pipe. As the gasoline is admitted to the chamber, the float rises and closes the valve controlling the flow of fuel. As the gasoline is sucked through the needle valve from the float chamber, the float in the latter lowers, and the fuel is again admitted by the opening of the above-described valve. The float and valve are exceedingly delicate in their operation and the gasoline is thus kept at a constant level in the chamber under all conditions of the car and tank.

The stem upon which the float of some carburetors is mounted is sometimes threaded and provided with a nut by means of which the float may be raised or lowered. This furnishes an adjustment for varying the level in the float chamber and determining at what point the flow of gasoline shall be cut off by the automatic valve. The float is supposedly properly regulated when the carburetor leaves the factory, but the stem may become bent or the carburetor may be applied to a motor other than that for which it was originally designed. In either of these events, it may be found necessary to raise or lower the float before the proper level of gasoline can be maintained in the chamber.

If the float is too high on its stem, the gasoline control valve may not be operated until the fuel overflows in its chamber. This is known as a "flooded" carburetor and produces a rich mixture which will ultimately prevent the proper operation of the motor. Turning down the gasoline supply at the needle valve will not remedy this, for the fuel will reach the vaporizing chamber by another route. A flooded carburetor often gives trouble, and while it may be remedied easily, the amateur may experience difficulty in locating its source.

As soon as it is discovered that a carburetor has become flooded, the needle valve should be tightened so that no gasoline can pass through it, and the motor should then be cranked. This will serve to evaporate the excess gasoline in the float chamber and reduce the level to the point at which it will not overflow. The exact number of turns and fractions of turns through which the needle valve nut was moved should have been noted in order that the valve may be reset to its original position after the surplus fuel has been "cranked out."

A float that is set too low on its stem will close the fuel supply valve before a sufficient amount of the fuel has flowed into the chamber, and will form a "lean" mixture at high speeds of the motor—even though the needle valve should be opened wide. The obvious remedy for such a condition is to raise the float until the gasoline will be maintained at the proper level. If there is no nut and screw adjustment by which the float may be raised, the arm to which it is attached, and which is connected with the valve, may be bent slightly.

But the motorist should not "jump at conclusions" and assume that the float is improperly set the moment the carburetor begins to flood or the motor appears to "starve" at high speed. The first condition may be caused by a piece of dirt or other foreign matter that may have become lodged on the valve seat and prevented the valve from closing when the gasoline reached the proper level in the float chamber. This will produce exactly the same results as will a high float and is a trouble that will more often occur in the average carburetor.

The difficulty may generally be remedied easily by draining the gasoline from the float chamber after the valve in the main supply pipe has been turned off. The offending foreign matter will generally be carried with the gasoline as the latter is drained, and the valve in the feed pipe may again be opened as soon as the drain cock is shut off. If this fails to remedy matters, it is probable that the difficulty lies with the float.

A clogged gasoline pipe or dirty strainer will produce the same effect on the operation of the motor as will a float that is set too low on its stem. When the motor seems to starve at high speed, and it is evident that there is sufficient gasoline in the tank, the union should be disconnected at the point where the feed pipe joins the carburetor. If there appears to be an ample flow through this pipe when the main valve is opened, it is probable that the stoppage has occurred in the strainer. If the flow through the main feed pipe is not free, however, it is possible that the vent hole in the filler cap on the tank has become stopped or that the latter has been screwed down too tightly. In the gravity feed systems, some method must be provided to allow the air to flow into the tank to replace the gasoline fed to the carburetor. If there is no hole in the filler cap, the latter should not be screwed down so tightly that an airtight joint will be formed.

Probably the simplest method of determining whether the trouble lies in a low float is to prime the carburetor and to observe the ease with which this can be done and its effect upon the engine. Nearly every carburetor is provided with a "flushing" or "priming" pin by means of which the float can be depressed so that the gasoline chamber will be filled rapidly to a point above its normal level. This is useful in starting, as the desired rich mixture is quickly obtained without an undue amount of cranking. If the carburetor flushes easily, it is evident that there is no serious stoppage in the pipe. If this easy flushing is followed by good running on the part of the motor, and if this, in turn, is succeeded by gradually-diminishing impulses indicating a weakening mixture, it is quite evident that the float is preventing the flow of the gasoline at the proper time.

In addition to the flush pin found on carburetors, many are provided with other devices to render starting easy. It is well known that a "high-test" gasoline, such as a 76, will vaporize more easily than will one of a lower degree of specific gravity. Also, every motorist has had impressed upon him the fact that heat aids in the vaporization of gasoline. If we try to start a motor on a cold morning with a low-grade gasoline, such as the 60- or 62-degree fuel now generally obtained, we know that a rag dipped in hot water and wound around the carburetor will help matters.

To enable low grades of fuel to be properly vaporized under all running conditions, many carburetors are provided with a water jacket surrounding the vaporizing chamber. This jacket is connected with the cooling system of the motor, and the hot water surrounding the chamber so warms the interior that vaporization is greatly facilitated. Some of these systems are provided with a shut-off cock by means of which the carburetor may be operated with hot water in the jackets, or not, as desired.

Other carburetors employ a jacket surrounding the exhaust pipe of the motor and connected with the vaporizing chamber. The air is heated by the hot exhaust pipe as it is sucked into the carburetor, and this also facilitates the vaporization of the fuel. Some carburetors are provided with both jacket systems, while others have neither, but whatever design is installed, the best results will be obtained if cold air is used after the motor is once started. Cold air is more "concentrated" and contains a greater amount of oxygen per cubic foot than does air that has been expanded by heat, and consequently many carburetors are provided with a means of turning off the hot air after the motor is started.

The higher the degree of specific gravity of a fuel on the Baumè scale, the more volatile will it be, and consequently a 68° gasoline will vaporize more easily and give more power than will a 60° or 62° fuel. 72° gasoline is often used in races, but the average motorist does not get better than 64°—and he is sometimes lucky to obtain fuel of that specific gravity. A hydrometer, or specific gravity tester, is a convenient instrument for the average motorist to own, and with it he may tell exactly what grade of fuel he is paying for. The Baumè scale, by which all gasoline is tested, reads in degrees, and the specific gravity is obtained by observing the depth to which the hydrometer sinks in the liquid. This instrument resembles somewhat a glass thermometer, and is so graduated that the deeper it sinks in a liquid, the higher will be the reading on its scale.

Water in the fuel is an annoyance that is often encountered by the automobilist and the motor boatman, and this will make its presence known by causing the motor to skip when all adjustments and connections seem to be in perfect condition. Water is much heavier than gasoline and has no affinity for it, and consequently, as it sinks to the bottom of the tank, a few drops in a large amount of gasoline will cause trouble by passing out through the needle valve at intermittent intervals and forming an unexplosive mixture.

The presence of the water in the fuel may be detected easily without the use of a hydrometer by drawing some gasoline from the bottom of the tank into a tin or white-enameled cup. If water is present, it may be seen in the form of small globules in the bottom of the cup. If the contents of the cup are poured over a flat surface so that the liquid may be allowed to spread, the gasoline will be seen to cover a large surface and evaporate quickly, while the water will seem to remain in the globules unevaporated for some time after the gasoline has disappeared. This latter test will sometimes show the presence of water when none can be discerned in the bottom of the cup before the contents are poured out on the flat surface.

The practice of "doping" the fuel tank by adding to the gasoline ether or some other highly volatile liquid is not to be recommended to the average motorist. A few ounces of ether or chloroform added to the fuel will form a more volatile and consequently more powerful mixture, but unless the greatest care is taken, the motor is liable to be completely ruined by such a procedure. Numerous cases are on record in which cylinder heads have been blown off or castings cracked by the force of some of the explosions when too much "dope" has found its way into the mixture.

Although the average motor gasoline obtainable nowadays is hardly all that could be desired as automobile fuel, a little care taken when filling the tank will eliminate many of the carburetor annoyances to which many cars seem to be subject. The cap of the tank should never be taken off when the air is filled with particles of dust that are liable to find their way into the fuel, and care should be taken to see that no pieces of the rubber or leather washer or packing drop into the gasoline when the cap is removed. Foreign matter and water that may be in the gasoline when purchased may be removed by straining the fuel through a chamois skin placed inside of the funnel through which the tank is filled.

CHAPTER VII

Lubrication

A lubricant acts as a sort of pacifier between two surfaces that would otherwise move in contact with each other. No surface can move in direct contact with another of the same or a different material without the generation of heat; but the amount of heat generated, or resistance met with, is determined by the nature of these two rubbing surfaces. The oil, or grease, or whatever suave, slippery substance is to be used as a lubricant, interposes itself in a thin film between the two rubbing surfaces and smooths matters over, as it were. If a sufficient amount of this mechanical soothing syrup is not fed to the rubbing surfaces, the temper and temperature of each will be raised to the point where they will "clinch," and much time and effort may be required before harmony can again be restored.

Thus it is actually upon a film of lubricant that a shaft rests, rather than upon the bearing, or "box," in which it turns. If the bearing is set so tight that there is no room for the interposition of an oil film, the shaft and journal will at once heat. The greater the pressure of the shaft in its box, the thicker, or heavier, should be the lubricant used, for a light oil would be squeezed out or "broken down" more easily than would one that possesses greater viscosity.

The "coefficient of friction" may be termed the mechanical "amount of irritability" generated when two surfaces are rubbed together. Thus if two metals are rubbed together, this figure is high, and a large amount of friction, or heat, will be generated. A metal rubbing over oil, however—as is the case with a well-lubricated bearing—will arouse but little resentment and its pathway will be made smooth and easy, for the coefficient of friction of these two materials is low. The lower this figure can be kept, the more easily can the surfaces be rubbed over each other and the higher will be the efficiency of the bearing.

Apply this to every bearing or rubbing surface of a motor, and we see that proper lubrication affects not only the length of life of the moving parts, but the ease with which the engine can be run and the consequent power development. Thus, a lubricant that will prevent wear between the moving parts may be supplied to the bearings and pistons of a motor, and under this condition the engine might "last" indefinitely; but this oil might be so viscous or possess so high a coefficient of friction that each bearing would turn with difficulty and much effort would be required to run the motor before it could begin to develop power.

But the introduction of oil to a bearing not only reduces the friction between the surfaces that would otherwise move in contact with each other, but it serves another very important purpose. Every properly-lubricated portion of a motor either moves in a bath of oil or is connected with an oil reservoir so that a certain amount will be fed regularly to the rubbing surfaces. There is always *some* heat generated in a bearing, no matter how well it may be lubricated, and the continuous flow or circulation of the oil serves to carry off this heat that would otherwise tend to dry the lubricant if there were no fresh supply.

The proper lubrication of the motor is even more necessary than is the adjustment of the carburetor or the condition of the ignition system. To be sure, if either the carburetor or the ignition system is out of order, the motor will not run, but no actual harm to the mechanism will result from this fact. On the other hand, a motor may be run indefinitely with a defective lubricating system, and no apparent harm will result—until the end of that indefinite time arrives and it is found that the machine is a fit subject for a junk heap.

Let us see how many parts of the motor are reached by the gallon or so of oil that we pour into the tank. A six-cylinder motor may have seven crank shaft bearings; it will certainly possess six connecting rods, each of which will be provided with a bearing at both its large and small ends—or twelve in all; there may be two cam shafts, each with five bearings and half a dozen cams; these will require, together with the magneto and pump shafts, five or six gears in the forward train; and the six pistons will demand their share of attention from the lubricating system. Here is a grand total of over fifty rubbing surfaces on a large motor, and the oil must be thoroughly and constantly distributed to each. Of course, many smaller motors, provided with but a single cam shaft and a three-bearing crank shaft, may possess but one-half of this number of lubricated parts, but at the least, the oil must reach with unfailing certainty two dozen vital places of the engine.

At some of these portions, the movement is comparatively slow and the pressure is not great. Therefore such surfaces as the cams or valve stem rollers will demand less oil than will the bearings revolving at higher speed and carrying heavier loads. But it is the hardest-worked bearings that form the majority of the friction surfaces of a motor, as will be realized when it is remembered that all points on the circumference of a three-inch crank shaft bearing will travel at the approximate rate of 1,000 feet per minute—and these are the portions that also carry the heaviest load.

But while the pistons can hardly be called bearings in the generally-accepted layman's definition of the term, they require the lion's share of the lubricant, and are the first portions of the motor to feel—and show—the effect of any failure of the oiling system. While in terms of miles per hour, the movement of the pistons may not seem very rapid, the thousand feet per minute at which each ordinarily travels is rather a high rate of speed when it is considered that it is entirely a rubbing or a sliding motion, and that the direction is reversed more than two thousand times during each sixty-second period. This means that each piston slides or rubs within the cylinder walls for a distance of between two and three thousand miles during an ordinary season. And remember that this is not a rolling motion, but a continuous rubbing! In addition to this high-speed rubbing, the pistons are pressed firmly against the side of the cylinders on each explosion stroke throughout a portion of their travel. This corresponds to a heavy pressure carried by the rubbing surfaces, and is caused by the side thrust induced by the angularity of the connecting rod as it overcomes the resistance of the load through the crank shaft.

But this is only a small portion of the difficulties that must be overcome in cylinder lubrication. Not only must the oil pacify the rubbing surfaces and keep them well separated, but it must remain within a restricted territory of the cylinder walls. Whatever oil reaches the upper portion of the cylinder walls will be burned and will contribute to the formation of the carbon that is the mortal enemy of efficient running. Large quantities of oil burned in the cylinder will also form the dense clouds of choking blue smoke that the health authorities of many cities have been investigating, which have led to the enactment of city ordinances making the driving of a smoking automobile a misdemeanor.

In view of the difficulty which has been experienced by many drivers in sufficiently lubricating the pistons without causing the car to emit clouds of smoke, it may well be asked, "Why cannot an unburnable oil be used and thereby eliminate this trouble?" This is out of the question, for the mineral oils now used are obtained from petroleum and are cousins of kerosene, gasoline, benzine, and many of the other highly-inflammable liquids that need but the touch of a match to burn almost with the rapidity of an explosion. But notwithstanding the excitable family to which the mineral oils belong, the modern motor car lubricants are removed a sufficient distance from their more inflammable relatives to enable them to withstand a temperature of between 400 and 500 degrees, Fahrenheit. This is sufficient heat-resisting ability to enable the oil to stay on the cylinder walls near the bottom of the stroke, where it is most needed; but even though its burning point could be raised to a degree double its present amount, it could not withstand the high temperature generated in the top of the cylinder at the time of the explosion. The temperature here reaches a point well above the 2000-degree mark, and were it not for the cooling system, parts of the interior of the cylinder would probably be melted by the continued application of this excessive heat.

Any oil, consequently, would find but small opportunity to remain in its normal state after it once reached a point at which it would be exposed to the heat of the explosions, and we must look for a preventive measure other than that of increasing the flash-point or burning-point of the lubricant. But this high temperature does not exist throughout the stroke, for as the piston descends and the gas expands, heat is given off until the oil on the lower portions of the cylinder uncovered by the piston is sometimes able to remain in comparative peace. And even though this oil remaining on the cylinder walls at the bottom of the stroke should be burned, it would not be present in sufficient volume to create the dense clouds of objectionable smoke. Consequently it is the endeavor of engineers so to design the pistons and lubricating system that excess oil will not be fed to the pistons and allowed to remain on the walls after the former have descended.

But an excess amount of oil fed to the cylinders will result in so much less harm than will an insufficient supply, that we are treading on rather dangerous ground when we warn the amateur to cut down his lubricant to the point where there will be no smoke. As there are no ordinances that absolutely prohibit the slightest appearance of smoke at the exhaust, and as a faint blue trail is an excellent indication that the motor is receiving sufficient lubrication in the cylinders, it forms a satisfactory test by which the novice can determine the condition of the oiling system.

By the time that the exhaust gases have passed through the pipes and have expanded in the muffler, some of the blue smoke may have disappeared, and consequently the fact that a car does not give a trace of vapor at its exhaust should not necessarily be taken as an indication that the motor is not well lubricated. If the owner would satisfy himself that the cylinders are receiving a sufficient amount of oil, he may open the individual pet cock on each, and if he finds there a faint blue trail of smoke at each explosion in that cylinder, he may rest assured that harmony exists between the rubbing surfaces of the piston and the cylinder walls.

With the increase in the size and power of the automobile motors and the proportionately greater number of parts demanding lubrication, the attention required from the driver by the oiling system has been greatly lessened. Instead of the necessity of turning on individual oil cups whenever the motor is started, the modern driver merely twirls the starting crank or presses the button of the self-starter, secure in the knowledge that whenever the motor runs, the lubricating system operates—provided, of course, the reservoir is filled and there is no stoppage in the pipes. The oiling system of the modern motor is absolutely automatic, and if supplied with a sufficient quantity of a good lubricant, it will perform its work with an absence of trouble that places it among the greatest improvements of the engine of recent years.

Individual oil cups such as were used formerly, have been eliminated from the cylinders, and whatever sight-feeds there may be are placed on the dash in plain view of the driver. Instead of relying upon the suction of the cylinders for the positive feed to the piston, mechanically-operated pumps are used to force the oil to the various portions of the motor. In some systems, there is a separate pump for each oil lead. This is known as a mechanical oiler, and generally consists of an oil tank located on the dashboard of the car—either in front of the driver, or under the motor hood—and connected by means of a belt or gear with some shaft of the motor. The belt or gear drives a shaft to which is connected the plungers of the various oil pumps that force the oil to the different parts of the motor. Before passing to the individual pipe, however, the oil drops through a sight-feed connected with that lead, and as all of these sight-feeds are mounted in a row within plain view of the driver, the condition of the lubricating system in part or in whole may be determined at a glance.

The parts of the motor that are lubricated by an independent feed line in this manner may vary with different motors. In general, however, it may be said that it is seldom that the oil is fed directly to the piston, but that the lubricant is first distributed to the oil wells in the crank case. Here, the splash of the cranks as they revolve in the oil is depended upon to throw the lubricant upon the exposed portion of the piston as it reciprocates below the cylinder walls. The sides of the piston thus covered carry the oil to the cylinder walls.

It is evident that if an excess amount of oil is continually carried up by the piston to the cylinder walls, a certain proportion of this lubricant will reach the open space in which the charge is ignited, and will there be burned—with the attendant formation of clouds of objectionable smoke. This trouble is overcome to a certain extent in some motors by the use of a type of ring set in the piston that prevents the lubricant from passing to the upper portion of the cylinder; but all the oil cannot thus be retained, and it therefore behooves the driver not to allow too great a quantity to be fed to the crank case if the "splash" system is used.

The main bearings on which the crank shaft revolves are generally supplied with oil by independent leads from the oiler, and when the above-described system is used they may be regulated independently of the splash feed lubricating pipes. Excess oil at the bearings will cause no damage, but each crank shaft journal does not demand as great an amount as that supplied to a piston and connecting rod bearing.

Many lubricating systems that are now in popular use employ but one pump to force the oil to the various bearings and rubbing surfaces, and regulate the supply by the size of the pipe leading to each. A satisfactory method of overcoming the possibility of excess oil in the cylinder has been adopted by some manufacturers. This consists in placing a channel, or trough, directly under the lower sweep of each connecting rod bearing. Each channel is kept filled to overflowing by a separate pipe connected with the main lead from the pump, and a constant level is consequently maintained at all speeds of the motor. An elaboration of this method consists in attaching one end of each trough to a rod operated in conjunction with the throttle, so that as the speed of the motor increases, the end of the channels may be tilted, with the result that the connecting rod scoop will dip deeper into the lubricant.

After the proper level in each trough has been reached the excess oil overflows into the bottom of the crank case. From here, it is again started on its way by the pump and is distributed to the various bearings and troughs through the different pipes leading from the pump. As a further precaution against a smoking exhaust, some designers have added a baffle plate above each crank case compartment that serves to reduce the size of the opening through which the oil may be splashed. With this combination of troughs and baffle plates the possibility of a smoking motor is practically eliminated.

All motors are not so equipped, however, and in the case of those provided with the bona-fide splash system, care must be taken to keep the separate crank case compartments filled to the proper level. Too high a level in the crank cases will cause the motor to smoke; while the supply should not be allowed to become so low that when the angle of the crank case is changed—as in ascending a hill—the lubricant will run toward the rear and will not be reached by the scoop on the connecting rod bearing. This latter danger makes it advisable to give this system plenty of oil when any touring is to be done through a hilly district.

In some lubricating systems, the oil is supplied as it is used, and either is discharged with the exhaust, or collects in the bottom of the crank case, from which it should be drained occasionally. In the circulating systems, however, which are now used on a majority of the cars, the same oil is used continuously until it becomes "worn" or filled with sediment and particles of dirt and other foreign matter. The pump used for maintaining this circulation may be either of the plunger, centrifugal, or gear type, and is generally housed in a portion of the crank case. A strainer is usually placed in the suction end of this pump for the purpose of removing all the free foreign matter from the oil before it is again started on its mission of lubrication. In these systems, the oil well is generally located in a "secondary" bottom of the crank case. From here it may be drained when the supply is to be renewed.

Another successful system by which all the bearings of the crank shaft are positively lubricated is used on many of the best cars. In this system, a continuous oil hole passes throughout the length of the crank shaft, including its "arms" and connecting rod bearings. At each bearing, one or two small oil holes connect with this main artery and extend radially to the surface. Oil is forced into the longitudinal oil hole by means of a small pump, and naturally finds its way through every radial opening to all the bearings. The excess may overflow into the individual oil wells, from which it will be splashed upon the exposed portions of the pistons as they descend.

It will be seen that, no matter what modern oiling system is used, the same kind of lubricant is supplied to all parts of the motor. This feature makes matters much simpler than was the case when one oil was used for the cylinders, another, of a different thickness, supplied to the crank case, and still a third required for the gears. By the old gravity systems, the flow of oil depended largely upon its viscosity, or thickness. Therefore, in winter, a thinner oil was required than in summer, for the more a lubricant is warmed, the thinner does it become—and vice versa. With the mechanical force systems now in use, however, practically the same kind of oil may be used throughout the year—although many motorists believe that better results will be obtained if a heavier oil is used in summer than in winter. The oil will be warmed by the motor and it will not require many minutes of operation before a lubricant made thick by a low temperature will flow freely and do its work as efficiently as a thinner oil.

But no matter how reliable a lubricating system may be in its operation, the driver must do his share and make certain that fresh oil of the proper quality is supplied when needed, and assure himself that all the passages are free from obstructions. Negligence on the driver's part may result in one or more "stuck" pistons that will either seriously injure the motor, or will put it out of commission until the trouble can be remedied. If a sufficient supply of oil is not fed to the rubbing surfaces between the piston and the cylinder walls, a high degree of heat is generated which will tend to expand the piston until it grips the cylinder so closely that the former cannot be moved. In this event the motor will stop "dead," and cannot be started again until the piston has cooled and contracted to its normal size. Even then, however, the motor should not be run under its own power until the burned and gummed oil has been removed and the scored surfaces have been cleaned. While this may best be done by removing the piston—at which time an examination for any badly burned rings may be made—this is not always possible, and it may be necessary to run the car home or to the nearest repair shop before the proper repairs can be made.

In this case, the motor should be turned by hand until it is certain that the piston is again free in its cylinder. Liberal quantities of kerosene oil should be poured in through the spark plug opening, and if possible, the motor should be "rocked" back and forth by the flywheel to give the kerosene an opportunity to reach all parts of the piston and rings. The kerosene will serve to cut and remove much of the carbon and gummed oil and to make the way free for the fresh lubricant, which should be poured in liberal quantities into the cylinder head. The flywheel should again be moved back and forth so that the oil will reach all parts of the piston surface, and after this—if the damage has not been too great—the motor should be ready for operation.

CHAPTER VIII

Cooling

To enable the parts of a motor to work well, there must be freedom of motion between all that move in contact with each other. This necessary freedom of motion is provided for to a certain extent by proper lubrication, but this is not all-sufficient. The necessity for some additional friction- and heat-reducing system can be better realized when it is understood that the temperature of the explosion in the cylinders of a gasoline engine is well over 2,600 degrees, Fahrenheit. The melting point of pure iron is less than 2,800 degrees. Therefore were there no escape for this heat, and could the motor be induced to run under these severe conditions, the cylinders would soon reach a temperature dangerously near the melting point. Long before this point could be reached, however, the intense heat would have expanded the pistons so that they would become stuck in their cylinders, and no more explosions could occur. An ominous knock in one or more of the cylinders, followed by a sudden laboring and final cessation of operation on the part of the motor, is sometimes the first intimation that the driver may have that his engine is over-heated; but serious as a "stuck" piston may seem, it is fortunate that the motor stops of its own accord, for to continue to run under these conditions of constantly increasing heat would be to wreak far more serious and permanent damage upon the moving parts than the broken rings or scored cylinders that usually result from a lack of lubrication or cooling medium.

A large amount of the heat resulting from each explosion is carried out through the exhaust pipe in the form of the burned gases, while other portions radiate into the surrounding air.

These outlets are not sufficient, however, to carry away all the heat that is necessary to enable the motor to run efficiently, for proper piston lubrication is exceedingly difficult to obtain at high temperatures. There must, therefore, be more positive and direct means for carrying off this undesired heat, and to accomplish this result every internal combustion motor is provided with a cooling system of either the air or liquid (usually water) type. Motorcycle power plants and a few of the small and medium-sized automobile engines employ the air-cooling system; the great majority of automobile engines, stationary plants, and marine motors use water as the cooling medium.

Let us consider first the air-cooled system. The area presented by the outside of a smooth cylinder is not large enough to enable sufficient radiation to take place. That is, the heat is concentrated on a comparatively small surface, and this is much more difficult to keep cool than is the same amount of heat distributed over a greater area—for the cylinder will be exposed to a larger quantity of fresh air in the latter case. Therefore many air-cooled engines are provided with a series of grooves and flanges on the outer surface of the cylinder. The heat is conducted to all parts of this surface—flanges as well as grooves—and the area of the surface that is exposed to the cooling air is greatly increased thereby.

These grooves and flanges may extend circumferentially around the cylinder, as is the case with many motorcycle engines, or they may extend longitudinally. Another form of air-cooling system consists of pins or spines projecting radially from the surface of the cylinder. The motion of the car through the air is generally sufficient to create a circulation of the cooling medium, but in order that this circulation may continue while the car is at rest a high-speed fan is provided that draws the air from the front toward the rear of the motor. This serves also to supplement the air circulation produced by the motion of the car, and keeps the motor much cooler than would be the case were the machine run without the fan. This fan is generally attached to a bracket at the front of the motor, and is driven either by a belt or geared shaft. In some designs, however, the fan blades are included in the flywheel at the rear of the motor and the air is thus sucked over the cylinders.

One of the most effective air-cooling systems for use on an automobile motor consists of the above-mentioned longitudinal flanges and grooves enclosed in a thin jacket or casing surrounding each cylinder. These jackets are open at the top and bottom of the cylinders, and connect with large pipes, or troughs, through which air is forced. The trough into which the top of the jacket spaces open is connected with the discharge end of a large fan. The air is thus driven into the top trough, through each jacket, and into the lower trough, the farther termination of which is connected with the suction end of a fan included in the flywheel. The two fans serve to set up a rapid circulation of air which, by means of the troughs and jackets, is concentrated upon the surfaces of the grooves and flanges of each cylinder and none is wasted on parts of the motor that it is unnecessary to cool. Furthermore, the rear cylinders receive as much air as do the forward ones, for the trough serves to distribute the circulation equally along the grooves and flanges of each.

Inasmuch as the heat from an air-cooled motor is radiated directly into the current of air itself, the surface is very susceptible to temperature changes from the interior. Thus, if the car is run for a great distance on the low gear, and the cylinders become hot in consequence, a larger amount of heat will immediately be radiated from the cooling surfaces than is the case when the motor is running slowly. A "coast" down a short hill, however, will serve to cool the motor rapidly, for if the engine is run from the momentum of the car with the spark turned off, cool air will be drawn into the cylinders, and this, in addition to the circulation of cold air on the outside, will reduce the temperature of the engine rapidly. This is a feature of the operation of an air-cooled motor that is not possessed to so large an extent by those of the water-cooled type.

It is, perhaps, hardly accurate to apply the term "water-cooled" to the ordinary type of automobile motor. Water is merely the medium that transfers the heat from the cylinders to the cooling surface of the radiator. As air is used to cool this heated water, we see that the only difference between the two systems lies in the point of application of the actual heat-absorbing medium—which is air in both cases. Thus in the air-cooled motor the air is carried directly to the surfaces to be cooled; while in the other type, the heat is transferred by means of the water to the point where it may be effectually discharged into the air.

Each cylinder of a water-cooled motor is surrounded by a space known as the water jacket. This space is generally cast with the cylinder, although in some designs of motors the jackets are formed by the subsequent application of a copper casing that serves to retain the water. The water jackets are connected with each other by means of piping and water-tight joints so that the water will pass successively from one to the other. If the water remained in these spaces, it would soon be warmed to a temperature far above the boiling point, steam would be formed, a high pressure generated, and infinite harm would result—both to motor and to passengers. The piping, however, does not end with the connections between the cylinders, but extends to and from the radiator.

This radiator is a large, perforated structure placed either forward of the motor to form the end of the bonnet-covering, or in front of the dash between it and the rear cylinder of the engine. The radiator is a mass of small cellular or tubular passages, each one of which possesses an exceedingly large outer surface in proportion to the amount of water that it can contain. When the hot water reaches the radiator it is distributed to these many cells or tubes, and is thus spread over a large cooling surface. A large fan is usually located directly behind the radiator, and as this serves to draw the air rapidly through the openings between the cells or tubes, cooling is greatly facilitated.

There are several types of radiators in general use. Some consist of a number of flat cells placed in such a manner that regular-shaped air openings will be formed. Each side of each flat water cell abuts on an air passage. Such a radiator is known as the honeycomb, or cellular, the former term being applied to those whose cells resemble a honeycomb. The tubular radiator consists of a number of vertical, parallel tubes through which the water passes, and which are placed a sufficient distance apart to provide ample air passages between them. Each tube is covered at frequent intervals with fluted, circular flanges that serve to increase the radiating surface in much the same manner as do the grooves and flanges on the cylinders of the air-cooled motor. All air passages in any radiator extend directly through the width of the radiator, while the water circulates from top to bottom in a vertical direction.

The reason for this circulation of the water will be apparent if we call to mind a bit of our elementary physics. When water is heated, it expands and rises, and for this reason, we always find the surface of the water in a teakettle warmer than is that at the bottom—although the latter is closer to the fire. As the water is circulated through the radiator, it is cooled by the passage of the large amount of air through the openings between the cells or tubes. The water thus cooled sinks to the bottom of the radiator and is replaced by the water just heated by the motor. The cooled water is conducted to the bottom portion of the end cylinder, and passes to the others in succession, gradually rising as it is heated, until it is again forced to the radiator at the top.

There are two methods of circulating the water through the cylinder jackets and radiator. The most common method consists of the introduction of a pump in the lower portion of the circulating system. In the case of automobile motors, this pump is driven by gears connected with the crank shaft of the engine. Such a pump will be either of the gear or centrifugal type, and will suck the cooled water from the lower portion of the radiator, and force it through the jackets. The second method is known as the thermo-syphon system because the circulation is automatic and depends upon the cooling of the water in the radiator. When the cooled water sinks, a syphon action is formed that tends to draw the hot water from the cylinder jackets, and the automatic circulation will thus continue as long as the successive heating and cooling take place.

Inasmuch as the pump is driven by the crank shaft of the engine, its speed will be proportional to that of the motor. The same holds true of the fan that serves to draw the air through the radiator. It will thus be seen that both the water and the air are forced at a more rapid rate when the motor runs at high speed, and that therefore the extra heat generated by the more frequent explosions in the cylinders will be counteracted to a certain extent. The increased number of explosions and the higher speed at which the fan turns also cause quicker heating and cooling of the water by the thermo-syphon system, thus forming a more rapid circulation. Inasmuch as the force exerted upon the water by its cooling and heating is not as great as that formed by a high-speed and efficient pump, the pipes and connections of the thermo-syphon system must be of ample size in order to keep the resistance to the passage of the water as low as possible. Care must also be taken in the design of this system so to construct and connect the pipes and jackets that the hot water will be allowed to rise and the cool to descend, and thus to make possible the syphon conditions on which principle the circulation is based.

The ability of the radiator to carry off the heat from the water depends upon the rapidity with which the air passes through the passages provided for the purpose. The amount of air passing through is determined by the speed of the suction fan and the rapidity of travel of the car itself against the wind. It has been shown that, when the motor runs at a high number of revolutions, the fan turns faster and the rapidity of circulation is increased. But if the car itself does not increase its speed in proportion to the higher revolutions of the motor, the maximum amount of air will not be forced through the radiator passages, and the excess heat will not be carried off entirely from the cylinders. This is a condition that prevails when the motor is run on low gear. The speed of the motor is increased, while that of the car is reduced; additional heat is generated in the cylinders, but the speed of the air is not increased in proportion.

Therefore a motor that is driven a long distance on the low gear will have a tendency to overheat.

Water under atmospheric pressure cannot be brought to a temperature above 212 degrees Fahrenheit without being converted into steam. Therefore, when the heat from a water-cooled motor cannot be carried away sufficiently fast, the water in the circulating system will begin to boil. As long as water remains in the jackets, the temperature of these spaces cannot well rise above 212 degrees, and consequently there is small danger that a water-cooled motor will become overheated to the point at which the pistons will "seize" in the cylinders. The moment the water in the circulating system begins to boil, however, exceedingly rapid evaporation naturally takes place, and the water will soon entirely disappear in the form of steam and vapor. To run the motor under these conditions will mean that pistons and rings will soon become stuck in their cylinders, although liberal quantities of oil will sometimes delay this inevitable result.

But even when the cooling water is not brought to the boiling point there is a vapor that is constantly dispelled from it whenever its temperature is brought above that of the air. The water system of an automobile must therefore be replenished at irregular intervals, depending upon the amount and nature of the running to which the car has been subjected. The older cars were provided with an extra water tank, generally located under the seat, and connected directly with the water jackets and the radiator. The usual water-cooling system of the present-day car, however, is self-contained—that is, there is no separate tank for the storage of the water. The water is poured into the top of the radiator, and from this high point it reaches every part of the circulating system. Whenever the radiator will accommodate a couple of quarts, or more, it is well to fill it, for *too much* water *cannot be used* on the modern design of cooling system. It is true that a motor runs at its highest efficiency when its temperature is as great as that at which proper lubrication of the pistons can be obtained—for a gasoline engine is a "heat engine," and the greater its unnecessary heat losses, the less will be the power developed by it. But a motor cannot be kept at the proper temperature by reducing the amount of cooling water in its circulating system. The best method is to lessen the rapidity with which the water is cooled, and this may be accomplished by placing a leather flap, a cardboard, or other obstruction over a portion of the radiator to reduce the number of openings through which the air may pass. It should only be necessary to do this in the coldest weather, however, for the cooling system of every motor is designed to maintain the proper temperature on all except the hottest or coldest days.

It has been stated in a preceding paragraph that continued running on the low gear is the most frequent cause of overheating a motor. This is true, but it is not the only cause. Obstructions in the circulating system that reduce the flow of water will have this effect, as will also deposits on the interior of the cylinders that serve to prevent the proper transfer of heat to the water in the jacket spaces. Removal of the carbon will remedy the latter trouble, but to clear out the circulating system is more or less of a complicated matter. Stoppage in the pipes or radiator cells may be caused by a lime deposit from "hard" water that may have been used in the circulating system. There are preparations intended to remove this deposit, but such should not be used without first advising with the maker of the car or an experienced repair man. A series of battered cells in the radiator may reduce the number of cooling spaces that should be traversed by the water, and thus the hot water cannot be distributed over as great an air area as is necessary to maintain the motor at the proper temperature. Such a condition will be apparent from a marked difference in temperature between the affected portion of the radiator and the remainder. If a deposit has been formed on a certain series of cells, or if they have been obstructed in any other manner, the hot water cannot circulate through this section of the radiator, and it will remain comparatively cool.

Water is a liquid that remains in its fluid stage only through a temperature range of 180 degrees—at atmospheric pressure. At 212 degrees it boils and turns to vapor, while at 32 degrees it freezes and becomes a solid. In neither of these stages does it form a desirable cooling medium for a gasoline motor. Of the two, however, its solid stage is the more harmful to the motor. Not only will it cease to flow when it becomes ice, but the expansion of the water during the formation of the solid is liable to burst its retainer—whether it be the cells of the radiator, the pump, pipes, or even the cylinder walls themselves. It is the radiator that is the most liable to suffer from such a cause, however, for each cell contains so small an amount of water that the liquid will be brought to the freezing point before the larger volume in the jacket spaces approaches this temperature. Of course the water will be kept well above the freezing point when the motor is running, and it is only when the machine has stood idle for several hours that care must be taken to prevent the formation of ice in the circulating system.

Aside from keeping the car in a warm place whenever the motor is to be at rest more than two hours, there is only one method of preventing the cooling water from freezing, and that is by the introduction of some chemical that lowers the point at which the liquid will turn to a solid. There are several ingenious heaters available that are attached to the circulating pipes and that serve to keep all of the jacket water warm; the use of these producing the same conditions as though the car were kept in an artificially-heated garage.

One of the most common liquids used in the cooling water to prevent freezing is alcohol. If equal parts of wood alcohol and water are used in the cooling system, the resulting mixture will not freeze until it reaches a temperature colder than 25 degrees below zero. A weaker mixture—one having 25 per cent. of wood alcohol—will freeze at about zero, and it therefore depends upon the prevailing cold-weather temperature as to the proper proportion that should be used. It must be remembered that the boiling point of alcohol is much lower than is that of water, and that therefore a mixture that will not freeze in exceedingly cold weather is liable to boil away on the first moderate day on which the car is run. The above-mentioned 50 per cent. mixture of wood alcohol and water will boil at 135 degrees, while the 25 per cent. solution will withstand a temperature 40 degrees higher before it is transformed into vapor. As the lower temperature will be reached easily if the motor is run for some time in comparatively moderate weather, it will be seen that the stronger mixture should be used only where winters are very severe. It must also be borne in mind that, as alcohol boils more readily than does water, it follows that it will evaporate more easily, as well. Therefore, in order to maintain a uniform proportion of wood alcohol to water, the former should be replenished more often than is the latter.

Glycerine is another substance that is often mixed with the cooling water to prevent the latter from freezing. A 50 per cent. mixture of this and water has a freezing point of about zero, or slightly lower, and boils at practically the same temperature as water—210 degrees. Combinations of wood alcohol and glycerine may be used—equal parts of each being the usual proportion—and thus various freezing and boiling points may be obtained.

The radiator is one of the most delicate parts of the motor car's construction, and yet it is the most exposed to flying sticks and stones that may be thrown up by the rapid travel of the car. The car owner may do well to follow the practice of many racing drivers who place a heavy wire mesh screen in front of the radiator as a protection against obstacles that may be struck by the front of the car. It would seem that sticks and stones would be thrown toward the rear of the car, and would therefore avoid the radiator by a wide margin, but experience has proved that, at high speed, such loose pieces are frequently forced forward and are *run* into by the front of the car.

CHAPTER IX

Two-Cycle Motors

There has always been a strong prejudice in favor of the four-cycle motor for the power plant of the gasoline automobile. This may be due to the fact that designers have spent most of their time and energy on the development of this engine, and that therefore the two-cycle type has not yet been sufficiently "tried out" in the motor car to enable us to judge fairly as to its real merits. Certain it is that in the few instances in which the two-cycle motor has been used as an automobile power plant, the results have been highly satisfactory, and the present vogue of the four-cycle motor—with well over 98 per cent. of the automobiles now made adhering to this type—is largely due to popular prejudice in its favor.

As has been described in the first chapter of the present volume, the four-cycle motor devotes a separate stroke to each of the events of expansion, scavenging or expulsion of the burned gases, suction, and compression. The two-cycle motor, on the other hand, devotes but two strokes to these four events, and there is therefore an explosion twice as often in the two-cycle engine cylinder as is the case with the four-cycle type. But in lieu of the suction stroke of the four-cycle motor, there must be some method of forcing the charge into the cylinder of the two-cycle engine. The base, or compartment below the piston, in which the crank revolves, is used for this purpose. As the piston travels upward on its compression stroke, a partial vacuum is formed in the base, and if a passage is opened between this compartment and the carburetor, the charge will be sucked in.

All outside connections with the base are tightly closed on the down-stroke of the piston, and consequently the recently-inhaled charge will be compressed, ready for its entrance into the cylinder above the piston as soon as the connecting passage is opened. This passage is opened, as has already been described, at the bottom of the stroke and the compressed charge rushes in and fills the space in the cylinder that at that time is being vacated by the exhaust gases.

The majority of two-cycle motors are made without any valve mechanism, the opening and closing of the passages being entirely automatic. These passages are cast with the engine and lead into the cylinder through openings in the walls called "ports." The opening leading from the cylinder to the exhaust pipe, or exhaust port, is placed near the bottom of the stroke so that it is covered by the piston, except at the lower extremity of the travel of the latter. Just below the exhaust port, and on the opposite side of the interior of the cylinder, is placed the intake port, or opening of the passage connecting the cylinder with the base.

Now, as the piston is forced downward, it uncovers the exhaust port and an easy means of escape is furnished for the burned gases. Immediately after this, the intake port on the opposite side is uncovered by the still-descending piston, and the previously compressed charge, which is only awaiting the opportunity in the base, "blows" in. The exhaust gases are still escaping when this happens, and therefore it is necessary to prevent the incoming charge from passing directly across the top of the piston and out through the exhaust port before use has been made of its explosive qualities.

Consequently, to keep it in its proper path, a baffle plate is attached to the top of the piston which serves to deflect the incoming charge toward the top of the cylinder, and this not only prevents the loss of the mixture, but also furnishes a blast of air that helps to blow out the burned gases. On the return of the piston to the top of its stroke, it first passes over the intake port and then covers the exhaust port, effectually closing both and preventing the escape of the charge during compression. While this is going on, it must be remembered, the piston is forming the partial vacuum in the base, which serves to draw in the charge for the succeeding explosion.

If the charge is drawn directly into the base from the carburetor, a check valve must be used in the pipe connecting the two; otherwise the mixture would be forced back into the carburetor the instant the piston began its descent. A two-cycle motor drawing its charge in this manner is known as the two-port type, for there are only the exhaust and the inlet ports in the interior of the cylinder walls. The passage connecting the carburetor with the base may enter at the bottom of the cylinder, for this space and the base are the same when the piston is at the top of its stroke. Thus if this port is placed so that it is uncovered when the piston is at the top of its stroke, it will admit the charge to the base at a time when a partial vacuum has been created in this compartment by the upward movement of the piston.

This port is again covered as soon as the piston starts on its downward journey, and thus the charge is prevented from escaping until the intake port connecting the base with the top of the cylinder is opened. Such a two-cycle motor is known as the three-port type, and it will be seen that not even an automatic check valve is used in its passages—and it is consequently a "valveless" motor in the liberal interpretation of the term.

The high velocity of the charge recompenses for the short time that the port is uncovered, and consequently the base is filled with nearly as large an amount of charge as is the case with the two-port motor—which allows the incoming gases to enter the crank case during the entire upward stroke of the piston.

It will thus be seen that the piston of the two-cycle motor acts as a pump in two ways. First, the vacuum is formed that serves to draw the charge into the crank case, or base, of the motor; and second, the return stroke of the piston compresses this recently-inhaled charge and makes it ready to be "shot" up into the cylinder as soon as the piston has uncovered the port that forms the upper terminal of the communicating passage. There can, of course, no greater amount of fresh charge enter the cylinder than is drawn into the crank case. Consequently, the amount to which the cylinder will be filled depends upon the vacuum formed and the pressure exerted upon the charge by the succeeding down-stroke of the piston. It is to be supposed that the piston rings will be tight and that none of the charge can escape by them, and therefore the vacuum formed and pressure exerted in the crank case will depend entirely upon the displacement of the piston in its travel compared with the total capacity of the crank case. In other words, if the crank case is large and the piston is small and travels but a short distance, its pump action on the entire volume will be small. But if the crank case is small and the travel of the piston alternately doubles and halves the volume, the motion of the piston will cause the pressure in the crank case to vary greatly.

In a preceding paragraph it has been described in what manner the incoming charge in the two-cycle motor was used to "scavenge" the cylinder, or rid it of burned gases, by deflecting the mixture and allowing this to force out the remaining exhaust before the exhaust port was closed by the upward motion of the piston. It is evident that the greater the force, within certain limits, with which the charge enters the cylinder, the more perfect will be the scavenging action. But there is a limit to the pressure that can be attained by the mixture when it is compressed in the crank case previous to its discharge into the cylinder. This limit is determined by the size of the space required for the revolution of the crank and "big end" of the connecting rod, and by the volume displaced by the motion of the piston. The crank must have room in which to revolve, and the displacement of the piston can only be the area of its top multiplied by its length of stroke. Thus eight pounds per square inch is about the usual limit of crank case compression with this type of two-cycle motor. This may be varied slightly one way or the other by the arrangement of the ports, but it makes slight difference whether the motor is of the two- or three-port type so far as this consideration is concerned.

Two-cycle motors have been designed which combine the principles of action of both the two- and three-port types. The most important departure from the generally-accepted type of two-cycle motor, however, is the design in which the charge is fed into the cylinder from a chamber that is absolutely independent of the crank case proper. This may be accomplished in several ways. There may be what is termed a "differential piston" in which a separate plunger operates in the interior of the hollow "trunk" piston, and by means of the proper connection with the crank shaft compresses the charge in the chamber thus formed at the time it is to be forced into the cylinder.

Another design for obtaining intake compression independent of the crank case consists of a collar, or circular enlargement at the base of the piston. This collar reciprocates within the lower portion of the piston in a chamber which has been bored to the exact size. The collar consequently forms a variable base for this compartment, and as the piston descends, the collar travels with it, thus drawing in a charge of the fresh mixture. On the upward stroke, this mixture is compressed by the collar as it reduces the size of the compartment. It will be seen that such a motor can be designed to compress the charge to almost any amount.

Inasmuch as the mixture, as mentioned above, is compressed on the up-stroke of the piston, it is evident that it cannot be discharged into that particular cylinder at that time—for the mixture should be delivered to its cylinder only when the piston is at the bottom of its stroke. In the case of a four-cylinder engine, however, one of the pistons would be in the proper position for the entrance of the charge, and it is into this cylinder, that the compressed mixture is forced. The compression space in each cylinder, therefore, works for its neighbor, rather than for itself.

This interchange of courtesies is obtained through the good offices of a distributor in the form of a rotating, hollow cylinder having ports cut throughout its length that register with corresponding passages leading to the various cylinders. This distributor is timed with the crank shaft of the motor, and may be driven either by a gear or by a silent chain. As the mixture is compressed in the separate chamber of one cylinder, the passage leading to the distributor is opened by the revolution of the latter, and the charge is led through this passage, the distributor, and thence through another passage—also opened by the distributor—to the proper cylinder. The cylinders thus operate in pairs, one receiving its charge while the other is about to begin its explosion stroke—and vice versa.

The force of the explosion in a gasoline engine cylinder is not only dependent upon the amount and nature of the inflammable mixture admitted, but upon the force with which it is compressed, as well. The average compression pressure of a two- or four-cycle engine of the ordinary type, is from 60 to 70 pounds per square inch. Inasmuch as this pressure, assuming that the rings and valves are tight, is proportional to the displacement of the piston stroke compared with the volume of the clearance space, the amount of compression is constant at all speeds and loads of the motor. Should it be possible to increase this compression at will, it would be found that, with a warm motor, a pressure in the neighborhood of 100 pounds per square inch would serve to generate sufficient heat to ignite the mixture before the formation of the spark—for it is one of the elementary laws of physics that a gas will become heated when compressed. It is for this reason that the compression pressure of the ordinary automobile motor is kept in the neighborhood of 70 pounds per square inch.

A method of varying compression pressure to meet individual load requirements has been devised for some motors, however, and while such types are not as yet in general use in automobiles, it is probable that the near future will find much advancement along these lines. One such two-cycle motor that has been designed especially for automobile use employs a separate air compressor driven by the engine itself and used as the clutch and variable speed transmission of the car. The amount of pressure generated in the compressor is dependent upon the resistance offered to its operation—or, in other words, it increases with additional load carried by the motor. The compression, or compressed air, rather, is carried directly from the compressor to the cylinders of the motor, being admitted at the proper time by a rotary valve driven by the crank shaft. Thus the compression in each cylinder is automatically regulated by the load, and a motor of this type possesses a high "overload" capacity.

The motor mentioned above operates on somewhat the same principles as those found in the Diesel engine, which will be, as many predict, the ultimate type of internal combustion motor. The Diesel motor is not necessarily a particular make of engine, but bears the name of the originator of the principles involved. These are distinct from those of the Otto cycle, which is the principle upon which practically all automobile motors operate. The Otto cycle consists of the well-known series of events in the cylinder, as follows: Ignition, followed by the explosion, or expansion of the burned charge; discharge of the exhaust gases, or scavenging; admission of the fresh charge, suction; and compression of the newly-received mixture previous to ignition and the repetition of the cycle. In speaking of the Otto and Diesel engines, it must be borne in mind that they are referred to as a class, rather than as a particular make—as one would mention poppet valve or sleeve valve engines—for there may be many manufacturers of each type.

Although the Diesel principle may be applied to either the two or four-cycle type of motor, it is to the former design that it lends itself unusually well. This motor operates a two-stage air compressor in conjunction with a storage tank. At the beginning of the compression stroke, pure air under high pressure is admitted to the cylinder. In its upward travel, the piston compresses this air to a pressure approximating 500 pounds per square inch. While it has been shown that such a pressure is about five times more than enough to generate sufficient heat to cause premature ignition, it must be remembered that, unlike the ordinary type of motor, this is only pure air that is injected into the cylinder and contains none of the explosive gasoline vapor. At the top of the stroke, however, when the compression is at its maximum, the fuel is injected directly into the cylinder without having been previously vaporized.

This is another feature in which the Diesel motor is entirely different from the Otto type, for the latter must employ a carburetor to vaporize the fuel before it can be admitted to the cylinder. But inasmuch as there is already a pressure approximating 500 pounds per square inch in the cylinder of the Diesel motor at the time the fuel is injected, there must be a force behind the latter of 750 or 1,000 pounds per square inch in order to enable it to overcome the resistance of the highly-compressed air in the cylinder. In short, the liquid fuel is sprayed directly into the cylinder at a pressure of 750 or 1,000 pounds per square inch. This tremendous pressure is sufficient, not only to vaporize the particles of fuel as soon as they enter the cylinder from the nozzle, or "atomizer," but to cause them to burst into flame, as well. In other words, the compression of the air previously has generated sufficient heat in the cylinder to ignite the fuel immediately on its admission.

The fuel continues to be injected into the cylinder during the greater part of the down-stroke of the piston. In this respect, also, is the Diesel motor radically different from the Otto type, for the latter receives its full charge at one time and fires the entire amount in a single "explosion." In the Diesel motor, on the other hand, the ignition continues as long as fuel is admitted, and thus this engine is of the internal *combustion* type in the strictest sense of the word. It is, after all, the expansion of the gases due to the heat of combustion that produces the power in a gasoline engine, and if the fuel can be so admitted that it can burn during the greater part of the stroke, a high efficiency will be obtained.

The exhaust gases of the ordinary two-cycle motor pass out of the exhaust port as it is uncovered by the descent of the piston. Those that remain are forced out by the sudden admission of the fresh charge, which is deflected upward and is intended to scavenge the top of the cylinder. But it is claimed that thus employing the fresh mixture as a scavenging agent is wasteful of the fuel-permeated charge and does not conduce to efficient running. The system is simple in the extreme, however, and does its work well in small installations in which fuel economy is not of vital importance. But in the two-cycle Diesel type of engine, the high pressure of the pure air is used for scavenging, and as this is admitted with so large an initial force, the exhaust port may remain uncovered for a longer period than would be the case were the air to rely entirely on the up-stroke of the piston for its compression. Then too, whatever air may escape contains no fuel, and consequently efficient scavenging may be obtained without waste.

At the high pressure at which the fuel is injected into the cylinder of the Diesel engine, practically any grade of gasoline, naphtha, kerosene, crude oil, or other form of petroleum can be vaporized. The compressed air employed in the compression and injection of the fuel is also used for starting the motor, for this is not a type that is amenable to hand cranking. Thus the Diesel type of engine can be run in any weather on any grade of oil fuel, and as the carburetor and electrical ignition system are absolutely eliminated, two of the great sources of trouble of the automobile motor are absent—and this feature, alone, even more than the superior economy of operation, will appeal to the average motorist.

Just when this type of motor will be taken up by automobile designers is difficult to state. The Diesel type of engine has proved so wonderfully successful for large stationary power plants and for marine purposes, and its reliability is so absolute on all grades of fuel, that this motor may solve the failing-gasoline-supply problem. As yet, about 100 horsepower is the smallest unit that has been made in any quantities, but it was recently announced that this type would, in the very near future, be built for motor trucks and other commercial vehicles. Consequently, it is well for all those interested in the application of the two-cycle motor to the automobile to understand the elementary principles on which this radically-different type operates.