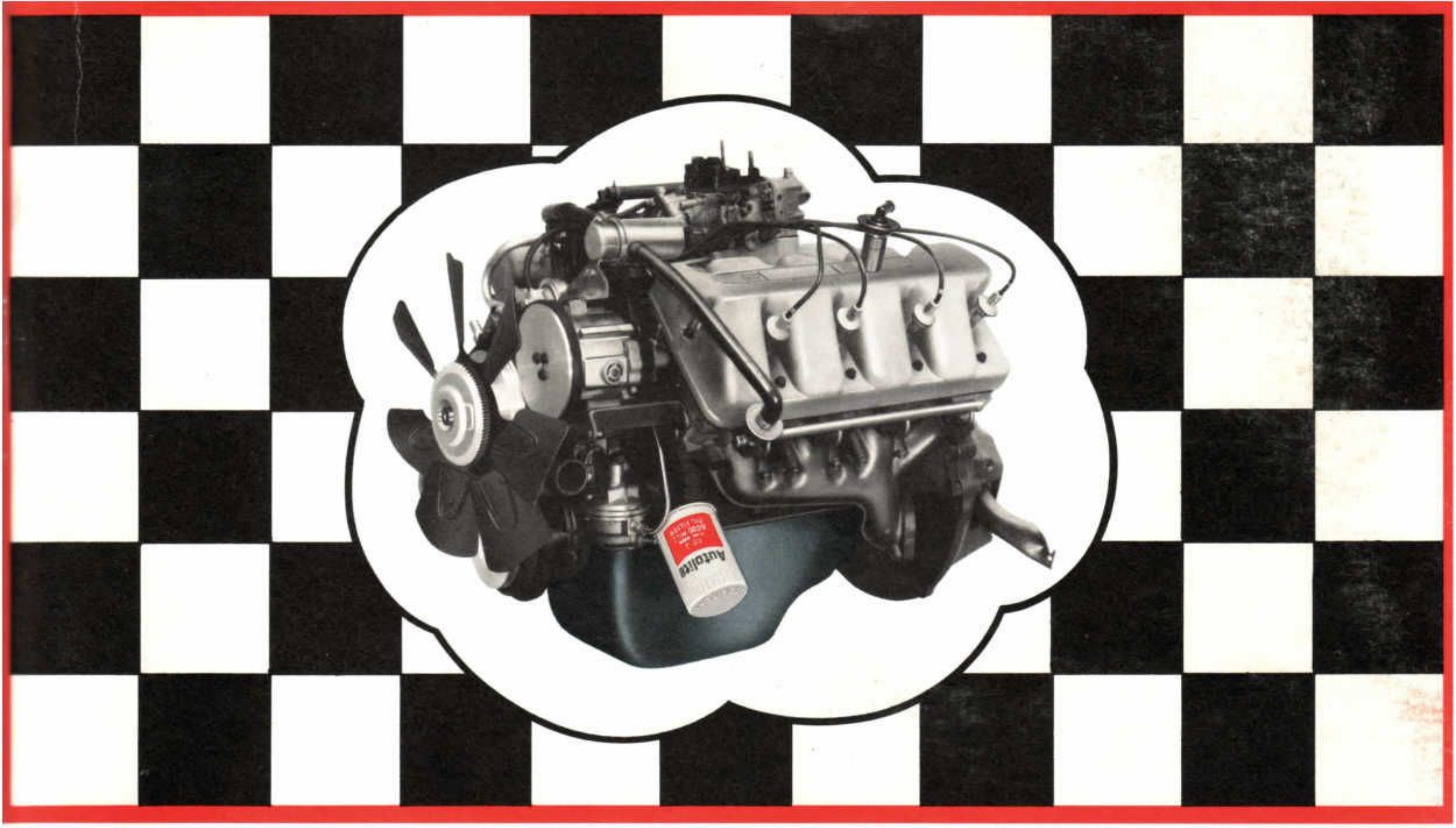

HIGH-PERFORMANCE ENGINES

FUNDAMENTALS...and...OPERATING PRINCIPLES

Autolite Ford

Foreword

This manual describes and illustrates the fundamentals and operating principles which apply to most "High-Performance" engines. Its purpose is to support the Autolite-Ford Field Service Training Programs with an authoritative reference book as well as serve as a basic text for a series of high-performance training courses and related publications.

Being aimed at a fundamental comprehension level, the content of this text deals with generalities. Accordingly, examples are meant to be typical. With this approach, the information will have less tendency to become obsolete as design concepts follow their normal course of rapid change. This doesn't mean, however, that we'll neglect coverage of specific engines. Pertinent modification data, parts information, and specifications for given Ford Motor Company engines will be covered separately in a forthcoming series of updating publications.

You will notice as you read this book that particular emphasis has been placed upon the cylinder head, cylinder block, and engine cooling and lubrication systems with somewhat lesser coverage being provided for carburetion, emission, and engine electrical systems. The difference in depth of coverage is intentional. Autolite-Ford already has training programs in the field which provide comprehensive coverage of the latter three subjects. Thus, we have confined our attention in this respect to those essentials which will be of particular background value when considering high-performance engines.

We invite your attention to the last six pages of this manual. They describe AUTO TECH . . . WHAT IT IS . . . HOW IT WORKS . . . and . . . WHAT IT PROVIDES. We encourage you to read about this low-cost correspondence training program . . . one which carries a money-back guarantee. (A registration form is included for your convenience.)

NATIONAL SERVICE DEPARTMENT
AUTOLITE-FORD PARTS DIVISION
FORD MOTOR COMPANY

Form No. AUD 7528-HP-1 **Price $2.00**

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Introduction

For openers, let's begin this manual with a few words about what we mean when we use the term "high-performance" in relation to an automobile engine.

Although the end results may be similar, a high-performance engine will be derived from one of two sources. First, there's the factory-installed package which is available as a customer option; and second, there's the post-production engine which a vehicle owner modifies to suit his own performance preferences. What's the difference?

FACTORY-INSTALLED HIGH-PERFORMANCE ENGINES

The Ford Motor Company, like most automobile manufacturers, gears its engine production facilities to give its customers some latitude in their selection of a power plant for the vehicle they're buying. By providing this type of flexibility in a high volume production operation, the concepts of "standard" and "optional" equipment come into play.

As a sidelight of interest, the process of determining what will be "standard" equipment for a given vehicle develops from the combined efforts of marketing, engineering, manufacturing, and production personnel. Together, these people forecast what will sell in the marketplace; and then, they proceed to design, test, manufacture, and assemble the products involved. With an eye toward cost in relation to demand, a given engine is designated as "regular production" equipment for a given vehicle application. Then, other engines and various component parts are engineered, tested, and released to production for optional installation on that vehicle. Being pre-planned into production, customers are free to select this equipment as a "regular production option".

There is still another category of equipment available to the customer as an option. It is referred to as a "dealer special order" part. Equipment in this category, which appears in the Ford Motor Company Master Parts Catalogs, usually consists of factory-approved, low-volume components aimed at customizing the performance and appearance of a vehicle to the specific needs and preferences of a certain portion of the total market.

Within this framework of production and marketing, the *high-performance engine* becomes a relative classification. For example, if the standard engine for a given vehicle is rated at 289 cubic inches of displacement, optional choice through production of a 390 C.I.D. engine certainly increases the performance potential of that vehicle. Similarly, substituting a 4-barrel carburetor for a 2-barrel unit is also a step toward a higher performance potential. Going a little further, a D.S.O. installation of a special camshaft and valve train is another factory-oriented, high-performance variation which up-rates vehicle performance potential.

THE MODIFIERS

Factory participation in high-performance vehicle installations through production is only part of the picture. There's a rapidly growing circle of performance buffs who are interested in improving the overall performance of cars which they have already bought. The range of interest of this group spans the engine and vehicle modification requirements which . . . at one end of the scale . . . would make a vehicle suitable for street use . . . and . . . at the other end of the scale . . . would adapt it for one or more of a variety of classifications of stock car competition. It is to this group . . . the modifiers . . . that the content of this manual is primarily directed.

While we're placing things into categories as an introductory step, we should also mention that "high-performance" is a matter of appearance. The high-performance look is certainly a part of the total picture. In fact, a sizable portion of the high-performance market is represented by those who are most interested in acquiring the "look" regardless of the performance potential of their car. (The trade refers to this type of car as a *wax job.)* Here are some of the appearance items which are available . . .

- Chrome dress-up components (valve covers, air cleaners, etc. . . .)
- Hood scoops
- Spoiler kits
- Mag or chrome wheels
- Metallic paint or decorative decals

Figure 1 shows a "wax job" in a light vein.

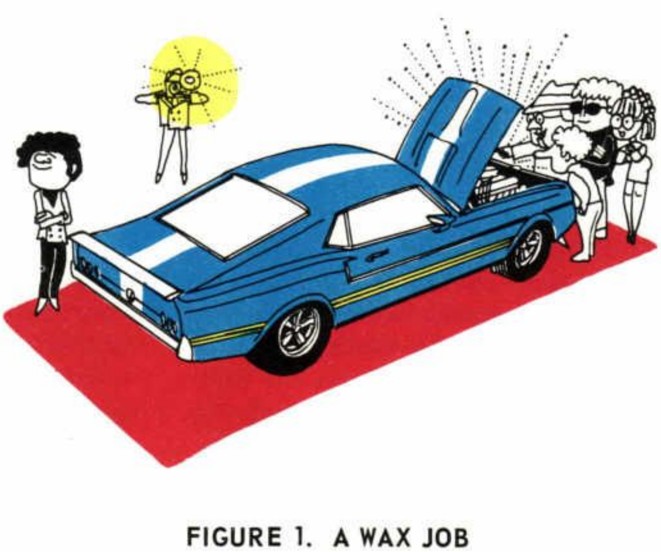


FIGURE 1. A WAX JOB

Of course, the full-fledged performance buff slants his interests toward the functional parts . . . those which will step-up the power, control, and handling characteristics of an automobile. The lengthy list of vehicle areas which might be involved include . . .

- Beefed-up transmissions
- Reinforced suspension systems
- Various rear axle ratios
- Various wheel and tire combinations

Special engine components such as . . .

- Induction systems (carburetors and manifolds)
- Exhaust headers and/or systems
- Ignition systems
- Cylinder heads (valve train components)
- Racing-type pistons (pop-up, eyebrow, etc.)
- Camshafts
- Stroker kits (crankshaft and rods)

Continuing in a light vein, Figure 2 shows several types of competition cars.

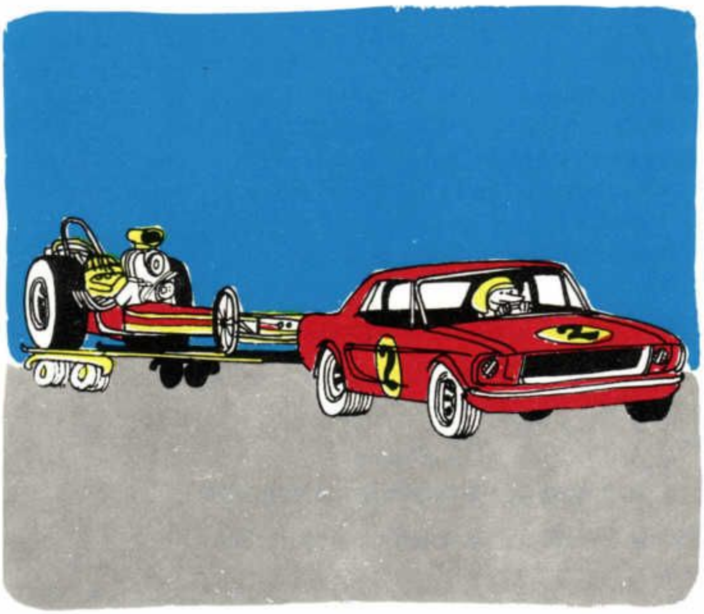


FIGURE 2. COMPETITION CARS

Although it takes a balanced combination of the many functional items listed to achieve an overall improvement in total performance, we'll place major emphasis on the engine itself in this manual. Before we get too involved with nuts and bolts, however, it may prove worthwhile to take the time to consider some of the factors which must guide your decision to face-lift the vehicle or squeeze more performance from the engine with which you are working.

IT'S YOUR DECISION

One of the first decisions you'll face after choosing to go the high-performance route is to select the area in which you want your car to perform. In other words, do you want . . . a show car . . . a car for street use only . . . a combination street and strip car . . . or a car prepared for all-out competition at sanctioned racing events? Should you decide to go the all-out competition route, it is essential that you obtain a copy of the latest "rules and regulations" of the sanctioning body or racing association. There are several of these organizations throughout the country. Some of the more prominent are:

- N.H.R.A.—National Hot Rod Association
- A.H.R.A.—American Hot Rod Association (Drag Racing)
- NASCAR—National Association for Stock Car Racing
- USAC—United States Auto Club (Track Racing)
- SCCA—Sports Car Club of America (Road Racing)

Each of the racing organizations listed have established strict guidelines which you must observe in order to be eligible to compete in the events which they sponsor. These rules and regulations include restrictions such as engine size, types of manifolding, carburetor throttle plate size, number of carburetors, as well as many other performance and safety features including roll-bar specifications, size, capacity and location of fuel tank, etc. . . .

Regardless of whether your decision is inclined toward all-out competition, a combination of some of the features of show cars and street cars, a rod you can drive to work during the week and still take out to the strip on week-ends . . . or . . . because you're the type of individual whose spine "tingles" at having a high-performing, finely-tuned machine at your command . . . you can't overlook the cost factors of high-performance equipment. This equipment is available to you from manufacturers in the form of individual components, kits, complete engine assemblies—or, for that matter, as an entire vehicle set-up for competition; and you can spend anywhere from one dollar upwards to several thousands of dollars for unique and exotic racing machines. This decision is one that only you can make, since you know how much money you're willing to invest.

As we mentioned, these are just some of the factors which may influence your decision to go the high performance route. Chances are you've already made your decision and now you are anxious to get on with it.

The extent of our high-performance coverage in this manual is aimed at providing a store of background information which will apply generally to all sizes of engines, rather than to an engine with a given cubic inch displacement rating. We acknowledge that your experience level will determine the utility of the material we've included. In effect, we're assuming that to some readers it will be new information . . . to others it will be helpful review or reference data . . . and . . . to the more experienced, it will probably be quite unnecessary.

We're also assuming, in the information we're providing, that you don't have an unlimited budget and you don't have an engine-building facility at your disposal. Further, we're assuming that you already own a regular production engine or are contemplating the purchase of one and need information that will help you with a modification project. Now, the question is—"where do we start"? Let's try "blueprinting"!

BLUEPRINTING

"Blueprinting" is a term you'll encounter frequently as you get more deeply into the business of preparing high-performance engines (see Figure 3 next page). It relates to all the processes and operations involved in checking each engine part for conformity to specified dimensions. In the case of moving parts, they must also be checked for working clearances.

The engine operations involved in blueprinting are:

1. Complete disassembly of the engine.
2. Cleaning all parts in degunking fluid.
3. Removing all burrs and scratches.
4. Magnafluxing the block and component parts. (When possible, repair or replace parts with surface irregularities.)
5. Checking bottom end for trueness. (Sometimes line-boring is necessary to assure that all parts and locating points oriented to the crankshaft centerline are within specifications).

It is essential that a clean working area be selected when performing the checks and operations mentioned above. The smallest particle of dirt, sand, or grit could cause early engine failure. There are many cleaning solvents or degunking fluids available commercially which are adequate for this purpose. You should exercise some care, however, in selecting a suitable cleaning agent, inasmuch as there are some which leave an undesirable coating of alkali and silicone deposits. Many engine builders prefer and recommend first washing parts in kerosene, then in hot water and detergent—followed by a clear water rinse. The final step is the drying of parts with compressed air and applying a light coat of rust preventive oil on the machined surfaces.

The purpose of blueprinting, then, is to provide the precision necessary for high-performance demands. It ensures that all dimensions and working clearances are tailored to provide the best possible results for an engine's specific application. Remember, there are two musts for a high-performance engine. One is top performance and the other is reliability or endurance. You can't expect to finish up front in any event if your car will not go the full distance.

There are additional operations in blueprinting which may be necessary. Depending upon the condition of the parts being checked, you may have to . . .

1. Hone cylinder walls
2. Hone and fit piston pins
3. Hand fit piston rings
4. Cut block face to provide 0.001″ conformity of deck clearance from cylinder to cylinder
5. Chamfer oil holes (block and crankshaft)
6. Provide specified clearances for . . .
   - Piston skirts
   - Rod bearings
   - Rod sides
   - Main bearings
   - Cam and crank end play
   - Wrist pins
   - Valve-to-piston
7. Check alignment of . . .
   - Rods
   - Crankshaft
   - Camshaft
8. Measure all combustion chambers and grind them as required so that they are within 1/10 cubic centimeter of desired volume
9. Provide proper valve seat and face angles, as well as maintain specified seat widths
10. Balance moving parts, such as . . .
    - Crankshaft
    - Vibration damper
    - Piston and rod assemblies
    - Flywheel and clutch cover (convertor)
11. Torque attaching parts to specifications
12. Provide correct ignition distributor advance curve
13. Final tune running engine with appropriate test instrumentation.

As you can see, there are many steps required in performing a complete blueprinting job. Most of the operations can be done with ordinary service tools and equipment. Some, however, will require the services of a speed shop. Usually the blueprinting operations involve dimensional changes only, and should not be considered as modifications, as all changes are within the original specified tolerances of the engine manufacturer.

The value of a completely blueprinted engine, in terms of its reliability and total performance capabilities, has proven itself many times—both on the dynamometer and in competition. In fact engine testing labs have reported as much as a 10% gain in horsepower over the regular production engine.

REVIEW OF 4-CYCLE ENGINE OPERATING PRINCIPLES

Up to this point in our text, our objective has been a general familiarization with the steps involved in basic engine preparation for high performance operation. The materials which follow review 4-cycle engine operating principles and then separately describe engine components, servicing techniques, and applicable modification procedures.

BLUEPRINTING

CRITICAL DIMENSIONS

Piston skirt clearance	.007"
Rod bearing clearance	.0025" – .003"
Main bearing clearance	.0025" – .003"
Rod end clearance	.025"
Wrist pin clearance	.0007" – .0009"
Valve seat and face angle: – Intake	30°
– Exhaust	45°
Valve seat width – Intake	.035" at outer edge of valve*
– Exhaust	.050" at outer edge of valve**
Hand hone cylinder wall	Approx. 5 minutes per cylinder with 150-180 grit stone.

*Drag strip racing only, 070" for street use
**Drag strip racing only, 080" for street use

CRITICAL BOLT TORQUES

Bolt – cylinder head	100 Ft. Lbs. Tighten in following steps: 30, 50, 70, 85 and 100 ft. lbs. max.*
Bolt – intake manifold	28 Ft. Lbs.
Bolt – connecting rod	58 Ft. Lbs.
Cross bolt – main bearing cap	42 Ft. Lbs.
Vertical bolt – main bearing cap	105 Ft. Lbs.
Bolt – rocker shaft hold down	50 Ft. Lbs.

*Refer to shop manual for cylinder head and cross bolt torque sequences.

BALANCE

Critical static weights:	
Piston	660 to 666 gms.
Connecting rod	833 to 845 gms.
	–pin end 254-260 gms.
	–crank end 579-585 gms.
Weight of oil in crankshaft end	15 gms.

Have dynamic balancing performed.

DISTRIBUTOR CURVE

Distributor RPMs	250	750	800	1250	2000
Distributor degrees	0°	0°	2½°	5°	9°

Distributor: Maximum safe full advance–38°. If pre-ignition or detonation prevails, retard lead as necessary.

Install BF-32, BF-22, BTF-1, or BF-601 spark plugs, depending upon heat range required.

Gap at .025"-.035".

CARBURETORS AND FUEL SYSTEM

652 – 715 CFM Holley's

77 Main metering jets (recommended as a jet to start with).

71 Secondary jets (recommended as a jet to start with).

Install electric fuel pump and set for 5½-6 psi at fuel filter.

Use the highest octane fuel available.

GENERAL MODIFICATIONS

Install lightweight fabricated headers.

Use "Detroit locker" type limited slip differential (Ford Part No. C3AZ-4880-A) and Ford high performance differential lube (Ford Part No. C2AZ-19580-D and specification number M2C57-A). This lube comes in 1-gallon containers.

Install clamps on the rear springs (two clamps, front and rear) and put a spacer under the rubber pinion nose bumper elevating it to about ½-inch below the bumper plate. Install heavy duty shock absorbers. This should eliminate wheel hop.

To aid power shifting, remove teeth on second and third gear blocker rings. Remove handle retaining bolts in shift tower, install a flat washer, re-install bolts. This will compress the rubber to a near solid condition.

For all-out drag strip performance, the following are strongly recommended for the protection of your engine:

Rear sump oil pan C8AX-6675-A; pick-up C5AE-6622-B.

Use 7 quarts of oil.

Low restriction oil filter.

Minimum piston-to-valve clearance – .120". Check clearance as follows: Use .120" valve lash (example: if valve lash is .025", feeler gauge should be .145"), insert feeler gauge between valve and rocker arm and turn engine over twice by hand. If valve does not hit piston, you have proper clearance.

FIGURE 3. TYPICAL ENGINE-CHASSIS BLUEPRINT

(427 SHOWN)

Work is defined as "the changing position of an object against an opposing force". Work is measured in foot-pounds (ft.-lb.) and calculated by multiplying distance times force.

Power, on the other hand, is the rate or speed at which work is done.

Work, in a 4-cycle, internal combustion engine, starts in the cylinder and combustion chamber. Air and a combustible fuel vapor is drawn into the cylinder on the intake stroke. The mixture is compressed when the piston is moved upward. A timed spark, in the upper part of the cylinder, ignites the fuel vapor and adds heat to the air. By the time the piston has reached the top of the cylinder, the ignited gases are pushing in all directions. As a result, the downward force being applied to the top surface of the piston causes it to move in the direction of least resistance. This force is transferred through the piston pin to the connecting rod and from there to the crankshaft. When the crankshaft rotates, work is being accomplished.

A pressure-volume (p/v) diagram is a method of tracing the compression and expansion process in a cylinder graphically. The vertical scale in this diagram represents pressure and the horizontal scale represents cylinder volume. (See Figure 4, Views 1 through 5.)

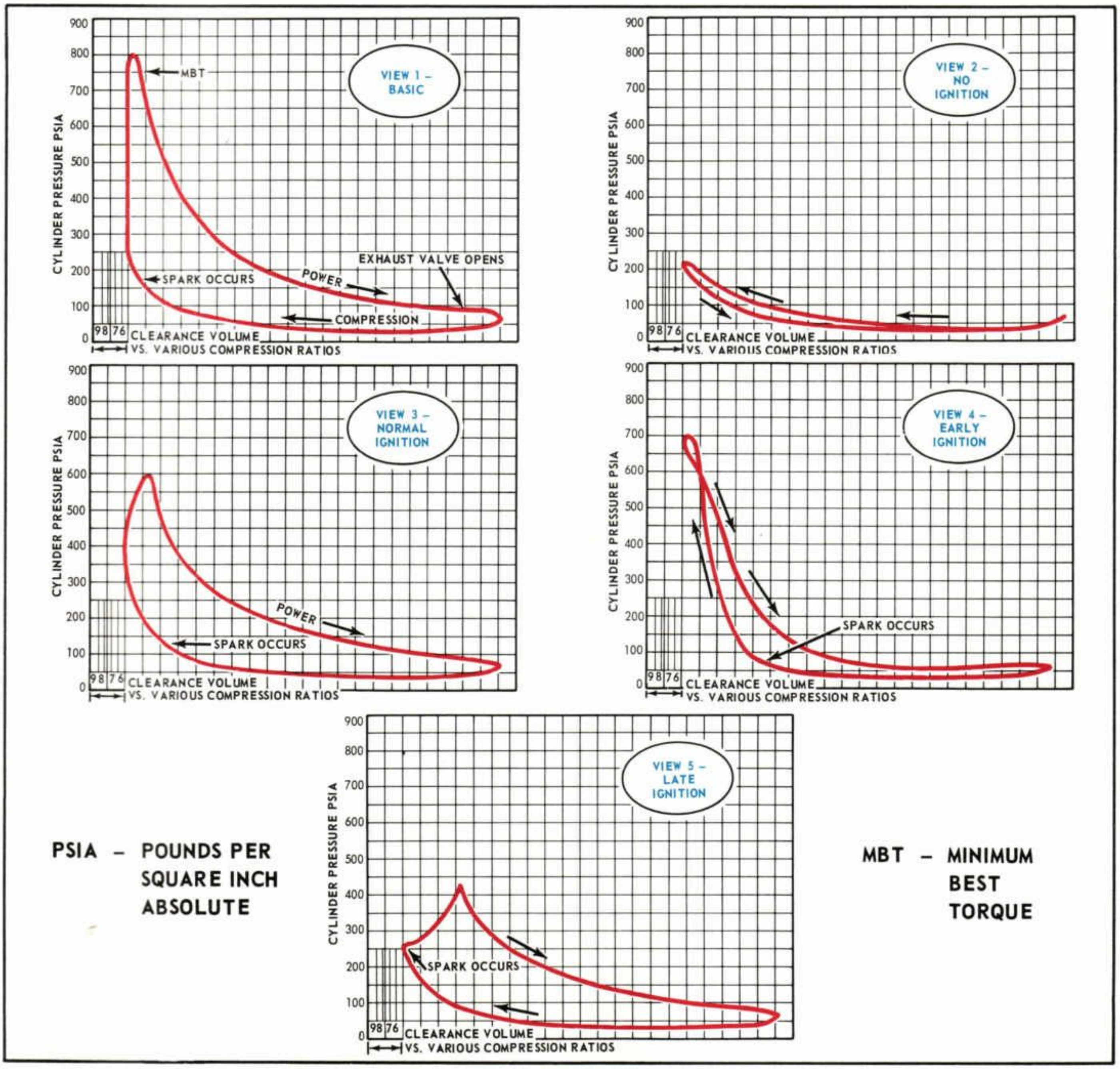


FIGURE 4. PRESSURE-VOLUME DIAGRAMS

The cycle starts when the intake valve opens and the piston is pulled down by crankshaft rotation. Air and fuel vapor rush in to fill the vacant space created by the movement of the piston. As the piston starts upward, the intake valve closes and the volume of air and fuel vapor mixture in the cylinder is compressed. *(See View 1.)*

If the content of the cylinder were not disturbed, the pressure would rise to a value approximately equal to atmospheric pressure times the compression ratio. There would also be a small amount of additional pressure due to the heat developed during compression. Assuming no spark is introduced, the pressure on the power stroke will fall slightly below the path it took during the compression stroke. This condition would relate to the heat and pressure loss in the cylinder. *(See View 2.)*

Now let's create a spark in the cylinder near the end of the compression stroke just before the piston has reached the upper limit of its travel. The pressure and temperature, due to the rapidly burning fuel vapor mixture, will quickly rise and reach their peak values just after the piston has started down on the power (third) stroke. *(See View 3.)* The peak pressure in the average engine will be approximately 600 pounds per square inch. Using an engine with a bore of 3.5 inches as an example, the force on the top of the piston would momentarily be approximately 5,800 pounds.

$$(\pi R^2) \times 600 = 3.14 \times 1.75^2 \times 600 = 5760$$

Several things will alter applied combustion pressures. Early spark occurrence will cause more of the pressure than is desirable to be applied before the piston has reached top dead center (TDC). *(See View 4.)* A late or retarded spark timing will rob the power stroke of pressure for the duration of time in degrees that the spark is retarded, as compared to a best power spark setting. *(See View 5.)*

Another power stealing and damaging effect, which might occur if conditions in the cylinder are not right, is detonation or spark knock. (See Figure 5.)

We want a rapid but smoothly burning fuel-air mixture. This mixture starts burning at the spark plug and progresses through the unburned portion on one or more fronts in a manner similar to a traveling rain storm. The unburned portion of the mixture is being heated by the flame front and by further compression due to expansion of the burned gases. A great deal of this heat is transferred to the walls of the combustion chamber. If the temperature of the unburned mixture rises to the point where it will start burning at a location other than the original flame front, then a violent explosion occurs. This is *detonation* or *spark knock.*

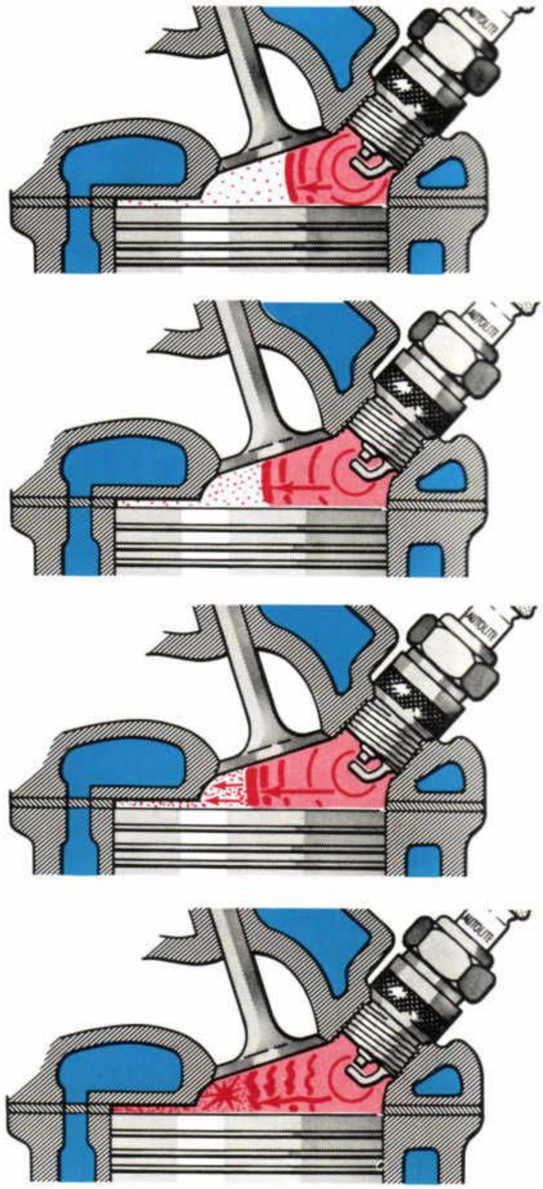
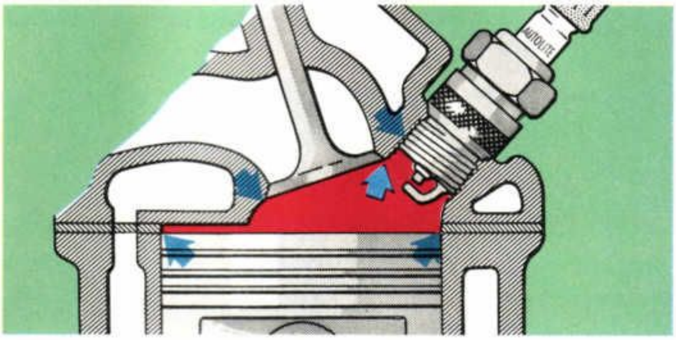


FIGURE 5. MIXTURE BURNING AND DETONATION

Spark knock can be caused by any one or a combination of the following: (1) too high a compression ratio for the fuel and spark timing used; (2) too low an octane rating of fuel for the spark timing and compression ratio used; (3) too high a spark advance for the fuel and compression ratio being used; (4) too lean a fuel and air mixture.

Fuel anti-knock characteristics will be covered in more detail later in the text. As introductory information, we'll merely mention that these characteristics are usually rated by octane number. Generally fuel with a high octane number is slower burning than that with a low octane number. Gasoline fuels are composed of a mixture of hydrocarbons. These are chemical compounds containing carbon and hydrogen in varying proportions. Gasoline contains some octane and iso-octane hydrocarbons that have been given an anti-knock rating of 100. If, during testing, a sample of gasoline performed the same as a mixture of 65 percent iso-octane and 35 percent heptane, (another hydrocarbon) then the sample would be rated at 65 octane. A performance number is given to fuels of over 100 octane rating.

High combustion chamber temperatures caused by detonation can result in pre-ignition. Pre-ignition is a premature or non-spark originated ignition. It is usually caused by a hot spot in the combustion chamber. (See Figure 6.) Extended engine operation with pre-ignition usually causes burned valves, burned pistons or cracked cylinders or head(s).



. FIGURE 6. HOT SPOTS IN COMBUSTION CHAMBER

The best prevention for detonation and pre-ignition is to follow the engine manufacturers' recommendation as to spark advance, fuel quality, spark plug application, coolant temperature, and compression ratio.

To obtain efficiency on the power stroke, the correct fuel-air mixture must be maintained. The best average mixtures for power and economy are shown in Figure 7. These curves are typical for cars intended

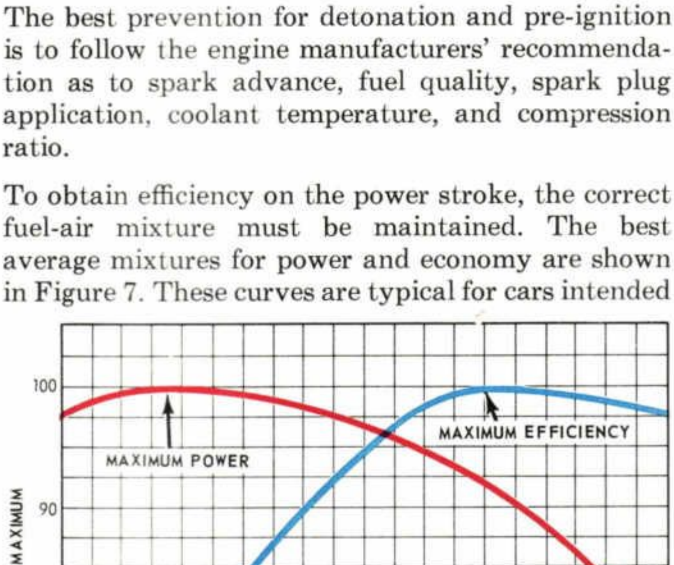


FIGURE 7. EFFECT OF AIR-FUEL RATIOS ON POWER AND EFFICIENCY

for street performance. Requirements for competition vehicles will be covered later in the text.

A rich mixture may foul spark plugs and cause carbon build-up in the cylinder. A lean mixture can cause excess heat, burned valves, pistons, and spark plugs. The exhaust stroke clears the cylinder of the products of combustion in preparation for the beginning of a new cycle.

ENERGY AVAILABLE FROM THE ENGINE

The only energy that is fed into an engine is air and fuel. The amount of energy that can be taken from the engine is largely determined by how efficiently the fuel and air are used.

Some of the more important items that affect available engine power are: piston displacement, compression ratio, intake system pressure (restriction or supercharging), valve and spark timing, air/fuel ratio, engine friction, engine strength (ability to withstand pressures and speed), and air or atmospheric conditions (pressure, moisture content, temperature). The *volume* of air-fuel mixture consumed will always be the same at a given speed, because the volume is determined and fixed by the engine cylinder volume. The *weight* of the mixture can vary, however, because gases and mixtures thereof are compressible and a variance of weight is possible within the same volume.

Now that we've reviewed the highlights of engine power and mechanics involved in its production, let's devote some attention to the mathematics of power ratings. Understanding the elements involved in these power ratings is a fundamental requirement for one who is concerned with high-performance engine concepts.

The Mathematics of Engine Power

The most frequently cited engine power specifications are probably brake horsepower and torque. An electrodynamometer is the conventional equipment used for accurately measuring useful power in this respect. A typical dynamometer includes a stand for mounting the basic engine to be tested, a remote supply source for fuel, coolant, and lubricants, and a torque scale device to which the engine crankshaft is coupled. The dynamometer operator, by flipping switches and turning knobs, can control torque (electrical load) and engine throttle position. By adding torque, the operator introduces resistance to the turning effort produced at the end of the engine crankshaft. The amount of torque (expressed in pounds-feet) is indicated on the torque scale and crankshaft rotating speed (r.p.m.) is shown on a tachometer which is usually a component of the dynamometer operator's console. The engine is operated under a variety of engine r.p.m. and load conditions with readings recorded at given increments. These readings are then used to construct a performance curve of the type shown in Figure 8.

Now, to better understand engine performance characteristics, let's determine what information the two curves in the illustration provide. To do this, we'll have to consider some performance characteristics of the component parts involved and some applied ideas from math and physics.

Basic Horsepower

First, when an engine is operating, it is performing work. Work, in this instance, is applying force to turn the crankshaft. The resulting power is the rate or speed at which the work is done. Horsepower, as the universal unit of measure for this type of work, is determined with the following equation:

$$HP = \frac{l \times w}{33{,}000 \times t}$$

where HP = horsepower
l = distance involved in work performed
w = force to accomplish work
t = time to complete work
33,000 = predetermined number of foot-pounds of work that a hypothetical horse can perform in one minute.

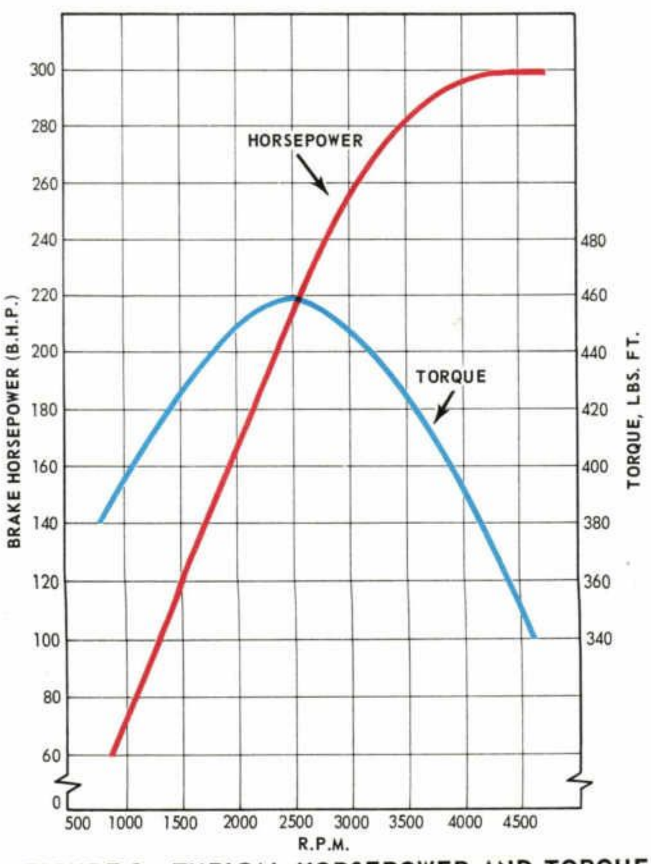


FIGURE 8. TYPICAL HORSEPOWER AND TORQUE CURVES

Brake Horsepower

This basic horsepower value is seldom, if ever, used when referring to automotive engine power. The curve in Figure 8, for example, shows brake horsepower calculated from dynamometer test results as described previously. The equation for brake horsepower in its simplest form is:

$$BHP = \frac{T \text{ (Torque)} \times RPM}{5252.1 \text{ (Dynamometer Constant)}}$$

Using our curve data, the following is an example of a brake horsepower calculation:

$$BHP = \frac{T \text{ (459 Ft.-Lbs.)} \times RPM \text{ (2550)}}{5252.1}$$

$$BHP = 222.28$$

Road Horsepower

The brake horsepower figure derived from this type of calculation is no more than a barometer of performance potential. As a published rating, it is usually representative of available maximum power under standard temperature and pressure conditions (barometric pressure—29.92 inches of mercury, temperature 60° F.) with a minimum of power absorbing accessories, such as an air cleaner, fan, muffler, and charging system, being driven by or attached to the engine during the test. In addition, fuel and ignition system operation approaches laboratory controlled conditions.

Because it is a favorable power figure, B.H.P. is often used for advertising purposes. To the performance buff, however, road horsepower is much more significant. It expresses the power available at the wheels (with a chassis dynamometer being used to determine the results) . . . again under given operating conditions. (The factors pertinent to road horsepower calculations involve the transmission, axles and wheels and tires. They will be covered in a separate manual.)

The Elements of Engine Power Calculations

The power in an internal combustion engine is a result of the pressure created in its cylinders during their compression strokes. Theoretically, the higher the pressure . . . the greater the power. There are limiting factors, however. The heat of compression is perhaps the most significant. It is fundamental knowledge that the more a gaseous mixture is compressed, the higher the temperature will rise. If the compression potential in the chamber is great enough and the act of compression is allowed to continue long enough, the heat generated will become sufficiently intense to ignite the gas being compressed without the intended, properly timed help from an ignition spark. This, of course, is the highly destructive condition we associate with detonation and pre-ignition.

Successful combustion chamber design is aimed at getting the highest possible compression in the chamber without igniting the air-fuel mixture; because, as we mentioned, compression and power are directly related. The specified result of this design goal is expressed as the *compression ratio* for the engine to which it applies.

Because compression is so important, let's spend a moment with the mathematics involved before we consider the design modifications which will safely raise compression. We'll use Figure 9 as a visual aid for our description.

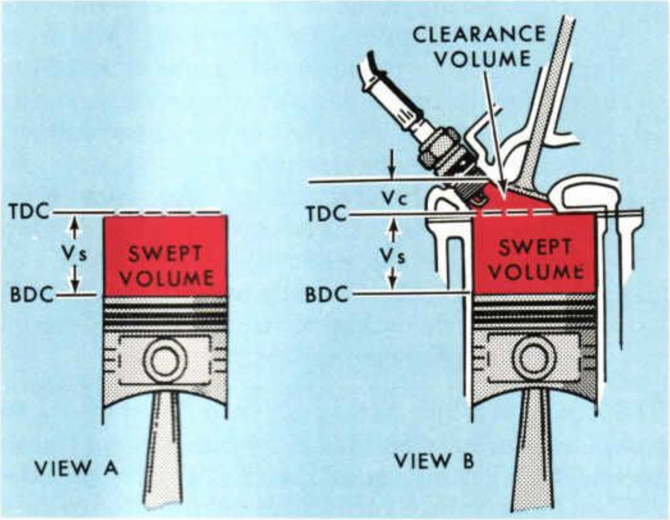


FIGURE 9. THE FACTORS INVOLVED IN COMPRESSION

Refer to View A. Here, we're illustrating the engine components and areas involved in *piston displacement* or, more familiarly, *cubic inch displacement.* You'll notice by the dotted lines in the picture that the volume of displacement coincides with the circular shape of the top of the piston and the distance this piston is moved from its lowest to its highest point. Accordingly, the mathematics involved are a simple determination of the total volume of the displacement in all cylinders. The equation is as follows:

$$CID = \frac{N \pi b^2 l}{4}$$

where N = Number of Cylinders
π = 3.1416
b = Cylinder Bore Diameter
l = Length of Piston Stroke

Applying this equation to published specifications for a Ford Motor Company engine rated at 390 C.I.D., we can develop the following example:

$$CID = \frac{N \pi b^2 l}{4}$$

where CID = Cubic Inch Displacement
N = 8 Cylinders
π = 3.1416
b = 4.05 Inches
l = 3.78 Inches

Then:

$$CID = \frac{8 \times 3.1416 \times (4.05 \times 4.05) \times 3.78}{4}$$

$$CID = \frac{1558.2702}{4} = 389.5674 \text{ or } 390$$

In View B, Figure 9, the cylinder cross-section is divided into two areas . . . the lower is designated as the "swept volume" and the upper as the "clearance volume". These two volumes must be determined in order to calculate the compression ratio for a given cylinder.

Swept volume is merely $\frac{1}{N}$ of the engine's total cubic inch displacement where "N" is number of cylinders in the engine. Clearance volume must be known or measured at piston T.D.C. by light oil displacement because piston and combustion chamber configuration constantly vary between engines. With this in mind, we'll include an equation for calculating a compression ratio for its reference value.

$$CR = \frac{V_s + V_c}{V_c}$$

where CR = Compression Ratio
V_s = Swept Volume
V_c = Clearance Volume

Refer to the C.I.D. example shown previously. Calculation of Vs requires bore and stroke specifications.

$$CR = \frac{V_s \text{ or } \frac{\pi}{4} b^2 l + V_c}{V_c}$$

$$= \frac{\left(\frac{3.1416}{4} \times (4.05)^2 \times 3.78\right) + V_c}{V_c}$$

Let's assume that we've been given or determined by measurement that the Vc is 5.7289. Accordingly the equation will read as follows:

$$CR = \frac{48.6959 + 5.7289}{5.7289} = 9.5 \text{ or } 9.5{:}1$$

If only compression ratio and swept volume are known, the clearance volume could then be calculated:

$$CR = \frac{V_s + V_c}{V_c} \text{ or } 9.5 = \frac{48.6959 + V_c}{V_c}$$

$$9.5V_c = 48.6959 + V_c$$
$$9.5V_c - V_c = 48.6959$$
$$8.5V_c = 48.6959$$
$$V_c = 5.7289$$

We've mentioned volumetric measurement by displacement several times. Some readers may not be familiar with this technique so we'll take a moment at this point to outline the procedure involved.

If we're faced with the need for finding the volume of a regular geometric figure such as all or part of a cube, a sphere, a cone, etc., we have only to apply the appropriate equation which is available in most textbooks or reference manuals dealing with geometry, physics, engineering, etc. As soon as a surface irregularity is introduced into the basic geometric forms, however, the standard equations are no longer adequate. The clearance volume in an engine cylinder involves a surface configuration which certainly modifies the basic segment of a sphere which forms the upper portion of the combustion chamber and the flat top of the piston which forms the lower portion of the chamber. For example, the top of the piston at the high point in its compression stroke may project above the deck or upper edge of the block. In addition, the top may have valve clearance recesses and a more than usual convex surface. Similarly, the head may have embossments or other irregular surfaces which would make a volumetric calculation almost impossible.

To cope with this problem, a measurement of the volume can be made by running the piston up to its peak position (T.D.C.) and slowly pouring light weight oil from a calibrated beaker through the spark plug hole for that cylinder until the oil level rises to the bottom thread in the spark plug hole tap. The difference in the amount of oil in the beaker before and after filling the combustion chamber is the volume of that chamber. Beaker calibration in cubic centimeters would be preferable. It allows simple conversion to cubic inches by multiplying the number of C.C.'s by 0.06092. For example, if we poured 93.9 C.C. of oil into a cylinder of a 390 C.I.D. engine with the piston at T.D.C. the calculated clearance volume would be 93.9 x 0.06092 which equals 5.720388 cubic inches. Again, the clearance volume plus the swept volume of a cylinder equals the total volume needed to calculate compression ratio.

To zero-in on what we've covered so far in our introductory remarks, we've laid the principle groundwork for a detailed consideration of the power potential in a given engine. Among the factors we've described are the output characteristics of all engines which are expressed as horsepower and torque. We've also described two important component power factors . . . piston displacement and compression ratio.

Now, before we leave theory completely, let's highlight some of the other factors which apply to engine output . . .

- Volumetric Efficiency
- Mechanical Efficiency
- Brake Mean Effective Pressure
- Friction Mean Effective Pressure

The following paragraphs comment on each of the above factors in the order listed.

VOLUMETRIC EFFICIENCY

The relationship between the available piston displacement volume in a cylinder and the amount of air it actually takes in per cycle at the prevailing temperature and atmospheric pressure is referred to as the volumetric efficiency of that cylinder. There are several reasons why efficiency, in this respect, never reaches 100%.

- The air cleaner assembly and intake manifolding have a restricting effect.
- The intake valve, by design, further restricts flow.
- Heat absorption by the mass of the intake mixture occurs when it is introduced into the manifold and cylinder. This heat, which is picked up from the elevated temperature of the components through which it passes, and the residual hot gases in the combustion chamber, causes expansion of the mass.
- The effects of valve timing also curb total efficiency. At high engine r.p.m., valve overlap creates an instant when both the intake and exhaust valves are partially open. Thus, a small quantity of the intake mixture is being diverted through the exhaust system.

The extent to which these combined factors work to reduce volumetric efficiency is dependent upon piston speed. The following curve (Figure 10) shows how the efficiency percentage varies with piston speed within a range which would cover most vehicle operating conditions.

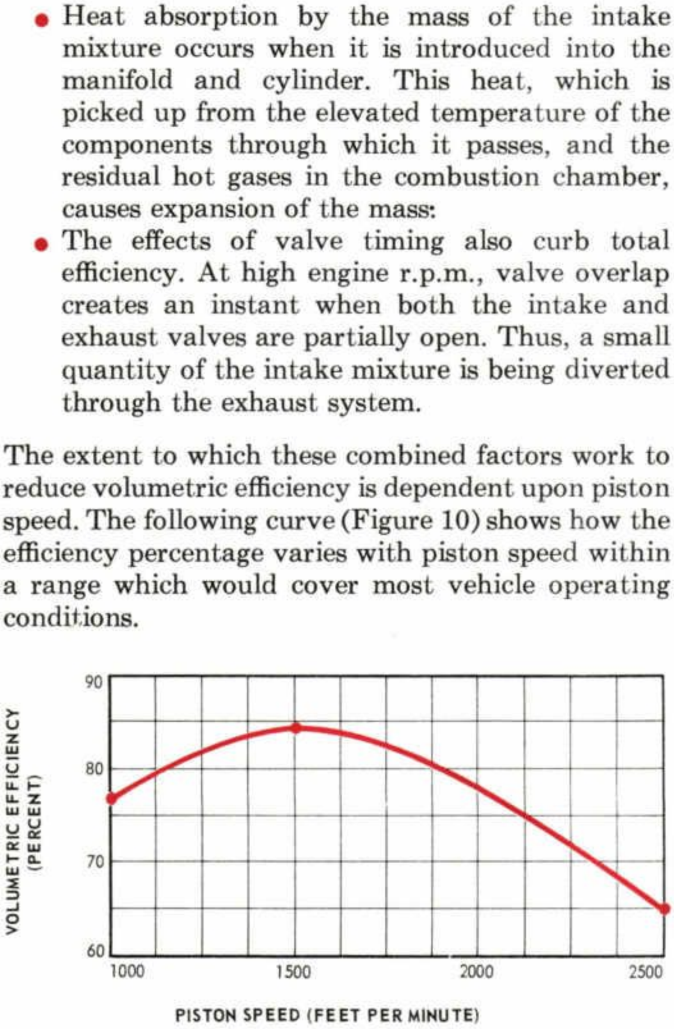


FIGURE 10. VOLUMETRIC EFFICIENCY CURVE

The values in this case are shown more to illustrate the curve pattern . . . which is typical . . . rather than relate the figures on the axes of the graph.

There is a proportionate relationship between the horsepower produced by an engine and its volumetric efficiency. An ideal condition is reached when an increase of 1% in speed is accompanied by a matching

1% loss in efficiency. This usually occurs when calculated efficiency falls between 65% and 70%.

MECHANICAL EFFICIENCY

The mechanical efficiency of an engine is tied to the relationship which exists between its brake mean effective pressure (B.M.E.P.) . . . an available power potential value . . . and friction mean effective pressure (F.M.E.P.) . . . a power loss potential. The applicable equation for calculating mechanical efficiency is . . .

$$\%\text{ Mechanical Efficiency} = \left(\frac{\text{BMEP}}{\text{BMEP} + \text{FMEP}}\right) 100$$

The following graph (Figure 11) illustrates typical curves for the factors involved in calculating mechanical efficiency . . .

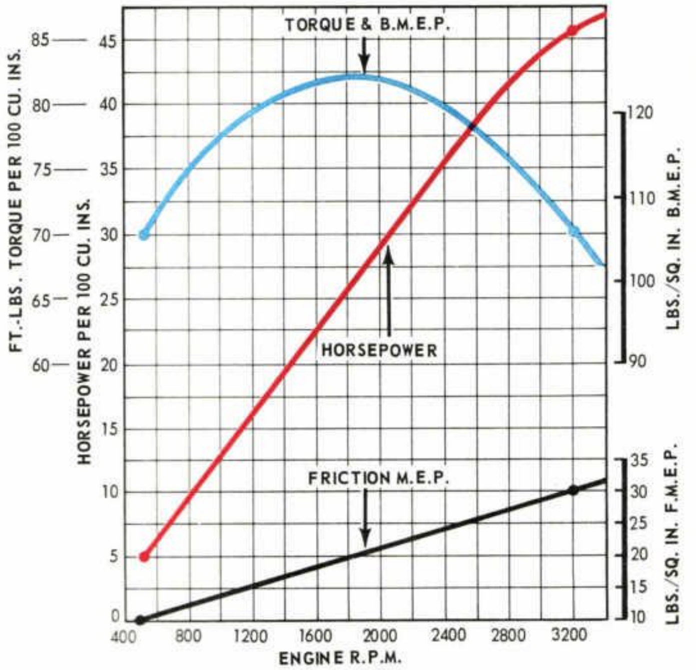


FIGURE 11. MECHANICAL EFFICIENCY FACTORS

For purposes of illustration, we'll arbitrarily select friction and brake mean effective pressure points from the curves we've shown and apply them to the formula.

$$\%\text{ Mechanical Efficiency} = \left(\frac{\text{BMEP}}{\text{BMEP} + \text{FMEP}}\right)100$$

$$= \left(\frac{107}{107 + 30}\right)100$$

$$= (.78)\ (100)$$

$$= 78\%$$

With this equation, we conclude our coverage of the mathematical tools which will enable us to interpret an engine manufacturer's published performance specifications as they apply to power. Awareness of the factors will also be good to know when considering the affect they have if a power-boosting engine modification is planned. If this is the case, we would also suggest that specific fuel consumption and engine weight characteristics be looked into. These factors will be covered in detail when carburetion and chassis design are considered.

THE "HIGH-PERFORMANCE" APPROACH TO POWER THROUGH ENGINE MODIFICATIONS

The do-it-yourself high-performance buff who wants to squeeze all the power he can get out of the basic engine with which he is working is the backbone of the high-performance market. Many of the enthusiasts in this category of vehicle owner are skilled automotive technicians who are aware of the success potential and pitfalls that modification might involve. The less experienced are more apt to be disappointed in poor results and, in some cases, may face costly engine damage if they approach their objective with a "trial and error" mode of operation.

With this in mind, we strongly urge . . . that *approved parts* be used . . . that all *specifications* be carefully observed . . . and . . . that the extent of modification undertaken to attain a given performance objective be governed by the knowledge, tools, and equipment needed to effect the change competently. We also suggest that engine modification may affect the performance of other chassis components. Total performance, in other words, is not measured from the fan to the flywheel; it is, rather, a fan to driving surface relationship. For best results, there must be a carefully planned . . . engineered, if you please . . . power source which efficiently transmits its output through the torque multiplication capabilities of the proper transmission, driveline, axles, wheels, and tires. The fundamentals in this publication generalize in this respect. Other publications in our high-performance series deal with specific engines and other chassis components.

Now, let's kick-off our high-performance engine materials with coverage of the induction system.

Fuel Systems and Induction

Induction, by definition, is the inspiration of the air-fuel mixture from the carburetor through the intake manifolds and into the combustion chamber. Actually, the air intake provisions on an internal combustion engine begin with the gathering and inducing of air through the air cleaner to the carburetor. As a result, we have ambient air induction on the intake side of the carburetor, a mixing-valve-type operation in the carburetor, and subsequent induction of an air-fuel mixture into the combustion chamber.

The usual high-performance arrangement is to induce temperature-controlled, ram air or supercharged air into the carburetor which, during the engine's intake stroke is under partial vacuum conditions. The objective is to use all or as much of this induced air as possible. Under ideal conditions, the ratio for complete combustion is 1 part of fuel to 14.8 parts of air. Economically uncontrollable factors, however, prevent the attainment of this ideal; so we must enrich the fuel at the price of maximum power and settle for a ratio of approximately 1 part of fuel to 13 parts of air. One of the bigger roadblocks to full use of the inherent power in an air-fuel mixture is the intake manifolding . . . another is the equality of distribution of the air-fuel mixture. Here, we're involved with cylinder location in relation to the carburetor, plus the resistance to air-fuel flow existing in the manifolds.

High-performance designers have made some significant progress toward minimizing the undesirable aspects of induction while keeping pace with modified carburetor design. The paragraphs which follow pertain to the results of their efforts.

AMBIENT AIR INDUCTION

Air Cleaners and Scoops

We mentioned the advisability of gathering and channeling outside air as a factor in efficient induction. The functional hood scoop is perhaps the more common device aimed at performing this function. There are several varieties of scoops on the market. Some are assembled to the hood, others attach to the carburetor air cleaner cover and project through a cutout in the hood. In either case, the operating principles are the same. They pick up ram air (when the car is in forward motion) and direct it to the air cleaner inlet door.

Figure 12, View A, shows a typical air cleaner for a multiple carburetor set-up. View B in the same illustration highlights an air cleaner with door which is typical of the type used with the functional scoop shown in View C.

Most induction components of this type are equipped with a thermostat which, on a 428 Cobra Jet for example, monitors engine compartment temperature in the area of the air cleaner duct and valve assembly.

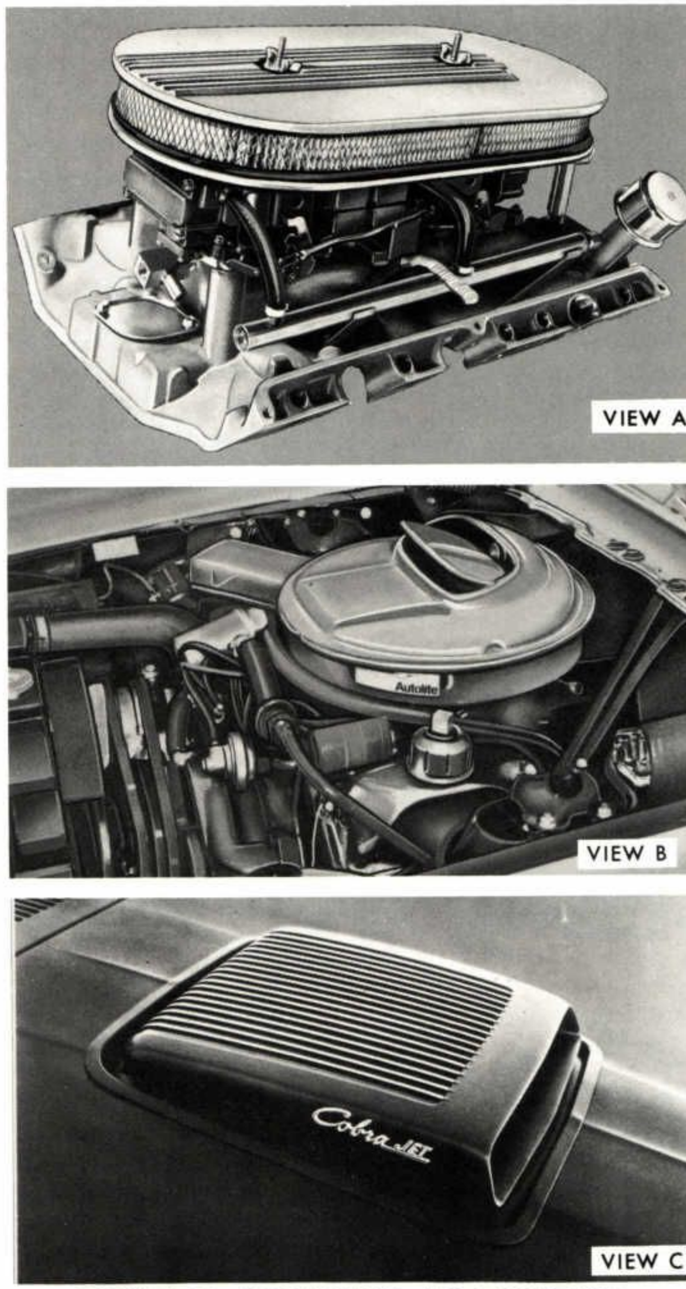


FIGURE 12. FUNCTIONAL AIR SCOOP AND AIR CLEANERS

In this example, a temperature of 130° F. determines whether the door or valve in the duct will be open for cooling or closed for heating. There is also a vacuum motor in this system which flips open the inlet air door in the base of the scoop assembly whenever engine vacuum falls below 5 inches.

What's the end result? . . . a better chance of supplying cool air (for its power advantage) under ram air pressure . . . particularly, when the occasion is right to put your foot in the carburetor.

There are mixed feelings about using an air cleaner filter element when the vehicle is being operated under track conditions. Engine manufacturers recommend that the element be in place under *all* operating conditions and a thoroughly clean element is important if power-loss is to be minimized.

Supercharging

We've established that proper engine breathing is a critical factor in obtaining the best possible engine performance. The ram air system of feeding air to the induction system is perhaps the most often used method for street and strip high-performance vehicles. We can't, however, overlook the increased power potential available with a supercharger.

A supercharger is little more than a blower or air pump which force-feeds the air-fuel mixture into the combustion chamber. Figure 13 is a typical example of the additional power which might be expected when a supercharger is used.

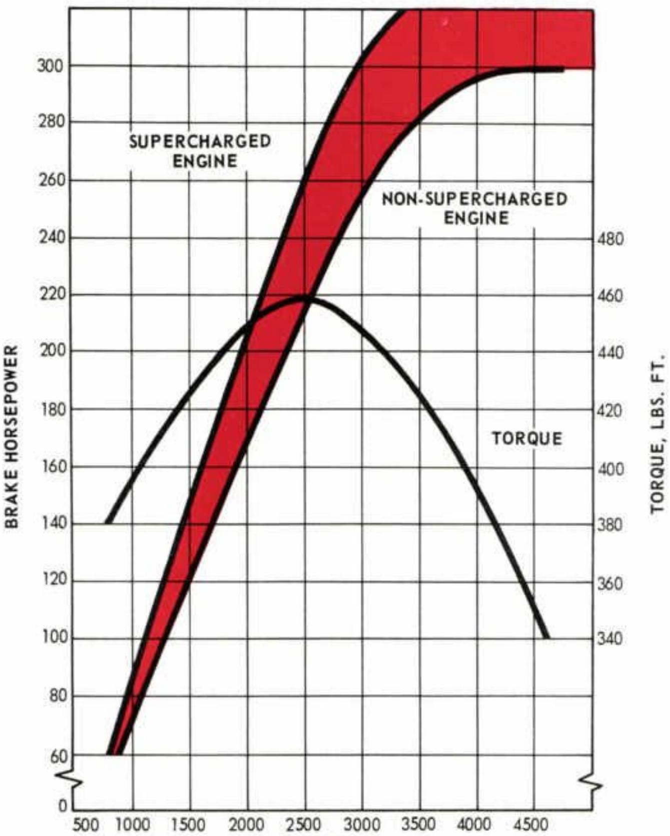


FIGURE 13. POWER AVAILABLE FROM A SUPERCHARGED VS. NON-SUPERCHARGED ENGINE

There are plus and minus factors to using a supercharger. In its favor is the comparable net power increase experienced under given atmospheric conditions. It is known that atmospheric density decreases as altitude increases; thus, the available air supply in a naturally aspirated engine will go down as the altitude at which it is expected to perform increases. Supercharging, depending upon the pressure developed, could compensate for some or all of the loss in breathing capacity at high altitude.

Supercharging also increases compression. Obviously, this would be accompanied with an increased power potential; but increased compression increases the potential for detonation if the octane rating of the fuel used is not high enough. This then, is a factor which should be considered when deciding whether or not to supercharge an engine. Another factor is the net gain that will be derived at the high r.p.m. end of the engine's speed range. It may take as much as 50 horsepower per pound of air per second to sustain supercharger pressures. Thus, we encounter a possible negative factor. Another factor which may influence one in his choice of a supercharged engine would be the fact that it burns more fuel than one which is not supercharged. For this increased fuel consumption, there is not a proportional increase in power.

When a supercharger is used, it is either installed between the carburetor and manifold or on the air inlet side of the carburetor. Of the two locations, the former is the more frequently used because it permits the use of conventional carburetion. (With the supercharger on the air inlet side of the carburetor, tubing must be added to equalize pressures in the carburetor float chambers and the outlet side of the supercharger.) (See Figure 14.)

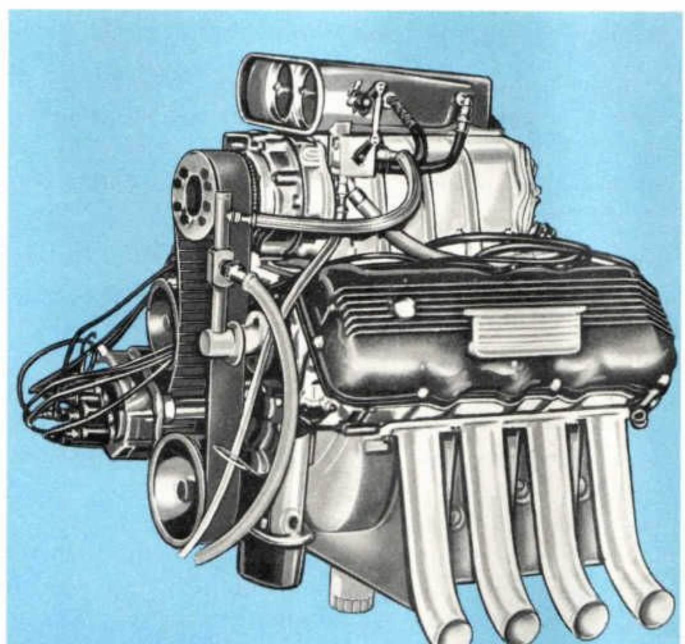


FIGURE 14. TYPICAL SUPERCHARGER INSTALLATION

FUEL PUMP

The fuel pump now being used on most high-performance gasoline engines is basically the same in design as that used on all production engines. It does, however, have a larger pumping capacity and requires a ⅜″ diameter fuel line between the pump and the carburetor. Figure 15 illustrates a pump which is typical of the type used interchangeably on the larger Ford Motor Company engines (390, 406, 427, and 428 C.I.D.). It is a recommended installation for those high-performance packages which include dual quad setups.

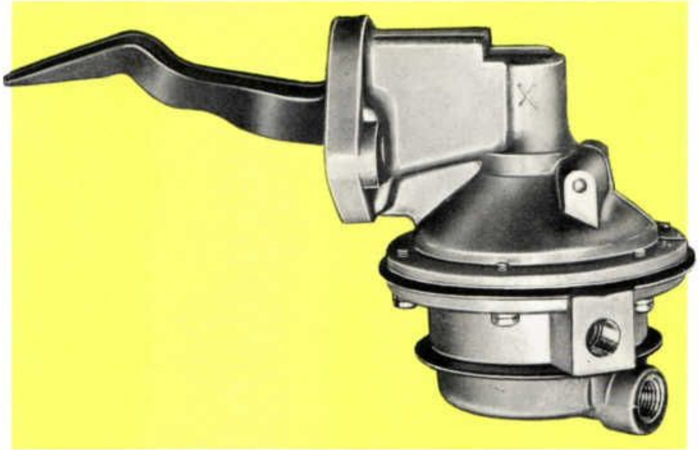


FIGURE 15. TYPICAL HIGH CAPACITY FUEL PUMP

There are several types of automotive fuel pumps which engine manufacturers install on their products. We'll now cover the highlights of each. First, there are two categories of pumps . . . the mechanical types . . . and the electrical types. Our description will follow this sequence.

Mechanical Fuel Pumps

The mechanical fuel pump is mounted on the engine block in a location where its rocker arm will make contact with an eccentric which is assembled to the forward end of the camshaft. (See Figure 16)

As the camshaft rotates the eccentric against the spring loaded rocker arm, it moves the arm up and down. This motion is transmitted through the linkage shown in the illustration. When the flexible diaphragm in the pump is pulled down, fuel is drawn into the chamber. (At this point in the pumping cycle, a vacuum is created in the pump's fuel chamber. The fuel in the tank and line to the pump, being under pressure, rushes in to fill the vacuum.) Then, as the eccentric rotates off its high point, the diaphragm is forced upward displacing the fuel in the chamber by forcing it past the outlet check valve enroute to the carburetor.

The engine you are working with may have an older design of mechanical fuel pump which incorporates a vacuum booster pump that is linked with the windshield wiper vacuum motor on the intake side and the intake manifold on the outlet side. The pump rocker arm in this type of dual-purpose assembly operates both vacuum diaphragms. (See Figure 17)

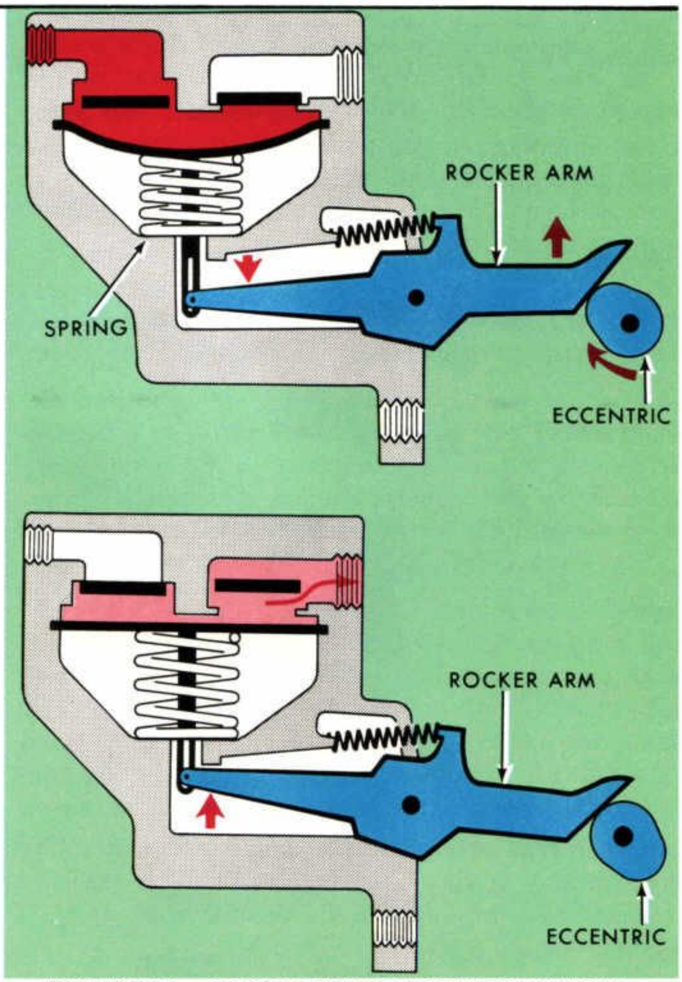


FIGURE 16. CROSS SECTION OF MECHANICAL FUEL PUMP

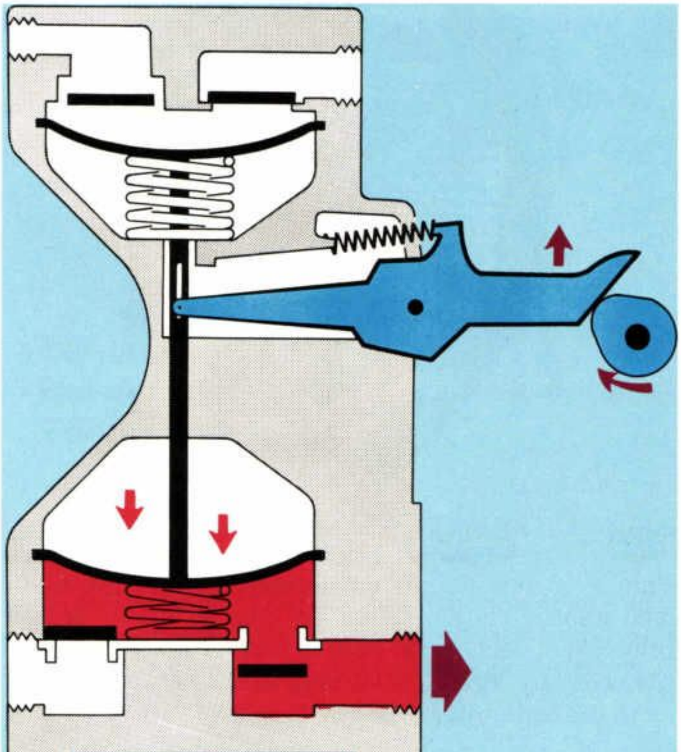


FIGURE 17. CROSS SECTION OF COMBINATION FUEL PUMP AND VACUUM BOOSTER

Electric Fuel Pump

Figure 18 shows a reciprocating electric fuel pump. Here, an energized coil pulls down the pumping element magnetically and, upon automatic de-energization of the coil, a spring pushes the pumping element upward forcing fuel on to the carburetor.

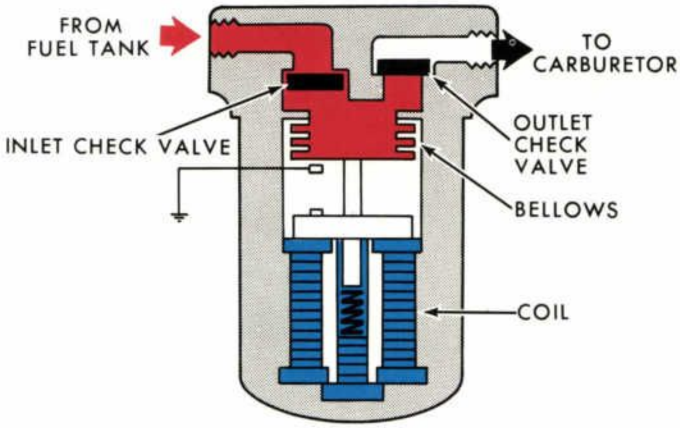


FIGURE 18. CROSS SECTION OF AN ELECTRIC RECIPROCATING FUEL PUMP

Another type of electric fuel pump with automotive applications is shown in Figure 19. This design is referred to as an impeller or pusher-type pump.

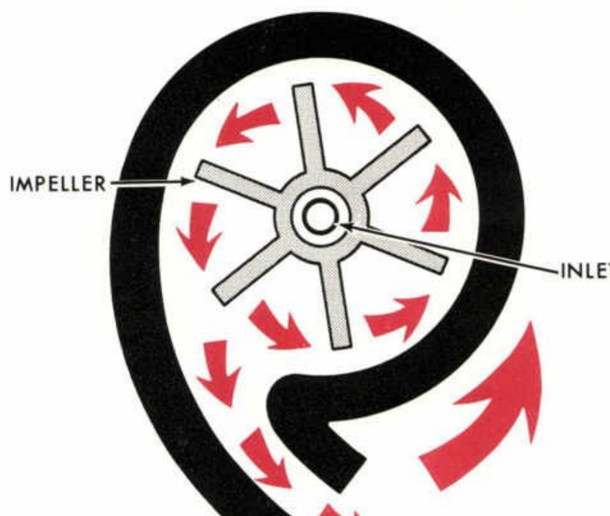


FIGURE 19. IMPELLER-TYPE ELECTRIC FUEL PUMP

Pumps of this design are located in the fuel tank. The impeller is driven by an electric motor as the principle of centrifugal force is used to move fuel from the centrally located inlet port to the outlet port and on to the carburetor.

SOME TROUBLE SPOTS

Now that we've identified the basic fuel pump designs, we'll mention two items which are important to proper fuel system operation. One is avoiding percolation; and the other is delivering clean fuel to the carburetor.

Percolation

Heat build-up in the engine compartment is a primary cause of a condition known as fuel percolation. By definition, percolation is the formation of liquid bubbles in the fuel circuit at a point beyond the fuel pump outlet. These bubbles are caused by the vaporization which accompanies excessive heat.

To prevent percolation, a recirculating system has been added to some of the mechanical-type fuel pumps. Pump porting for this additional circuit is shown in Figure 20. (When all of the fuel being delivered to the carburetor from the pump is in vapor form, the trouble which results is referred to as vapor lock.)

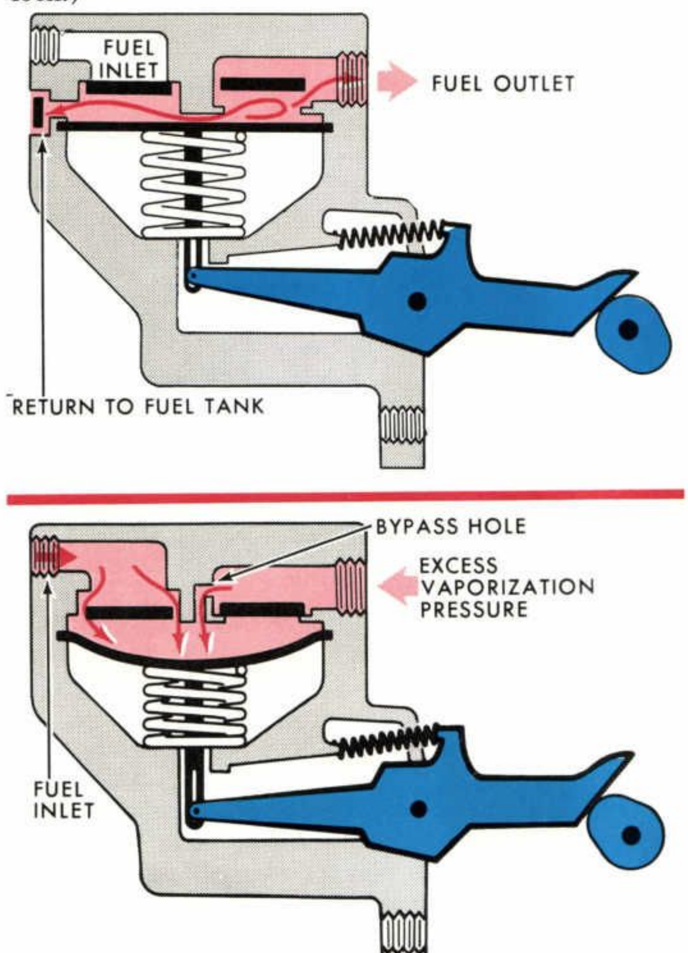


FIGURE 20. FUEL PUMP RECIRCULATING PORT

The electric pump, because it can be located away from undesirable heat levels, should not become involved with percolation or vapor lock.

Fuel Filtration

The majority of engines built in recent years have been equipped with an in-line fuel filter. Figure 21 illustrates two typical designs. View A shows a "throwaway" type . . . View B, the type with a replaceable element, is used most often on high-performance engines. The capacity of the latter design is such that it will best accommodate the increased output of the high capacity fuel pump used on a high-performance engine.

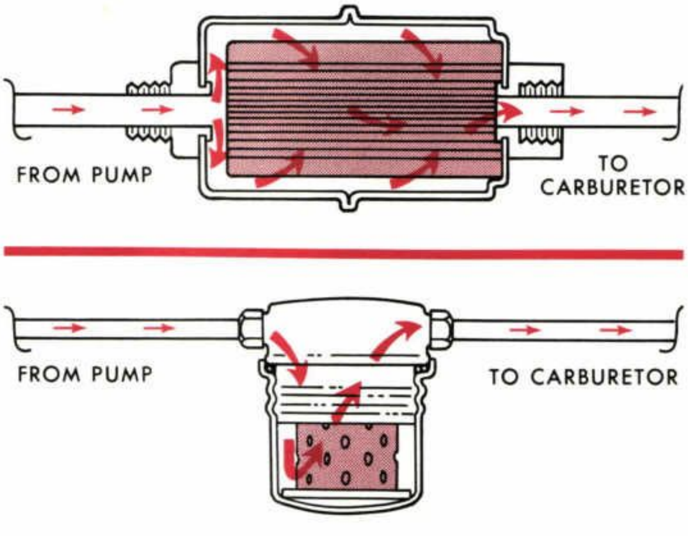


FIGURE 21. FUEL FILTERS

CARBURETOR

Proper carburetion is extremely important to the effective operation of *any* engine; to a *high-performance* installation, it is *critical.*

With all carburetors, maximum flexibility is needed to accommodate a wide range of engine speeds. In many high-performance set-ups, emphasis will be placed on the results achieved at the high end of this range. At high speeds, large venturi areas are needed to accommodate increased air-fuel mixture demands. In the low speed range, however, the carburetor must be designed to handle high air velocity so that it will sufficiently atomize the fuel being fed into the venturi.

With these clear-cut design objectives, we must face our first roadblock. It's impractical to build a carburetor with a single venturi which would accommodate the full range of high-performance demands. The obvious solution to this problem is the use of a carburetor or carburetors with more than one venturi which, cumulatively, will meet high speed requirements; and, when the secondary throttle plates are closed, will produce the most efficient and smoothest operation.

Nearly all high-performance engines are equipped with at least a 4-barrel (venturi) carburetor. Those which are outfitted for racing usually have any one of several multiple types of carburetor installation. In the information which follows we'll describe these multiple carburetor installations; but, before we do we'll insert some basic carburetor data for those who may need some background or review.

The Basic Fuel Circuits

All carburetors operate on the principle of pressure differentials. The pressure of induced air is applied to the vacuum created by the engine when the pistons are moving downward during their intake strokes.

Obviously, air under pressure will rush toward any vacuum it contacts. In a carburetor, the venturi is the design point where pressure and vacuum meet. This venturi has another function. It suddenly restricts the mass of incoming air causing a marked increase in its velocity as it flows through the smaller opening.

The fuel discharge nozzle in the carburetor is located in a position where the fast moving air will draw fuel into the stream to provide an air fuel mixture. It is this mixture which engine vacuum draws through the intake manifold and past the open intake valve and into the combustion chamber. Figure 22, although overly simplified, illustrates the flow pattern we've been describing.

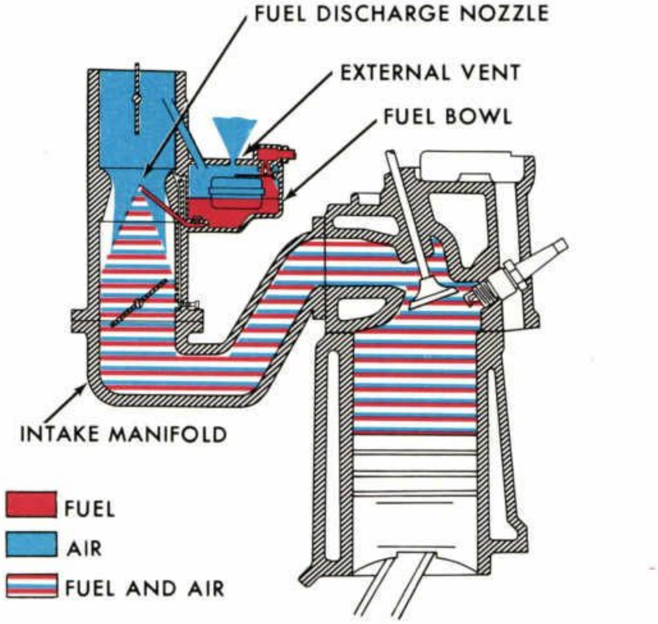


FIGURE 22. BASIC AIR-FUEL FLOW PATTERN INTO COMBUSTION CHAMBER

The carbuetor must respond to a variety of engine operating conditions. Thus, to accommodate these variations it is equipped with several component circuits . . .

A Float Circuit

An Idle or Low Speed Circuit

A Main Fuel or High Speed Circuit

- A Power Circuit
- An Accelerating Pump Circuit . . . and . . .
- A Choke Circuit

Now, let's very briefly consider the functions of each of these components with the aid of simple schematics.

FLOAT CIRCUIT (Refer to Figure 23)

Functionally, the float circuit is designed to maintain a predetermined fuel level in the fuel bowl in response to the buoyant action of the float assembly. Fuel pump pressure delivers the fuel to the inlet needle and seat. The float tends to hold the needle in the partly closed position to best meter or balance the input to the bowl with the amount of fuel being drawn through the jet and discharge port into the venturi.

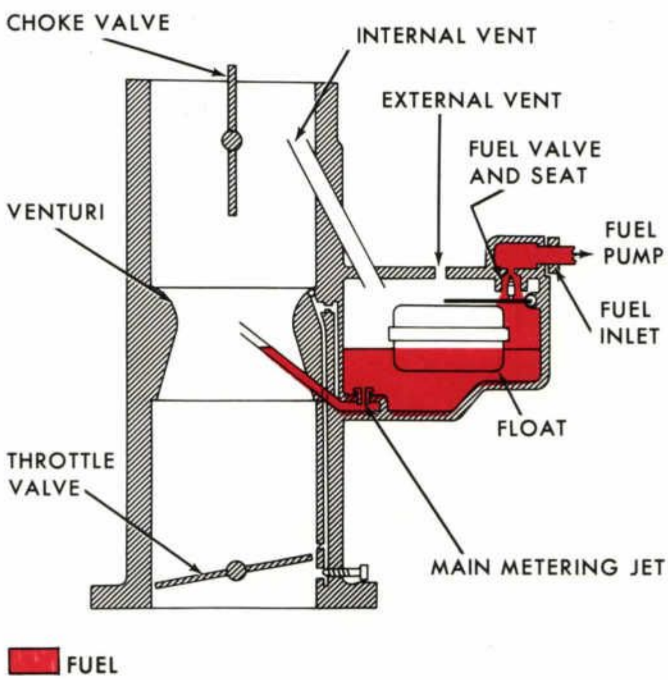


FIGURE 23. THE CARBURETOR FLOAT CIRCUIT

The controlled level of the fuel in the bowl is very important...

- If this level is low, a lean air-fuel mixture will result.
- If it is high, an overly rich air-fuel mixture is likely to occur.

Remember, an incorrect fuel level setting will disrupt the entire calibration of the carburetor.

With a 4-barrel carburetor, a separate fuel bowl is provided for the primary and secondary stages. The two bowls are linked with a drilled passage and usually balanced with a pressure equalizing chamber in the main body.

The fuel bowls in all carburetors are vented to the atmosphere and, in most cases, are also vented internally to ensure positive evacuation of fuel vapors.

IDLE OR LOW SPEED CIRCUIT (Refer to Figure 24)

At low engine speeds, the main fuel discharge nozzle can't supply fuel because the air flow through the venturi is too small. To compensate for this condition, an idle fuel discharge port is provided just below the throttle plate. Here, engine vacuum draws the required fuel from the bowl.

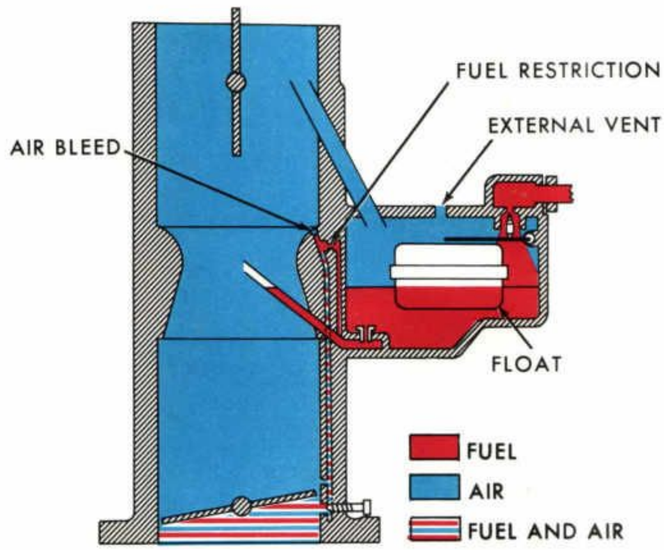


FIGURE 24. THE IDLE CIRCUIT

The main metering jet feeds fuel to the idle circuit for mixture with air at the air bleed. The quantity of the mixture is controlled by the idle adjusting needle.

During "off-idle" operation the idle circuit performs a transitional function. One or more holes located above the idle discharge port assist as air bleeds when the throttle plate is at or near its curb idle position.

MAIN FUEL CIRCUIT (Refer to Figure 25)

The main fuel metering circuit is designed to supply the fuel required for engine operation during the cruise or part throttle range. This system starts to function when the air flow through the carburetor venturi creates a sufficient vacuum to begin fuel flowing in the main system. The air flow through a carburetor is proportional to engine speed and load. The vacuum at the

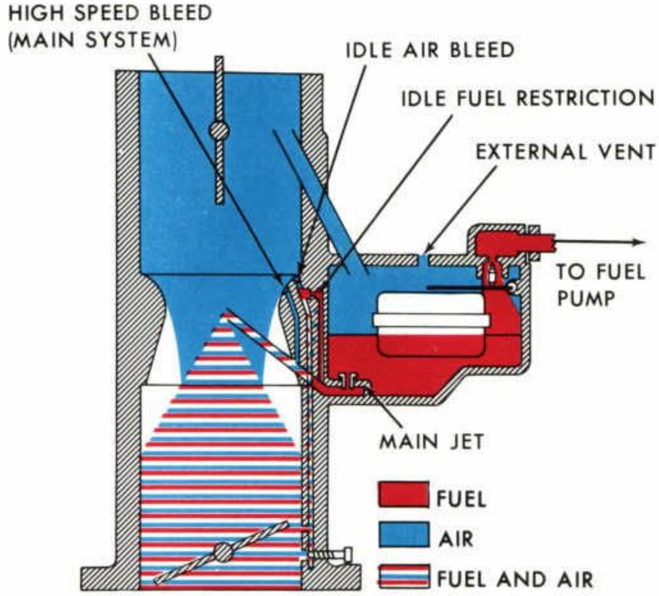


FIGURE 25. THE MAIN FUEL CIRCUIT

discharge nozzle will increase as the air flow increases. Therefore, the faster the engine operates, the more fuel will flow through the main metering system.

The main metering system supplies a leaner fuel-air mixture than any of the other fuel systems of the carburetor. This is because the main system functions when the engine is operating under a part throttle condition and the engine is not under a heavy load or power requirement. An engine can operate efficiently on a leaner fuel mixture under these circumstances.

As the throttle plate moves toward the open position, a sufficient amount of air is drawn through the carburetor to create a vacuum at the venturi. The main discharge nozzle is located in this area of potential vacuum. A pressure difference is created between the fuel bowl and the tip of the main discharge nozzle. This pressure difference will force fuel from the fuel bowl into the main metering system.

Fuel enters the main metering system through the main metering jet which is located in the bottom of the fuel bowl. Fuel lies in the main well. It is forced up the main well to be mixed with air drawn through a high speed air bleed. The high speed bleed hole is located in the air horn of the carburetor. The air from this bleed will mix with the fuel in the main well passage and prepare the mixture for efficient distribution. The mixture is further broken up as it mixes with the airstream flowing past the main discharge nozzle.

POWER CIRCUIT (Refer to Figure 26)

When an engine is required to deliver more power to meet an increased road load demand or wide-open throttle operation, the carburetor must deliver a richer fuel air mixture than supplied during the operation of the main metering system.

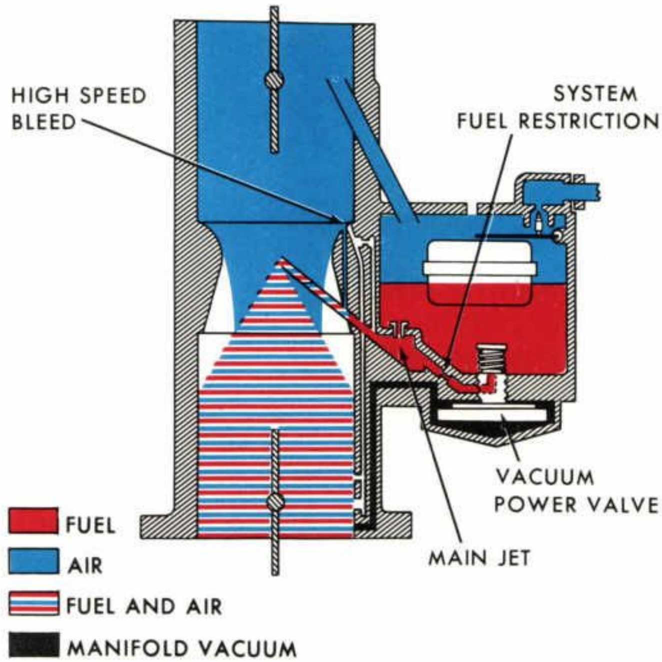


FIGURE 26. THE POWER CIRCUIT

A carburetor must be able to supply this richer fuel-air mixture at the precise moment that the engine demands it. Some method must be used to signal the carburetor of the changing engine demand.

If you were to attach a vacuum gauge to the engine intake manifold, you would notice that manifold vacuum is high when the power demand placed upon an engine is low. When the intake manifold vacuum is low, the engine is operating under a high power demand.

The power system of a carburetor utilizes those vacuum signals within the intake manifold. The carburetor is mounted on the engine intake manifold and the vacuum below the carburetor throttle valve is identical to intake manifold vacuum. The carburetor power valve will open when the manifold vacuum drops below a predetermined value. The carburetor fuel-air mixture is then automatically enriched to meet the increased engine power requirements.

Located below the carburetor throttle valve is a manifold vacuum pick-up port. This port channels the engine manifold vacuum to one side of a diaphragm-operated power valve. This valve is screwed into the bottom of the carburetor fuel bowl.

The power valve is composed of a diaphragm attached to a valve stem. The valve stem has a calibrated coil spring attached to it. The spring tends to push the valve stem off a seat, so that fuel can flow through the valve from the fuel bowl.

When engine manifold vacuum is above a specified value, this vacuum will be great enough to allow the pressure within the fuel bowl to force the diaphragm and valve stem closed against the seat. This stops any fuel flow through the valve. When manifold vacuum is below a specified value, then the power valve spring will force the stem off the seat and allow fuel to flow through the valve.

The power system has a drilled passage to the main fuel system. The power system will allow a calibrated amount of fuel to enter the main metering system. Fuel flow is controlled by a restriction located in the passage. This restriction has the same function as a main metering jet and will meter the extra fuel allowed to enter the main metering system.

The power system is a means of adding additional fuel to the main metering system. A main jet controls the maximum fuel flow for the main metering system and the power system provides a supplemental fuel passage to allow more fuel to enter the main metering system when a power load is placed upon the engine.

For every engine design, the engineer determines the exact operating range for the power system of the carburetor. In performing any carburetor repairs, the prime function is to restore the carburetor to its original specifications. Do not fall into a common fault of changing specifications. Only trouble can result from this practice. This advice applies to all systems of the carburetor. Follow the specifications released by the manufacturer when overhauling a carburetor. If the power system is not functioning properly, it can cause major problems.

ACCELERATOR PUMP CIRCUIT
(Refer to Figure 27)

Air flow through the carburetor responds almost immediately to any change in throttle opening. When such a change takes place, however, fuel in the metering passages will momentarily lag behind the altered flow of air.

To eliminate this condition, an accelerator pump circuit is provided. It is operated by the throttle valve linkage and is calibrated to supply a momentarily enriched fuel mixture.

Fuel is supplied to the accelator pump chamber from the carburetor bowl. It enters this chamber through a small hole in the bottom of the fuel bowl. Fuel passes through this passage and past a pump inlet check ball. The inlet check ball is used as a check valve to prevent fuel from within the pump chamber being forced back into the fuel bowl when the accelerating pump is operated.

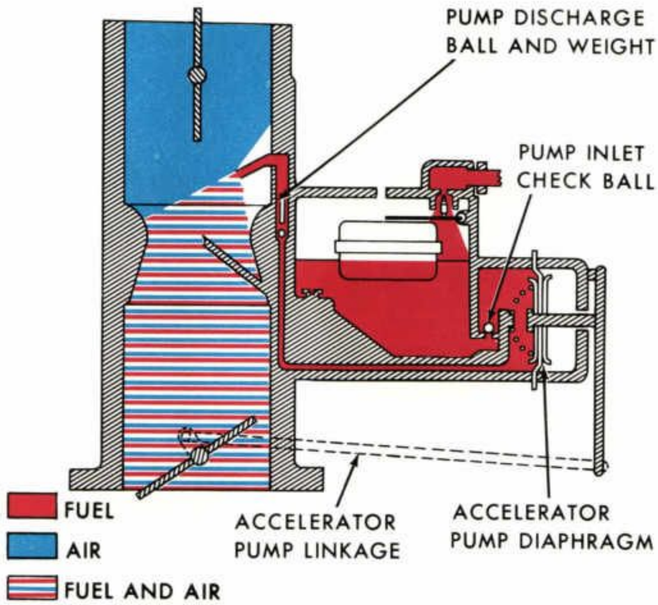


FIGURE 27. THE ACCELERATOR PUMP CIRCUIT

A pump diaphragm and stem (some models use a pump cup and stem) is actuated by a rod attached to the carburetor throttle lever. When the carburetor throttle is opened to allow more air to enter the carburetor, the rod will force the pump diaphragm against the fuel within the pump chamber. This pressure on the fuel will force the inlet check ball firmly against its seat. Fuel will then be forced through the pump discharge passage. Inside the pump discharge passage is located a discharge check ball and in some instances a weight. The ball and weight are forced off the seat. The fuel then continues up the passage and is discharged through the accelerating pump discharge nozzle. The accelerating pump nozzle is drilled with a small calibrated hole that allows only the required fuel discharge to enter the carburetor air horn. The fuel mixes with air flowing through the carburetor providing the temporary fuel enrichment needed during acceleration.

A pump over-ride spring is incorporated with this system. The over-ride spring has two functions:

1. Provides a fuel discharge with a sufficient time duration to take care of the acceleration range.
2. If pump linkage did not incorporate an over-ride feature, a quick throttle movement would put a strain on the linkage since the fuel in the pump will not compress.

A pump stroke adjustment can be made on the accelerating system to compensate fuel needs of the engine during the extremes of hot or cold temperature. In most climates, the pump adjustment can remain the same all year long.

CHOKE CIRCUIT *(Refer to Figure 28)*

An extra rich mixture must be introduced into the intake manifold when the engine is cold. The choke circuit meets this requirement. It provides the needed fuel enrichment for all of the fuel metering circuits. This is accomplished by means of a choke plate located inside the air horn of the carburetor. The plate can be designed to either close manually or automatically to restrict the amount of air admitted through the carburetor.

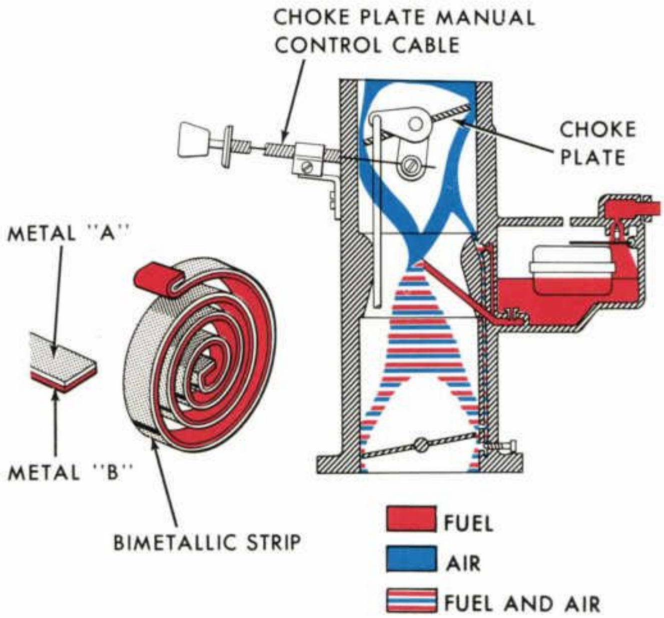


FIGURE 28. THE CHOKE CIRCUIT

The various fuel circuits in the carburetor will continue to function; but, by varying the air allowed past the choke plate, the air-fuel mixture is controlled to the desired richness. As the manifold temperature increases, more of the fuel inside the intake manifold is vaporized and less choke action is required. (Gasoline is manufactured to include a controlled amount of light and heavy fuel fractions. These fuel fractions control the ability of the fuel to vaporize at various temperatures. The lighter fractions of gasoline are more volatile and will remain vaporized at much lower temperatures than will the heavier fractions. In blending winter gasolines, the manufacturer will aid the starting characteristics of a cold engine by including more of the lighter, more volatile fuel fractions. A better fuel vaporization will take place in a cold engine with a winter blended gasoline.)

Engine manifold vacuum which normally exists below the carburetor throttle plate will, during the cranking of the engine with the choke plate closed, extend this vacuum to the bottom of the choke plate. A sufficient vacuum will then exist at the idle system discharge ports and the main system discharge nozzle to cause fuel to be discharged into the intake manifold. Since the air drawn past the closed choke plate will be very small, the fuel-air mixture will be rich. When sufficient fuel vapor reaches the cylinders of the engine to support combustion, the fuel mixture is ignited. As the engine begins to operate, the choke plate must open sufficiently to admit additional air in order to continue engine combustion. With a manually operated choke, the vehicle operator must adjust the choke plate to compensate for the degree of engine coldness. To aid in easier choking adjustment, a poppet valve or spring loaded choke plate is incorporated into the manual choke system.

The automatic choke incorporates a calibrated bi-metal thermostatic coil spring to effect choke plate action. When the engine is cold, this spring exerts considerable pressure on the choke shaft lever to hold the plate in a closed position. During engine warm-up, the spring pressure decreases in proportion to the increase in operating temperature.

Some automatic choke applications use a vacuum operated piston to aid in choke control under light load, low r.p.m. operating conditions. This piston opposes the spring force which acts to keep the choke plate closed.

Another fuel supply control mechanism which is built into the carburetor is the choke unloader. This device is built into the throttle linkage to prevent flooding while the engine is being cranked. It's operated by fully depressing the accelerator pedal to set the throttle plate in a fixed wide open position and the choke plate in a partially open position—a condition which remains until the engine is started or the fixed linkage setting is released by again depressing the accelerator pedal.

So much for our review of the component circuits in a carburetor. Now, we'll look at an exploded view of a typical 4-barrel carburetor which might be used singularly or as a multiple carburetor installation.

The 4-Barrel Carburetor

If necessary, study Figure 29. It will help you to relate part names to their configuration and location in the carburetor assembly.

As a high-performance enthusiast, you should have a pretty sound grasp of the theory involved in carburetion. There are undoubtedly, many design variations which manufacturers use to accomplish the same objectives. If you know what must be provided for efficient carburetion, the mechanical means by which this objective is reached will be much easier to understand.

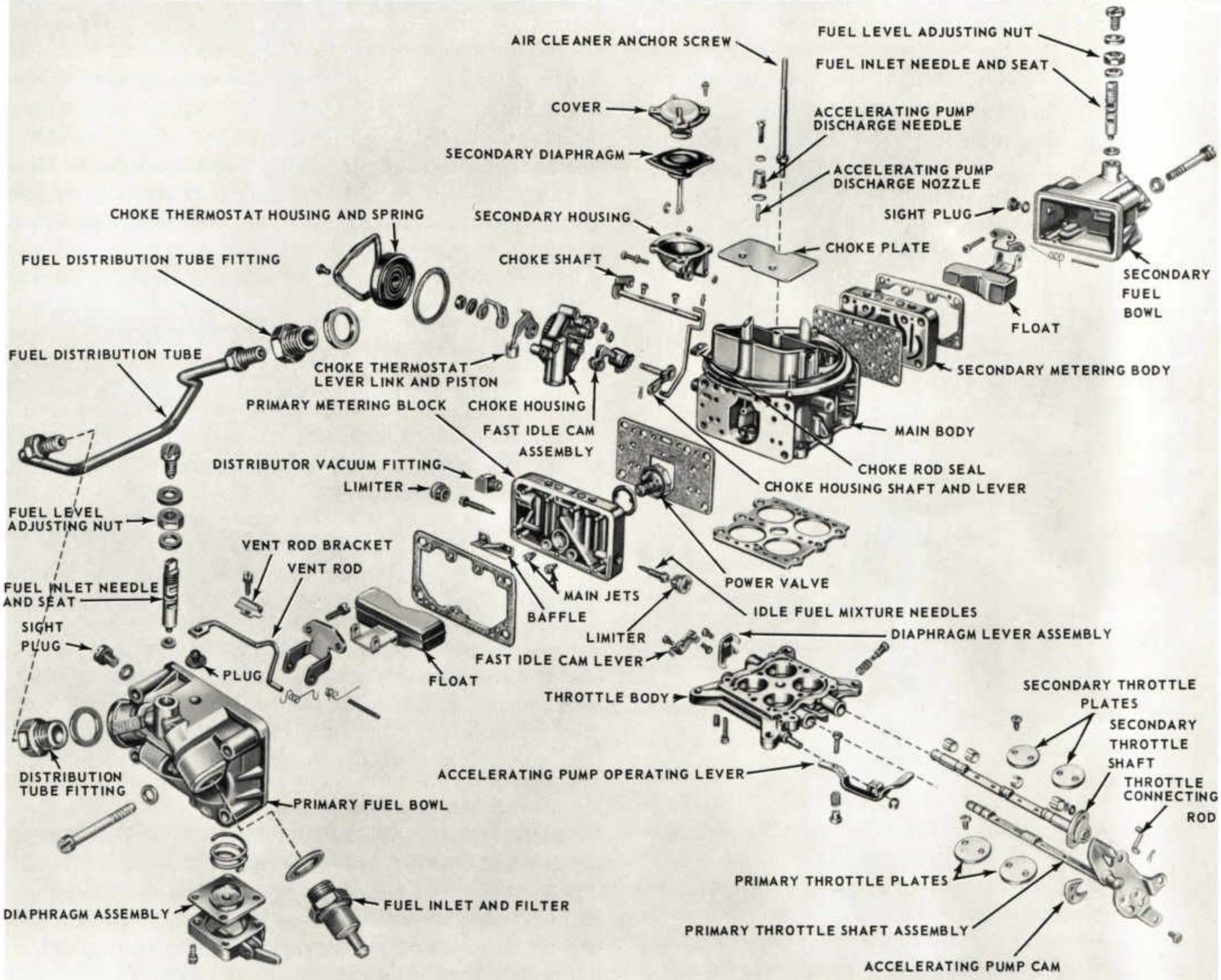


FIGURE 29. TYPICAL 4-V CARBURETOR (HOLLEY DESIGN)

Mutiple barrel carburetors (2-V and 4-V) are used primarily to gain the advantage of improved distribution of the air-fuel mixture. For example, when a 4-barrel unit is used on an 8-cylinder engine, each barrel supplies four cylinders. In effect, a 2-barrel carburetor is two complete carburetors with a common float circuit.

By the same token, a 4-barrel carburetor is made up of two 2-barrel sections. The primary section operates the same as any 2-barrel unit; the secondary section responds at a predetermined point to extra performance demands.

Coordination of throttle plate action is worth noting when considering a high-performance application. Most carbuetors of the type shown in Figure 29 operate off vacuum from the primary venturis. With this arrangement, the secondaries will open when air velocity through the primaries is enough to transfer the vacuum thus created through transfer channels between the two carburetor segments. This vacuum is transmitted to a diaphragm chamber where, depending upon amount, it overcomes spring tension on the diaphragm which controls secondary throttle plate action. (Figure 30 illustrates how vacuum and mechanical linkage work together to effect secondary throttle plate movement.)

We emphasize that air supply to the carburetor is an important factor when aiming toward maximum power. The volume involved is usually expressed in cubic feet per minute (c.f.m.). Let's consider an example...

The regular production 390 C.I.D. engine will have a 4-V carburetor rated at 540 c.f.m. If we were to substitute a 4-V carburetor with a 600 c.f.m. rating the net power gain would be from 5 to 7 horsepower. (Without intake manifold changes, a further increase in c.f.m. capabilities would be an impractical step toward increasing power. This same engine with a larger manifold and a single carburetor with a higher c.f.m. rating might perform with flat spots between the low, intermediate, and high speed ranges. For this reason, a better course to follow when up-rating one of the larger engines would be to use multiple carburetion.)

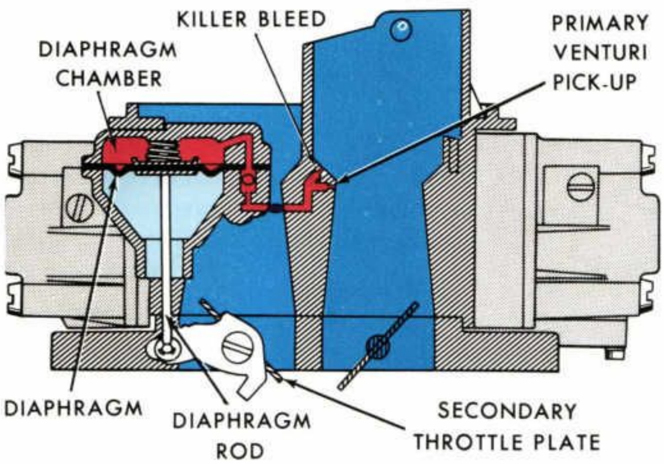


FIGURE 30. SECONDARY THROTTLE PLATE ACTION (VACUUM-CONTROLLED)

Multiple Carburetor Installations

The Ford Motor Company offers several types of multiple carburetor packages. They are illustrated in Figure 31.

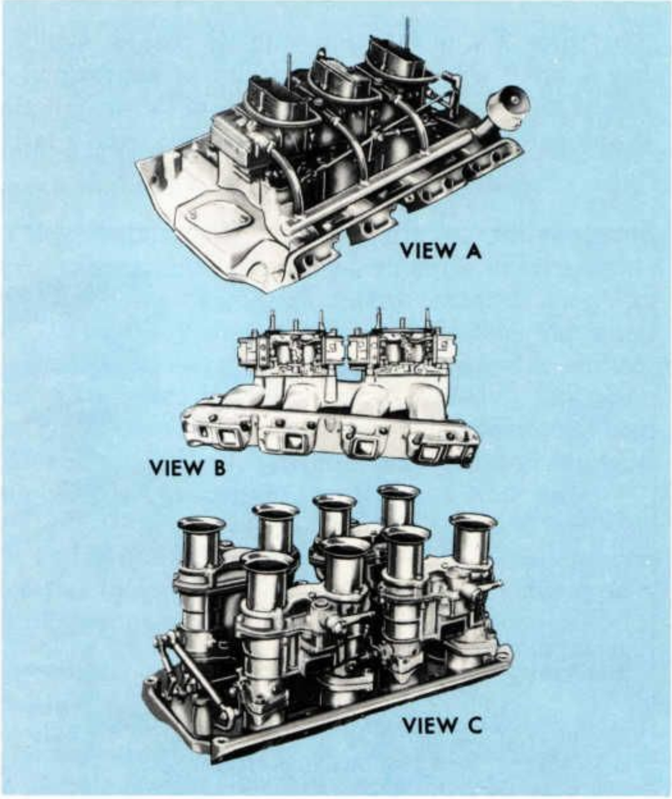


FIGURE 31. TYPICAL HIGH-PERFORMANCE MULTIPLE CARBURETORS

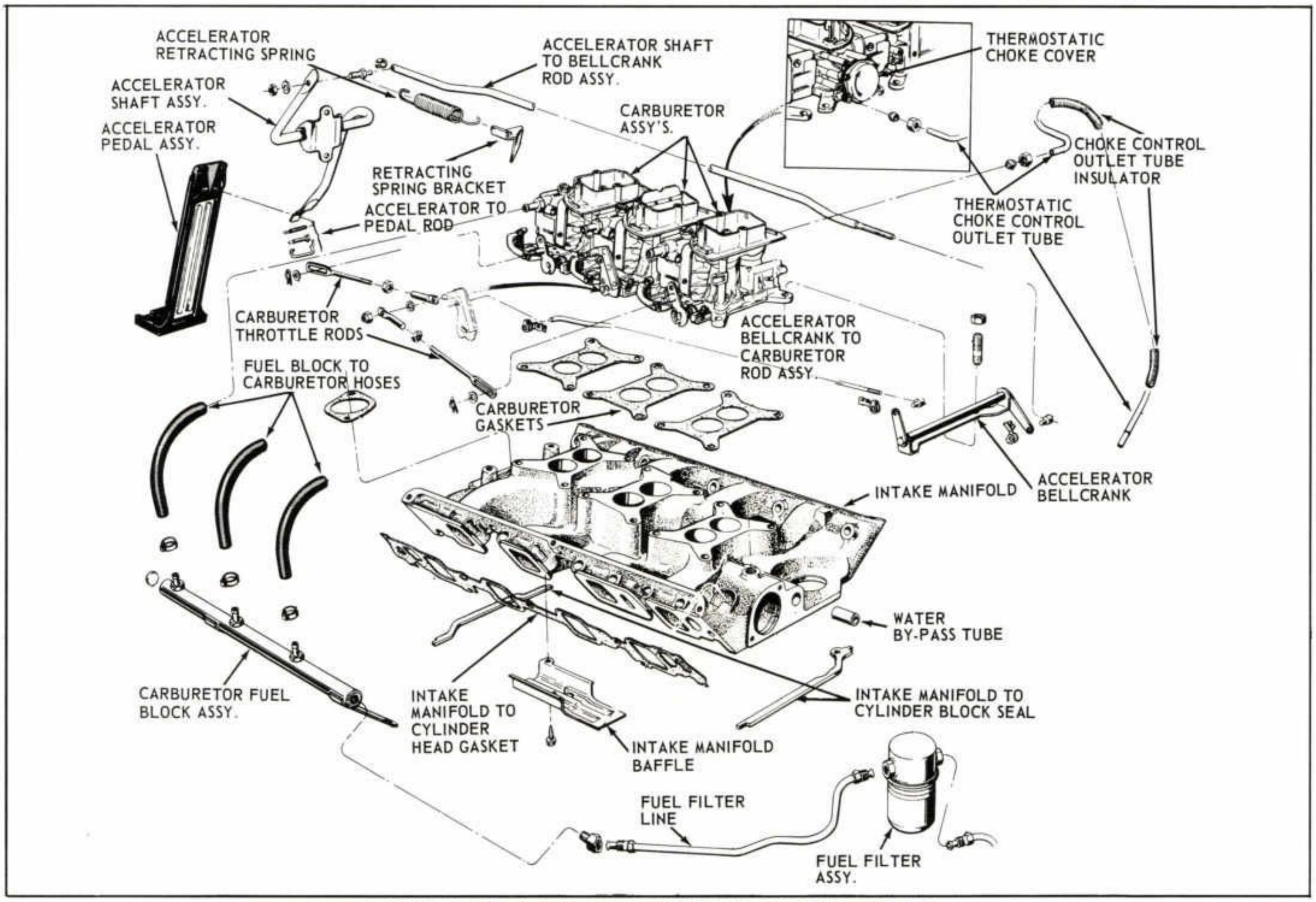


FIGURE 32. A 6-V CARBURETOR INSTALLATION

The three 2-V installation with its custom manifold has a rated air induction capacity of approximately 860 c.f.m. The functional advantage of this installation is the spreading of carburetor venturis over a larger area in relation to the inlet port locations. By just being closer to the cylinders which must be fed an air-fuel mixture, the distribution is obviously much improved. Progressive mechanical linkage, which must be care-

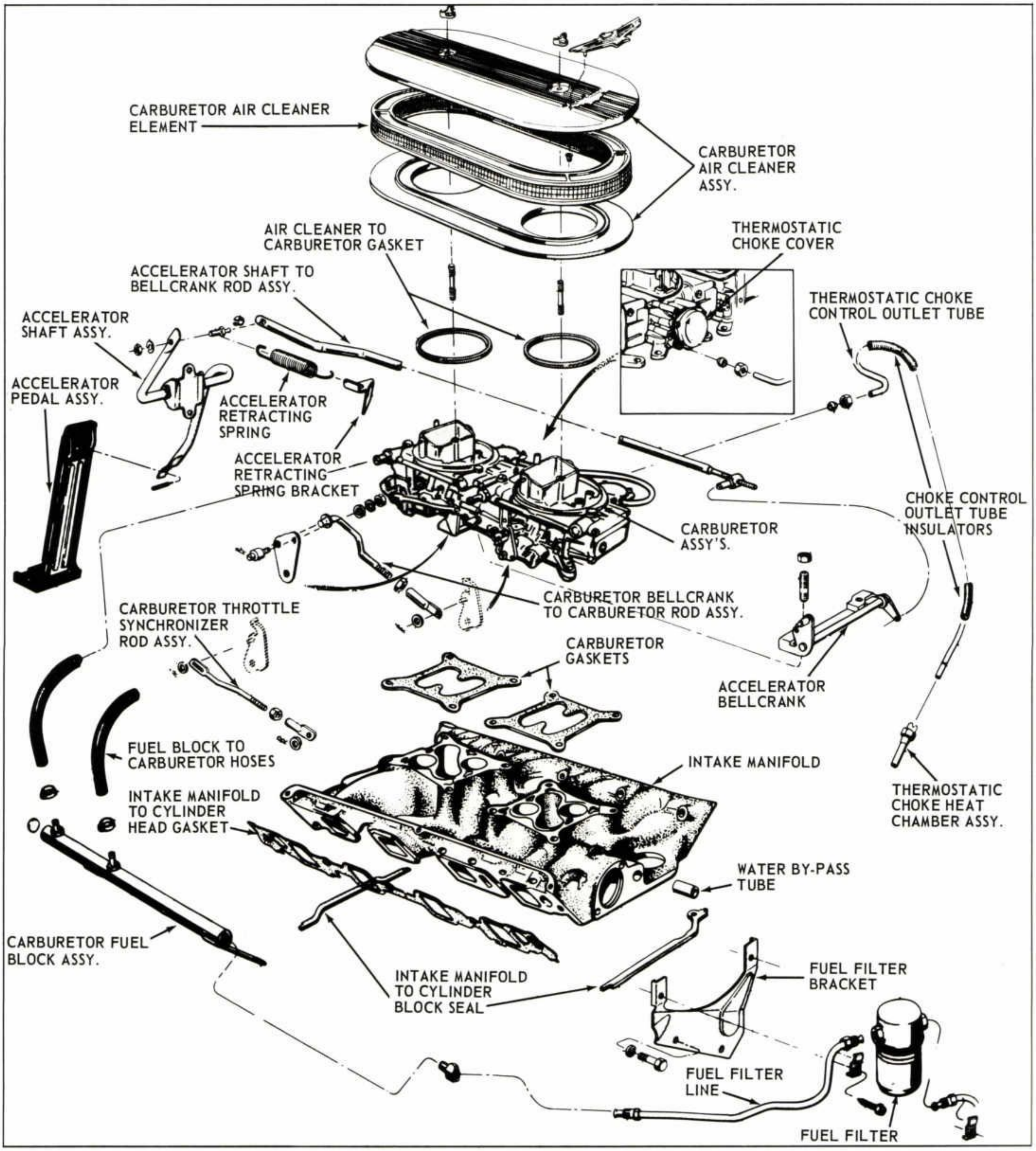


FIGURE 33. A DUAL 4-V CARBURETOR INSTALLATION

fully adjusted, also provides a functional advantage. One carburetor is used for normal operating conditions with the additional carburetors available when maximum horsepower is desired. A typical installation, together with pertinent linkage is shown in Figure 32.

Another type of carburetor installation is the 8-V system, also shown previously. This dual 4-barrel setup when used on a 427 C.I.D. production-type high-performance engine has a rating of 1200 c.f.m. With this carburetor arrangement, 8 small venturis handle the air-fuel requirements at both ends of the engine's performance range.

As with the 6-V installation, a progressive throttle mechanism is used. The 8-V set-up, however, has an added advantage. The secondary system is fully automatic. This means that engine operating conditions . . . or, more specifically, venturi vacuum conditions . . . will act upon vacuum diaphragms in the carburetors at just the right time. The result is the best use of available air flow capacities and the smoothest possible transition through the four speed and power range. Figure 33 illustrates a dual 4-barrel installation.

The Weber carburetors, which typify the ultra in custom installations, incorporate three or four 2-barrel carburetors on a specially designed intake manifold for bolt-on application on 6- or 8-cylinder engines. (They also produce 1-venturi units which we'll omit from our coverage.) The ability of their combinations of 2-barrel carburetors to distribute the air-fuel mixture to all cylinders is perhaps their primary advantage over other single and multiple carburetor installations.

The distribution system they provide allows smooth engine operation in the low r.p.m. range and the desired efficiency when high-performance demands are placed on the engine. Webers are also very flexible. The manufacturer produces a variety of interchangeable venturis, as well as main jets, air mixing jets, idling jets, pump jets, and emulsifier tubes. With this selection of components available, the high-performance buff can tailor his car's carburetion for a variety of specific uses.

In listing a few generalizations about Weber carburetors for those who might be interested in this type of equipment, we would include the following:

- Attaching parts require metric tools for service.
- Float settings, although very important on all carburetors, are critical on Webers. With some models, a special go, no-go gauge must be used.
- Each venturi and then each carburetor must be checked for specified adjustments. When this is

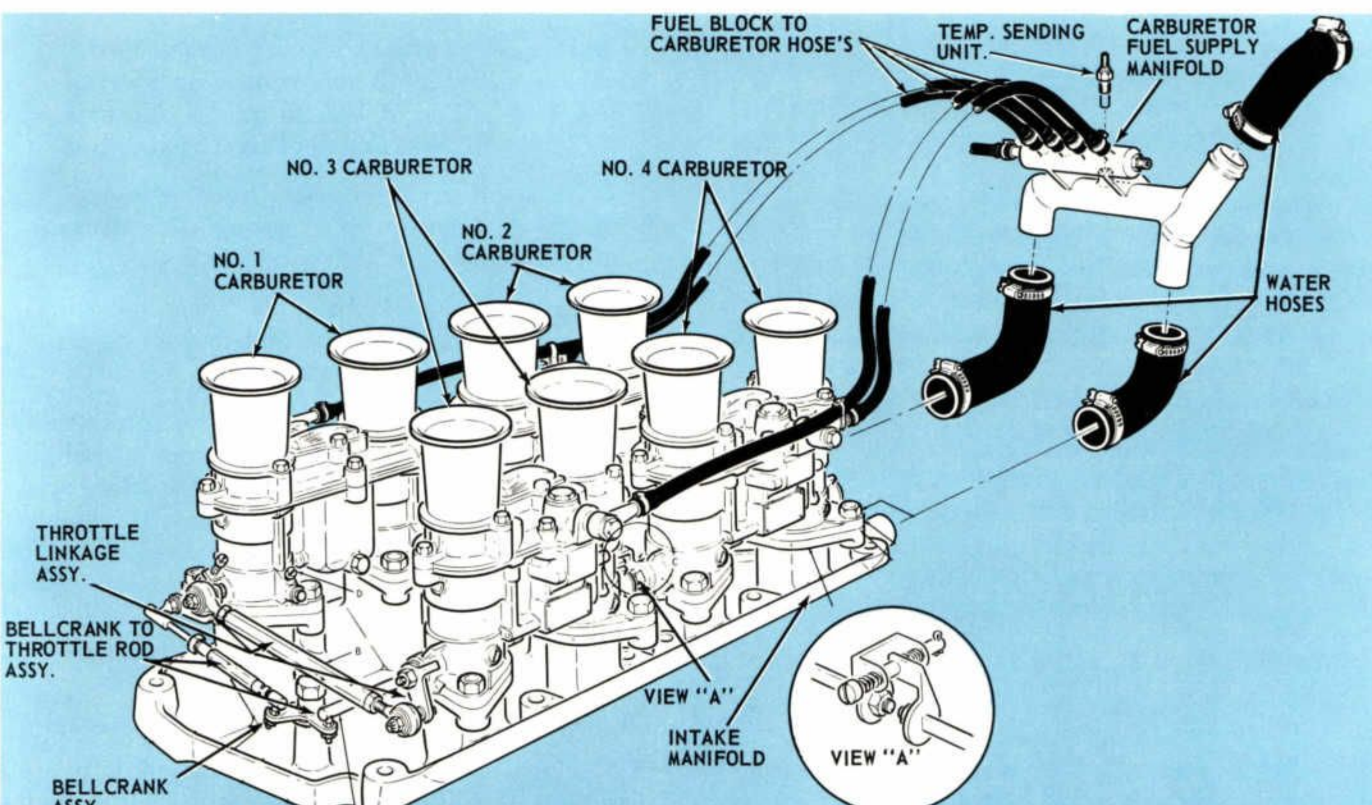


FIGURE 34. AN 8-V (WEBER) CARBURETOR INSTALLATION

accomplished, all carburetors must be balanced or equalized with each other.

- A cold air box is usually mandatory on street vehicles to guard against fire hazards. Filters on some racing applications are used to prevent cold air backflow.
- The only mechanical connection between carburetor assemblies is the ball bearing mounted butterfly shaft.

Figure 34 illustrates a Weber installation and related linkage.

HIGH-PERFORMANCE FUELS

The objective in selecting a given fuel for a given engine is to make a choice which will produce the most efficient use of heat energy when it's properly ignited in the combustion chamber. After all, it's this heat energy factor which is directly related to the amount of torque force transferred to the crankshaft.

The heat value of a fuel, by the way, is expressed in British Thermal Units (B.T.U.'s) . . . an accepted industry standard which represents the amount of heat needed to raise the temperature of one pound of water one degree Fahrenheit. This B.T.U. unit is a potential energy factor which, in the case of average gasoline type automotive fuel at an ideal ratio of 15 parts air to 1 part gasoline, will have approximately 1125 energy units per pound of mixture. (A pound of gasoline will have approximately 19,000 B.T.U.'s.)

Octane rating is another automotive fuel value to which reference is frequently made. This octane rating or number is the measure of its ability to resist detonation during the high temperatures and pressures of combustion. (Detonation (knock) is affected by the molecular structure of the fuel involved. In the case of gasoline, a hydrocarbon, there are many controlled variations into which the component hydrogen and carbon elements might arrange themselves as a compound. Just how this compound is structured will determine how effective it is as a knock-free fuel.)

The engine compression ratio is the usual guide to the need for high octane fuel. There are, however, other engine design and operating characteristics which are factors. These characteristics include atmospheric pressure, humidity, air temperature, spark timing and advance, intake manifold temperature, water jacket temperature, type of transmission, carburetor mixture ratio, and the presence of hot spots which could introduce pre-ignition and detonation. A cross-section of all factors will, in the long run, dictate the chemistry of the fuel which should be used.

Up to this point we've limited our attention to gasoline as an automotive fuel. In all probability a car which will see street use will be limited to this type of fuel for two reasons . . . it's readily available . . . and . . . the carburetor jets are sized to operate with gasoline. Even the selection of gasoline will be fairly clear-cut . . . a high-performance engine will need a high octane (premium) fuel.

For track use, it's a different story. There is a wide selection of racing fuels sold under numerous brand names. Basically, however, they boil down to four chemical groupings . . . the methanols, the nitromethanes, the benzols, and the ethanols.

Why would a competition driver want to use one of these fuels? One answer to this question . . . and perhaps the most pertinent one . . . would be the fact that they offer a higher potential for fuel efficiency. The ignition of a gasoline-air mixture is power-packed but its burning time is short. As a result, there is a relatively high percentage of the mixture which is emitted as unburned hydrocarbons. The non-gasoline type fuels mentioned, burn more slowly and more completely. Their kindling points are also lower. As a result, they can withstand higher compression pressures . . . and the heat thus generated . . . without causing the pre-ignition which these same pressures would impose on a gasoline mixture.

In practice, the fuels we've mentioned are usually blended to suit the track conditions, type of race, and limitations of the race sanctioning body. The high "nitro" blend, for example, is a short race mixture. This low B.T.U. fuel (3400 B.T.U./lb.), particularly in combination with methanol (8,500 B.T.U./lb.) becomes an extremely hot racing mix because of its ability to absorb very high compression ratios. The performance capabilities are realized at or near the flat-out range. As a result, engine stresses are at their maximum where, except for short drag races, they shouldn't remain for any extended period of time.

Specific fuel consumption becomes a factor in the longer races. (An extra pit stop for fuel has lost a race more than once.) Thus, if fuel chemistry is not controlled by the sanctioning body, skillful blending can make an important difference. Benzol, for example, will provide high octane and high B.T.U. characteristics which approach those of gasoline. Methanol provides more complete combustion and high compression characteristics. Ethanol is strictly a blending agent because it has both high B.T.U. and the high latent heat qualities which would best adapt to lower compression ratios. Nitro, which we mentioned earlier, is the real power mix in some cases raising the rated power to 1½ times its potential with gasoline—but it is consumed very rapidly. So . . . when considering Nitro . . . remember it's expensive, fast burning, and, in its unblended state, performs best at top engine r.p.m. which produces high . . . and sometimes dangerous . . . stress characteristics.

INTAKE MANIFOLDS

Introduction

We've described the ambient air intake side of the induction system, fuel pumps, and carburetors pretty much as though they were separate entities. This, of course, is not the case. The ultimate in performance demands a tuned relationship between all components which are related to ignition of the air-fuel mixture in the combustion chamber and those which are related to the exhausting of the gases and unburned hydrocarbons from the chamber. All of the components involved perform a critical function. Their design is critical . . . their installation is critical . . . and their conformity to production or blueprint specifications is critical. In the latter instance, we include component materials, clearances, torques, and operation according to specified standards. If one element is deficient or sub-standard, it will obviously have an adverse effect on the potential of the total package being developed.

We repeat . . . as a means of bringing loose ends together . . . a well-engineered high-performance car must have—

- A scoop or ducts which will gather ram air (or perhaps a supercharger system) and direct it through a filtering device in order to remove as much of the ambient impurities as possible. The filter must do its job with a minimum of restriction to the air flow.
- A fuel pump, probably a heavy-duty type with larger than regular fuel lines, which will draw a constant supply of fuel from the tank and lift it through a filter to the carburetor.
- One or more carburetors which singularly or cumulatively have a c.f.m. rating that will handle but not overdo the job you have in mind.
- Intake manifolding which will most efficiently direct the air-fuel mixture provided by the carburetor to each combustion chamber.

The text materials which follow are devoted to a description of intake manifold designs and their affect on performance. Ensuing materials provide detailed coverage of the design and operating principles involved in basic and high-performance cylinder head and cylinder block assemblies.

Air Flow Characteristics

The movement of the air-fuel mixture in the intake manifolds is governed by the opening of the intake valves. Because this occurs only during the intake stroke, there is of necessity, an erratic or turbulent action in the manifolds. When the valves open, the mixture is drawn into a low pressure area (partial vacuum) in the cylinders which develops as the pistons move downward. This condition, of course, exists only momentarily because the rotating camshaft moves past the high point of the lobe which is holding the valve open. The frequency at which valve action occurs is so great that the opening and closing have an abrupt reaction. At one instant, air is rushing into the cylinder; at the next instant the flow is cut off, only to repeat the cycle over and over again.

This same characteristic of turbulence is experienced by the carburetor. Intake air is picking up and atomizing fuel droplets as it passes through the venturi into the manifold. In effect, the lighter intake air is dragging the heavier fuel into an erratic air flow pattern in the manifold. (We say the fuel is "dragged" because of the comparative inertia of fuel in relation to air.) Engineering tests indicate that runner and port design . . . particularly increased runner length between the intake valve and main air-fuel supply passage in the manifold helps to smooth out the flow. (Some manufacturers have added a plenum chamber between the carburetor(s) and intake ports. The intent of this chamber is to calm the turbulence in the manifold in lieu of lengthening the intake runners to accomplish the same objective.)

Before we go any further let's take a look at a schematic of an intake manifold with a single 4-V carburetor mounting boss. The purpose of the illustration (Figure 35) is to show a typical V-8 air-fuel flow pattern through the manifold.

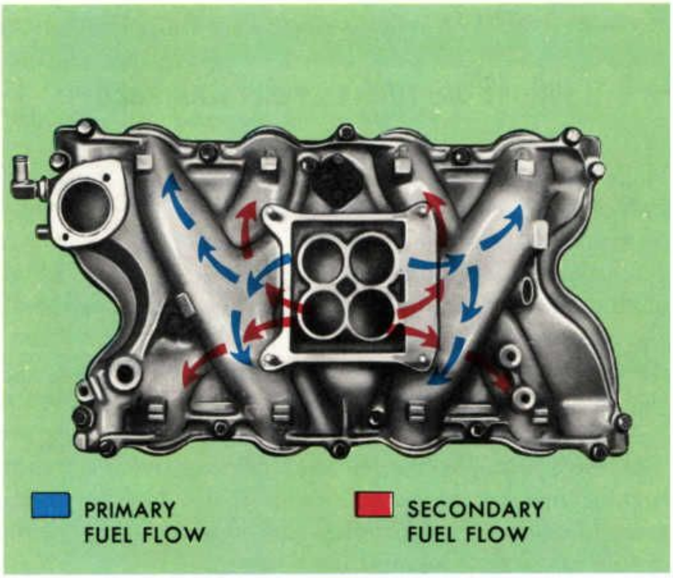


FIGURE 35. AIR-FUEL FLOW IN THE INTAKE MANIFOLD (TYPICAL V-8)

Types of Manifolds

Now, let's look at some typical Ford Motor Company intake manifold designs.

Among the more important features of an intake manifold, in terms of its performance potential, we'd have to include the success the design engineers have in making a smooth transition from the typically round manifold runners to the rectangular configuration of the intake ports in the cylinder head. Of similar importance is the diameter and curvature of the manifold runners. (This isn't as simple a design objective as it may at first appear. The probable *best design* is prohibited by interferences and accessibility problems in an O.H.V. engine . . . namely, the pushrods and the manifold attaching locations. Historically, to clear the pushrods, manifold runners took on a less desirable rectangular shape . . . that is . . . until the fairly recent tunnel port designs were introduced. With this design, the pushrods passed directly through the runners and the hold-down locations retained a satisfactory position.) (See Figure 36.)

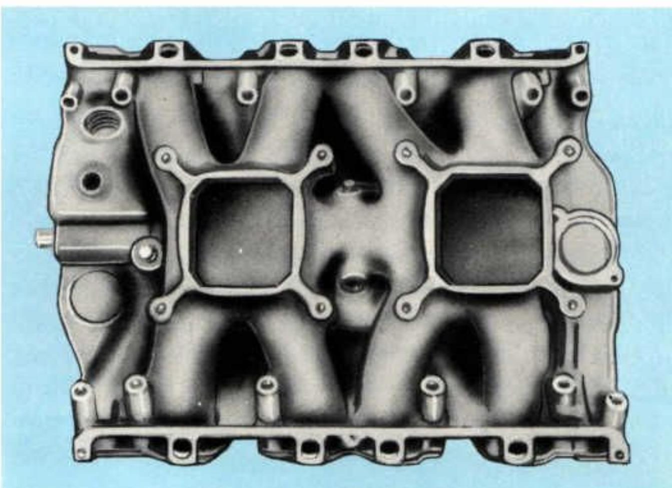


FIGURE 36. TUNNEL PORT MANIFOLD

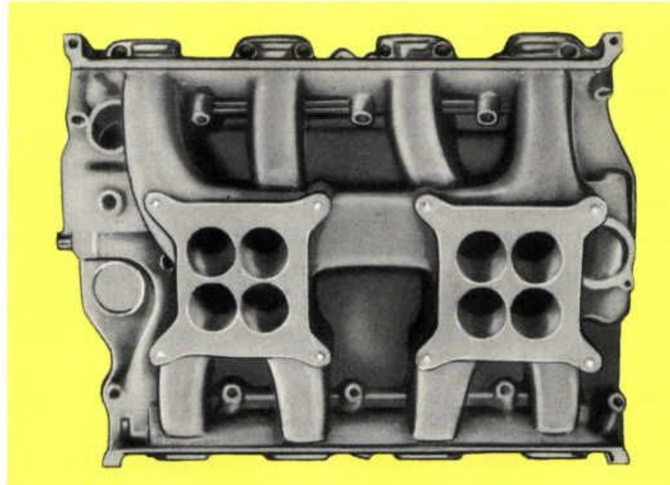


FIGURE 37. HIGH RISER MANIFOLD

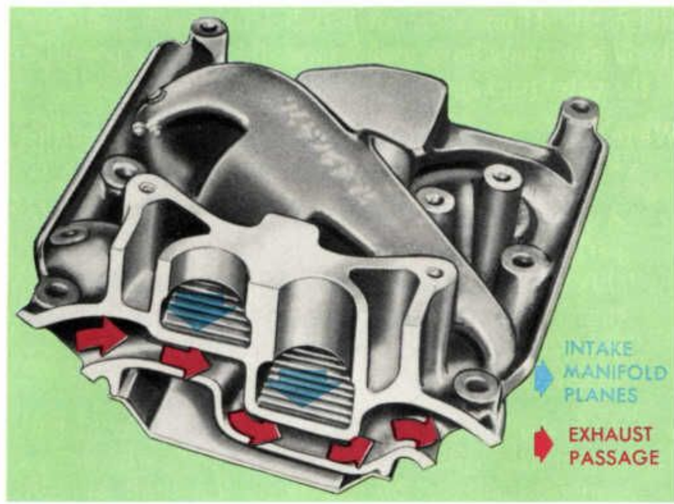


FIGURE 38. DUAL PLANE MANIFOLD

High-risers are another design approach to improved induction. Here, the objective is to increase the angle at which the manifold runners and their ports approach the inlet ports in the cylinder head. As a result of changing manifold design in this way, the elevation of the carburetor mounting boss was increased . . . a visual difference which some mistakenly identified as a high-rise installation. (See Figure 37.)

The true high-rise manifold is an improvement over regular production manifolding. It is capable of increased volumetric efficiency and superior atomization of fuel in the air-fuel mixture.

Another innovation in manifold design is the dual plane set-up. Here, the adjacent ports lie in alternately high and low planes. With this arrangement, fresh air-fuel induction occurs with each 180° of crankshaft rotation. The advantage of dual plane manifolds is their potentiality for minimizing flow turbulence and cramming the air-fuel mixture in the runners and ports. (See Figure 38.)

WHICH ONE?

With the variety of intake manifold designs available . . . again . . . the choice is yours. A blueprinted production manifold may satisfy your needs if you're interested in a high-performance street vehicle. If, on the other hand, your goal is a competition set-up, a tunnel port, high-rise, or dual plane intake manifold may better suit your needs.

Regardless of your objective and choice of manifold, there are some *musts* which will apply to any high performance installation . . .

- The manifold must be blueprinted and thoroughly clean inside.
- The ports in the manifold and cylinder head must match exactly. (Because of the inevitability of production variations from head to head and manifold to manifold, this matching condition should be very carefully checked.)
- Torque on the attaching bolts must be applied with a torque wrench instead of by guess.

HOW ABOUT FUEL INJECTION?

The majority of performance enthusiasts agree that fuel injection has the capability of increasing the horsepower ratings for almost any given engine application. The use of wilder cams with longer periods of duration and overlap, plus the fact that fuel is injected directly into the airstream immediately ahead of the intake valve (in most applications), and timed so that it coincides with exhaust valve closing . . . all add up to greater volumetric efficiency.

A lot of attention has also been directed toward the use of injection as a solution to smog control problems. It has been established that most contaminants are emitted during deceleration and idle conditions. The typical injector system simply shuts off the fuel supply on deceleration and relies on a separate idle circuit for engine idle conditions. Why aren't more fuel injection systems being used then? Cost is probably the single restricting factor. The component parts of a fuel injection system require such precision machining and fitting that unit costs are necessarily higher than carburetor-equipped engines. More emphasis is now being placed on research and development of injection systems—becoming more sophisticated by the addition of electronic switching devices – and research activities are all directed toward squeezing more power from today's hydrocarbon fuels.

A schematic diagram of the fuel injection system, typically used on Ford's D.O.H.C. engine is shown in Figure 38-A. It consists of a constant-volume gear-type fuel pump, metering block, economizer valves, by-pass orifices, primary barrel valve, and the matched nozzles. The constant-volume gear-type pump is mounted on the front gear cover, and is driven at one-half engine speed by the camshaft gear. During operation, the pump will actually discharge twice the amount of fuel required for any operating condition. The amount of fuel delivered to the metering block is controlled by the fixed-orifice by-pass, which returns a precisely predetermined amount of fuel back to the tank. The primary barrel valve is the "switch" which permits selection of one of three fixed-orifice by-passes. This feature enables the flow rate (pounds of fuel per hour versus engine speed) to be moved up or down for rich or lean fuel injection.

The metering block and secondary barrel valve are linked with the throttle plates to control the fuel at part throttle. Improved fuel atomization is achieved with booster venturis installed in the throttle bodies. This reduces fuel requirements, and improves the performance and response of the engine.

The two economizer valves between the metering block and the nozzles maintain the balance of fuel delivery in accordance with the established fuel flow curve. The dual economizer valve installation also helps to improve throttle response during the transfer from the low to the high speed range.

Now, before we proceed to our in-depth coverage of cylinder heads, just one last reminder . . . don't over-carburate your high-performance package. It can only result in an unnecessary expenditure. A rule of thumb accepted by the car buffs is *a square inch of venturi area for each 50 to 65 cubic inches of engine displacement*. Admittedly, this is a "guesstimate" which cannot replace the accuracy of flow testing, but it does provide a starting point.

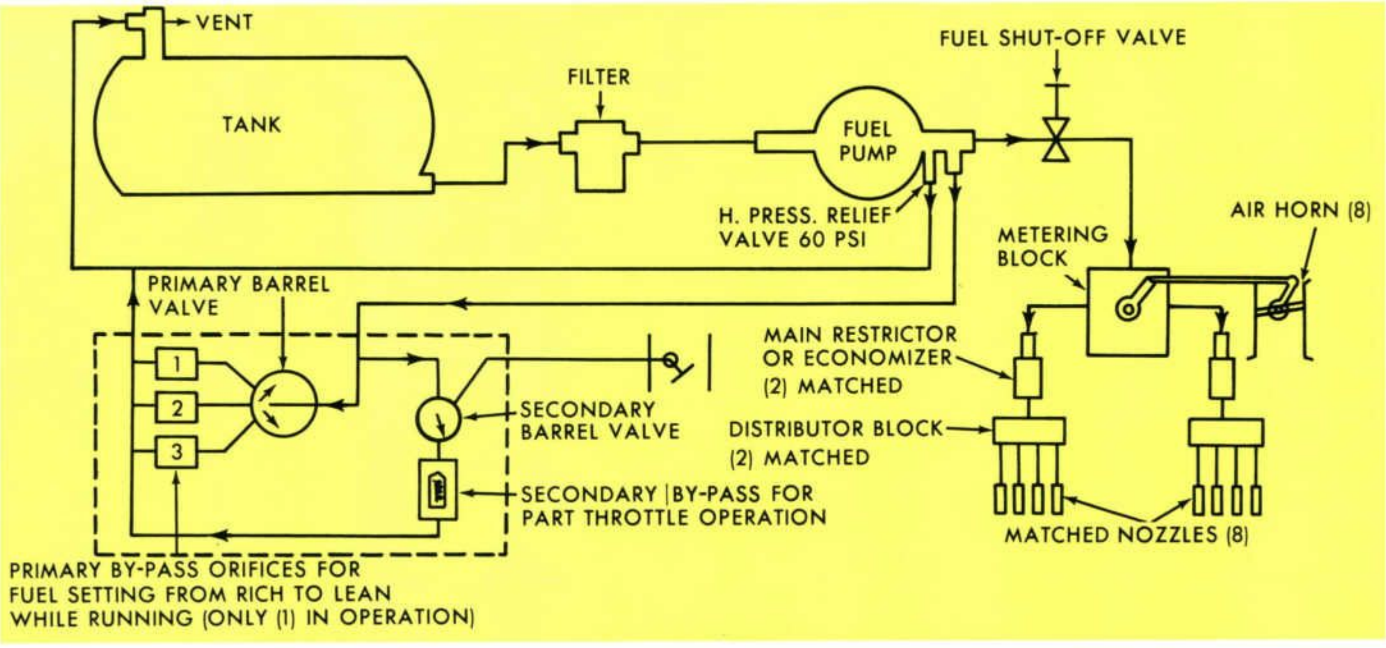


FIGURE 38-A. FUEL INJECTION SCHEMATIC DIAGRAM

Cylinder Head Assembly

BASIC DESIGN AND OPERATING PRINCIPLES

After considering all the factors affecting engine power output, you'll find that there are really only two basic ways of squeezing a few extra horses out of that engine of yours. The first and most popular method is to increase the engine's "breathing" ability (volumetric efficiency) and the second method is to increase combustion efficiency.

It is not too uncommon to find the part-time speed buff eagerly spending his weekends attempting to bolt-up a high riser intake manifold or trying to unscramble the linkage on a big throat, high C.F.M. (cubic feet per minute), multiple carb set-up. However, these modifications could be futile if you forget to look beyond the intake manifold and carburetion in your search for additional horsepower. If you make this unfortunate mistake, your efforts could be likened to those of a person trying to increase fluid flow by passing a liquid from a 12″ diameter pipe through a soda straw. Remember, volumetric and combustion efficiency are functions of a number of factors including manifold design, carburetion, valve size, engine bore and stroke, piston, camshaft, cylinder head design, etc.

CYLINDER HEAD DESIGN

As an individual interested in ultimate engine performance you must take into consideration the cylinder head and its component parts relative to the job they perform in the induction system and in the internal combustion process. Cylinder heads and cylinder head components can easily be changed or modified for sizeable horsepower gains through increased volumetric and combustion efficiency at high engine r.p.m.s.

Cylinder heads are usually cast as separate engine components from an iron alloyed with other metals. However, in some instances they may be cast from an aluminum alloy. Aluminum offers the combined advantages of lightness and high heat conductivity. The cylinder head used on the overhead valve engine must provide space for water jackets and intake and exhaust passages. In addition, it contains the valves and valve operating mechanisms. (See Figure 39.)

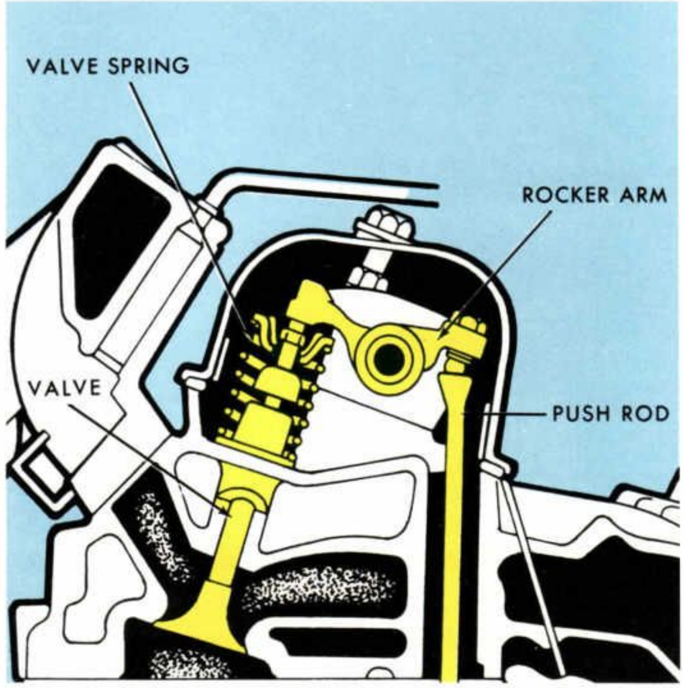


FIGURE 39. O.H.V. CYLINDER HEAD

Combustion Chamber

The combustion chamber is that area in which combustion takes place. It includes the surfaces of both intake and exhaust valve heads, a portion of the cylinder head, the top of the piston, a portion of the upper cylinder wall, the edges of the head gasket and even a portion of the spark plug. As you can see, the combustion chamber is an area which can be altered by changing or modifying any one of a number of components.

Of all the engine design features affecting power output, that of the combustion chamber is probably the most important. In spite of its importance, there is very little that you as a performance enthusiast can do to alter the original combustion chamber shape. You can not, for example, modify a "wedge" head and turn it into a "hemi." However, by understanding combustion chamber designs, you can plan your engine modifications to gain additional horsepower within the limits of a particular design.

A good combustion chamber design should provide for adequate turbulence and quench (cooling) of gases. It should have a low clearance volume for high compression ratios, yet have enough room to allow the use of adequate-size valves. In addition, the design should result in a short flame travel for efficient and rapid combustion.

Several combustion chamber designs have been employed in the casting of a cylinder head; however, the most common of these are the "wedge" or quench type and the hemispherical (Hemi) combustion chamber.

"WEDGE-SHAPED" COMBUSTION CHAMBER

The wedge-head design has proven to be strong, economical, and dependable. It is a design compatible for use in both the standard "street" type engine or the high-winding, deep breathing high-performance engine. The wedge-head derives its name from the shape of the combustion chamber when the cylinder head is cross-sectioned. (See Figure 40.)

Intake and exhaust valves are side-by-side with the

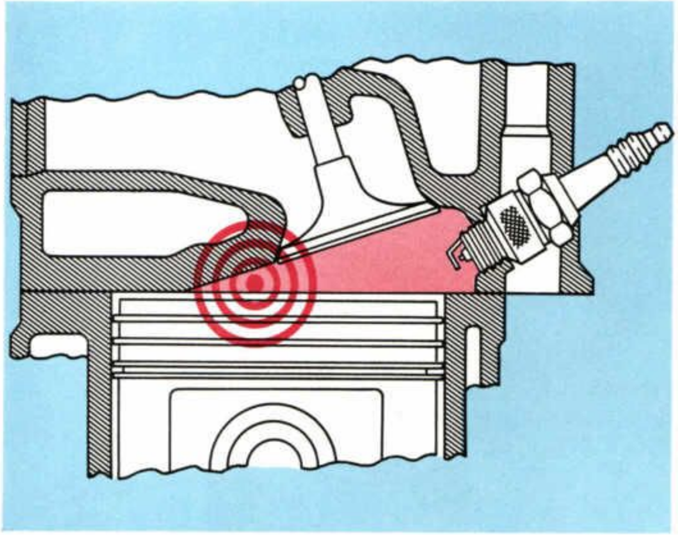


FIGURE 40. WEDGE-SHAPED COMBUSTION CHAMBER

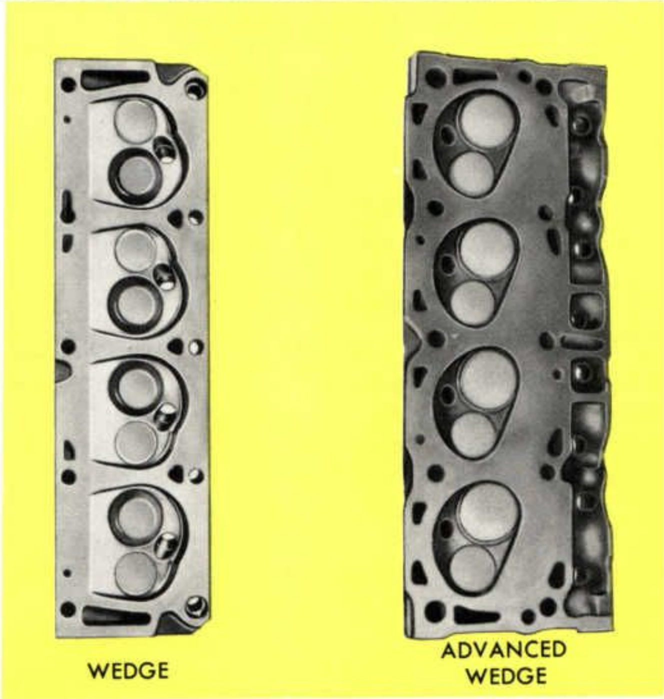


FIGURE 41. ADVANCED WEDGE DESIGN

spark plug located as centrally as possible. In some wedge designs, the valves may be slightly shrouded by the chamber walls. (Valve shrouding can affect engine "breathing" and should be taken into consideration when you plan your engine modifications.) The wedge design produces a highly efficient "swirling" action of the incoming combustion gases for smooth engine operation. This swirling or turbulence of the mixture speeds up the rate of flame burning to help complete combustion in a shorter period of time. In addition, the wedge design forms a "quench" area with the top of the piston to cool the portion of the air-fuel charge that burns slower. This cooling is important to prevent detonation at lower engine speeds when faster burning fuels are used.

Variations or modifications of the wedge design, include the canted valve or porcupine head. In this type of cylinder head, the combustion chambers are cast in an advanced wedge (quench) design with more rounded contours. (See Figure 41.) The valves are canted or staggered to permit the use of larger intake valves and reduced valve shrouding. This improves the breathing characteristics of the engine.

HEMISPHERICAL COMBUSTION CHAMBER

The hemi combustion chamber, as used in some high-compression, high-performance engines, does not have a quench area. The good breathing characteristics and high volumetric efficiency of this design in a high compression engine virtually eliminates the possibility of detonation. *However, it is prone to detonation if low octane fuels are used.*

The hemi design permits the use of larger valves and more direct intake and exhaust ports, thus accounting for its free-breathing characteristics. (See Figure 42.)

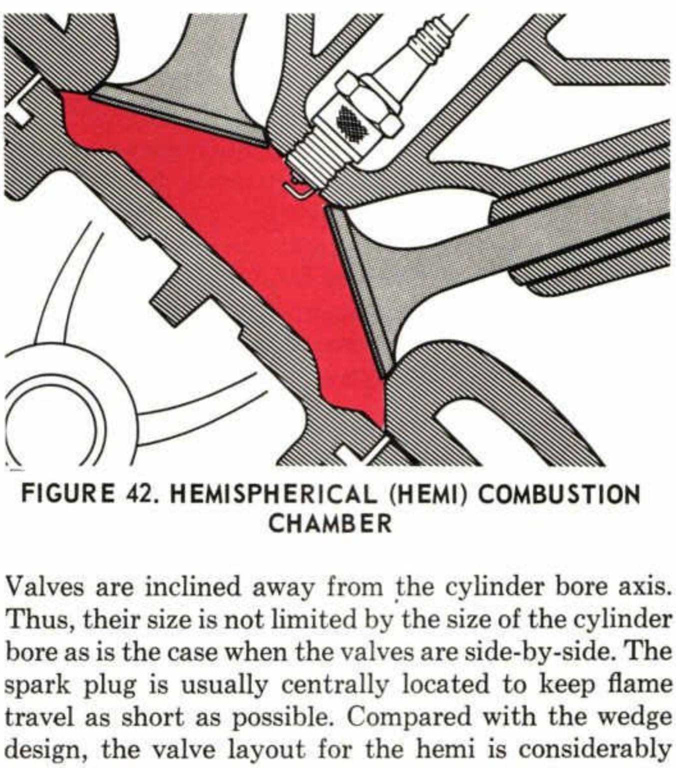


FIGURE 42. HEMISPHERICAL (HEMI) COMBUSTION CHAMBER

Valves are inclined away from the cylinder bore axis. Thus, their size is not limited by the size of the cylinder bore as is the case when the valves are side-by-side. The spark plug is usually centrally located to keep flame travel as short as possible. Compared with the wedge design, the valve layout for the hemi is considerably more complicated. It consists of twin rocker shafts with opposing rocker arms. The hemi valve arrangement results in a costly and complicated cylinder head casting. As such, the hemi head is usually found on limited production, high-performance engines.

Cylinder Head Ports

The combustion chamber is only one area of cylinder head design. You've probably heard the terms medium riser, high riser and tunnel port head. In each case the terminology refers to the cross-sectional area and design configuration of the cylinder head ports. As can be expected, intake and exhaust port dimensions and configuration can greatly assist the free-breathing capabilities and volumetric efficiency of an engine. Cylinder head port design is largely based on atmospheric pressure flow characteristics for a particular engine.

FLOW TESTING

Intake port flow characteristics are often a subject of heated debate among speed buffs. Some of the argument centers on the value of porting and polishing, a subject which is dear to the hearts of a large segment of the hot rod population. We'll have more to say about porting and polishing later in the text. For the moment, we'll concern ourselves with an explanation of flow characteristics and flow testing.

The intake port is nothing more than a tube or passage in the intake manifold and cylinder head. Within the intake port there is a quantity of air equal to the volume of the port itself. This mass of air is subject to the laws of inertia and in order to get it moving it must be acted upon by an "outside" force. The force that moves the air and air/fuel mixture into the cylinder is atmospheric pressure. This movement occurs when the intake valve opens and the piston begins its intake stroke. The intake stroke creates a low pressure area in the cylinder and the atmospheric pressure, which is higher, actually pushes the charge into the cylinder. Ideally, the intake port should be designed to eliminate any possible opposing pressures and guide the column of air and fuel without restriction into the cylinder. In essence, this ability describes the flow characteristics of the intake port in the cylinder head. Flow characteristics are determined by using a flow tester which simulates the low pressure of the cylinder on the intake stroke while measuring the amount of air drawn through the port. Modifications are then made to increase the flow and improve volumetric efficiency for a given engine design. As such, cylinder head ports are precision cast to allow for maximum air flow under a given set of engine operating conditions. Conventional intake ports are rectangular in design and offer good flow characteristics. However, the performance-minded can turn to the high riser or tunnel port head for the increased flow rates associated with high engine speeds.

HIGH RISER HEAD

The high riser designs are often used with street vehicles. They feature extremely large rectangular intake ports to improve mixture flow at high r.p.m. (See Figure 43.)

The large rectangular intake ports of the high riser

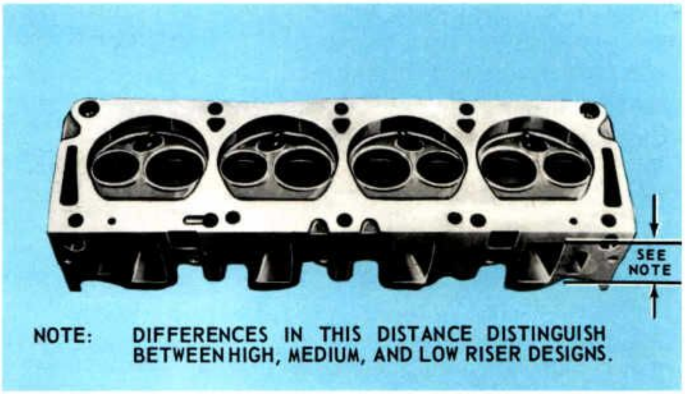


FIGURE 43. HIGH RISER CYLINDER HEAD

head generally call for a high intake manifold runner entry angle. As a result, the use of high riser heads will require the use of a high riser intake manifold.

Cross sectional port area is important in a high-performance engine. Equally important, however, is the contour of the intake and exhaust ports. It is generally accepted that high speed air tends to flow in a straight line. Thus, any bends in the cylinder head intake or exhaust ports, regardless of how smooth they are, will tend to restrict mixture flow. The intake ports, of conventional cylinder heads, are usually designed to curve around pushrod guides. However, for high speed engine operation, when high volumetric efficiency is a must, the performance enthusiast may find it well worth his while to invest in a tunnel port induction system.

TUNNEL PORT HEAD

The tunnel port head derives its name from the fact that it uses extremely large, round ports which come straight out from the intake valve. (See Figure 44.)

FIGURE 44. TUNNEL PORT HEAD

To accomplish this, the ports do not bend to clear the pushrod holes as in the conventional head. Instead, the intake charge passes directly around the pushrod which is now enclosed in a sleeve that passes through the intake port. A tunnel port intake manifold is mandatory with the use of tunnel port heads. The tunnel port system offers sizeable horsepower gains, due to the large, nearly circular intake ports which allow a much greater volume of air/fuel mixture to move directly into the cylinders during high engine r.p.m.

Head Gasket Function

Thinner-than-stock head gaskets can effectively decrease combustion chamber volumes, since the combustion chamber includes all the space (a part of which is taken up by the head gasket) above the piston at T.D.C. Alteration of gasket thickness will not only change chamber volume, but will also affect compression ratio, cylinder pressure, and engine power output. The basic functions of the head gasket are to seal each cylinder to prevent compression loss and to prevent leakage of the coolant and lubricant that flows between the block and head. The most common type of head gasket construction consists of asbestos "sandwiched" between a layer of copper or steel. The asbestos material assists in heat absorption and sealing. The advantage of copper is that it is soft and readily conforms to head and block surface irregularities to form a better seal. On the other hand, steel is stronger than copper and more resistant to failure. (Tips for proper selection and installation of head gaskets are covered in detail later in this manual.)

Engine Valves

The intake and exhaust valves used in the internal combustion engine control the flow of gases into and out of each cylinder. They must also form a gas-tight seal during the compression and power strokes. This may, at first glance, seem like a relatively simple job. However, this is not the case when you consider that in a high-performance engine, combustion temperatures can reach 4200° F. and the exhaust valve may have to operate at a cherry-red temperature of 1500° F. while still maintaining a gas-tight seal under 1800 p.s.i. cylinder pressures. As a result, valve construction, design, size, timing and operation can greatly affect engine volumetric efficiency and power output. Proper valve size, seating, cooling and timing are of critical importance to engine performance. Gases flowing through a "high riser" head or one "ported" for better breathing can't adequately fill the combustion chamber if valves are too small or improperly timed. In some cases, a simple change in valve shape can increase mixture flow and volumetric efficiency with no changes to the intake ports. Likewise, improperly seated valves may result in inadequate valve cooling or cylinder leakage and pressure loss during those critical periods of the engine's compression and power strokes. Remember, horsepower is a function of cylinder pressure; and valve leakage is no less than letting a few horses escape on each of these strokes.

VALVE ARRANGEMENT

There have been a number of valve arrangements used in past production engines including the L-head, T-head, F-head and the current overhead valve design. (See Figure 45 which illustrates the more recent of these arrangements.)

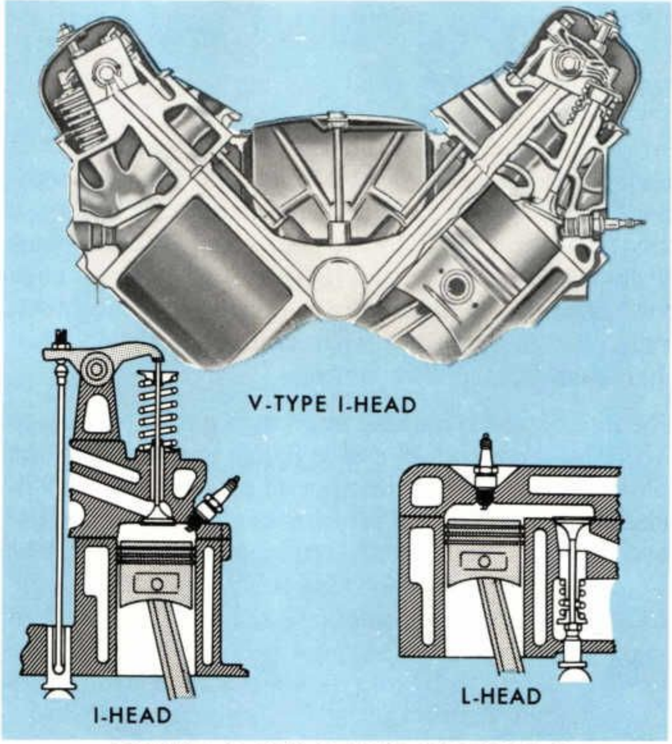


FIGURE 45. VALVE ARRANGEMENTS

Although there are still some die-hards who look back with pride at the old faithful flat heads, today's performance buffs are intent on beefing up the O.H.V. engine. The O.H.V. design features valves located and seated in the cylinder heads. Its popularity is primarily due to improved volumetric efficiency and easy adaptability to high compression ratios.

VALVE CONSTRUCTION

The valves are mechanically operated poppet or mushroom types consisting of a head, margin, face, fillet radius and stem. (See Figure 46.)

The fillet radius is that portion of the valve where the head blends into the stem. The size of the fillet radius can affect the flow of gases past the valve into the combustion chamber. Because of this it is an area of valve design given considerable attention by the performance-minded individual. A large radius for example, reduces the area of the port as the valve seat is approached. This results in a venturi effect which gives the gases a last-minute boost in velocity before they enter the chamber. The end result is more efficient cylinder filling and improved volumetric efficiency. So,

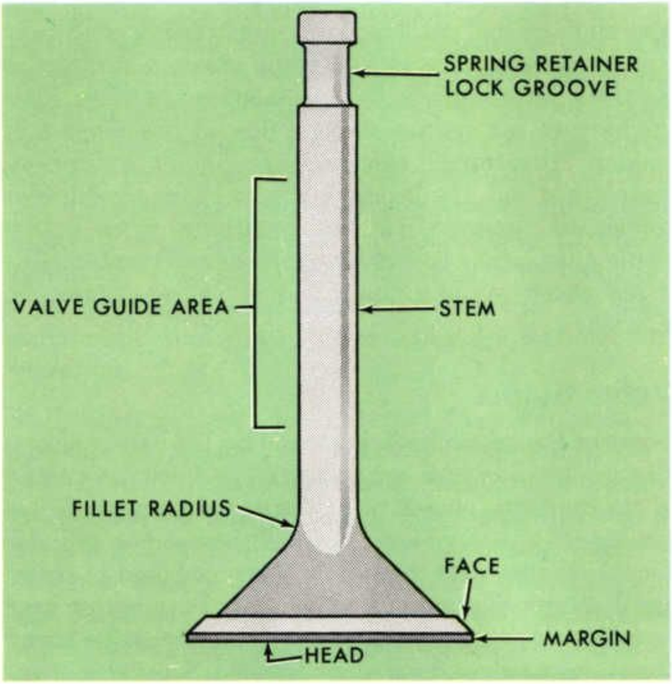


FIGURE 46. TYPICAL VALVE

don't rush off to the grinding wheel to shave some stock off the fillet radius and lighten those valves. First, consider the possible consequences and remember that valve alterations will affect flow characteristics.

There are three types of valve head designs currently in use; the flat top, the tulip and the SAE standard. The most common is the flat top which has a relatively large fillet radius. The SAE standard features a spherical convex radius head with increased head thickness at the center. The tulip head, which is gaining in popularity among speed buffs, has a concave head and large fillet radius.

Intake Valve

Most O.H.V. engines incorporate intake valves which are larger than exhaust valves. For example, the stock 428 Cobra Jet head features big 2.097" diameter heads on the intake valves and 1.660" diameter heads on the exhaust valves. One reason for larger intake valves (and intake ports) is that less pressure is available to push the intake mixture into the cylinder than is available to push the exhaust gases out. The larger intake valve offers less restriction to the incoming air-fuel mixture, thereby, improving the engine's "breathing" ability. Intake valves may be either solid or hollow stemmed. The stock Ford Cobra Jet engine, for example, features special solid-stem, silchrome alloy steel intake valves. For those interested in all-out competition, Ford offers optional, hollow stem, chrome plated, high-performance valves. (See Figure 47.)

These light weight valves are designed to maintain the free breathing, perfect sealing characteristics essential to the performance of an engine wound up to the 7500-plus r.p.m. range.

FIGURE 47. FORD HIGH-PERFORMANCE VALVES

Exhaust Valve

The intake valve, which passes only cool inlet air-fuel mixture, operates at lower temperatures in comparison to the exhaust valve. Exhaust valves, on the other hand, may actually become red hot in operation since they are subjected to much higher temperatures and more corrosive gases. (See Figure 48.)

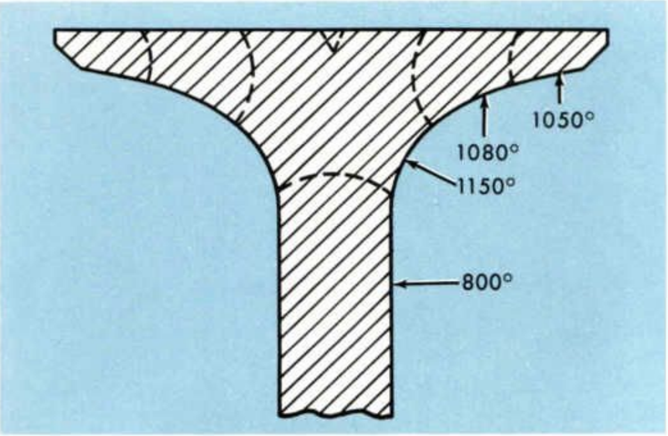


FIGURE 48. EXHAUST VALVE TEMPERATURES

Exhaust valves are usually made of high thermal absorbing and corrosive resistant material to prevent possible valve distortion or burning.

In some high-performance engines, the exhaust valves may be filled with sodium. The sodium melts at normal engine operating temperatures and moves freely inside the valve stem. It will absorb heat and transfer it from the valve head to the valve guide faster than solid metal. This results in cooler valve operation, longer valve life and more efficient engine operation.

VALVE FACE AND SEATS

The majority of the combustion heat must be transferred through the valve face to the valve seat from there it is transferred to the engine coolant in the cylinder head. If the valve face and seat do not mate properly (make full contact), the valve may leak or run several hundred degrees hotter than normal. In addition, the valve seats must be concentric with the valve guide bores to form an effective seal against the loss of cylinder pressures. Most modern high-performance engines use integral valve seats rather than removable seat inserts. Integral seats eliminate the thermal barrier existing between the two different metals of the valve seat inserts and the head. This has the advantage of reducing valve head operating temperatures.

Valve seat angles are intended to center the valve on its seat. In theory, smaller seat angles allow for better gas flow since they increase the valve opening area. Stock valve face and seat angles are normally 45°. However, blueprint specifications for one Ford high-performance engine specifies an intake valve seat and face angle of 30°. The 30° angle provides better breathing, due to an actual increase in effective valve opening area. The face angle is usually made one degree less than the seat angle to allow fast seating and a wedging action. The difference between the seat and face angles is called an "interference" angle. (See Figure 49.)

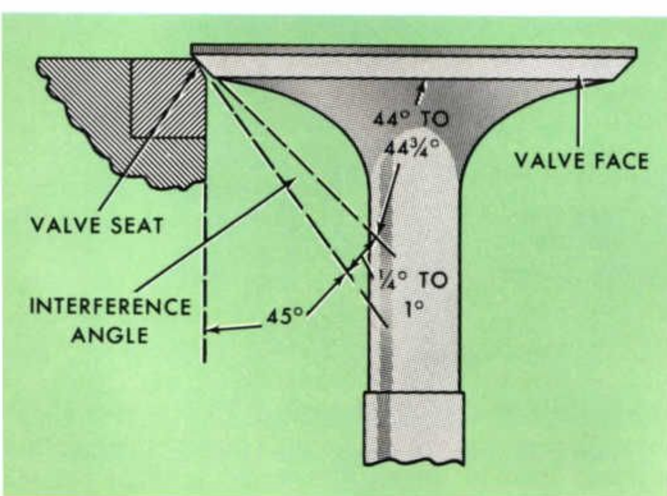


FIGURE 49. VALVE SEATING

Exhaust valve face and seat widths are ground slightly wider than intake seats to transfer more heat to the cooling system.

Many automobile manufacturers and performance experts consider valve seat and face angles as dimensions of critical importance to intake flow characteristics. If the angle is not designed for compatibility with port shape and flow direction, it could create a turbulence as the mixture enters the combustion chamber. This turbulence can reduce mixture flow at the expense of engine "breathing" efficiency. So, *don't* indiscriminately hog out the intake ports or change valve seat angles to "improve" engine breathing. Such action could alter intake flow characteristics and create a situation which would actually reduce engine volumetric efficiency.

Valve Guides

Some of the excess heat, absorbed by the valves during the combustion and exhaust strokes must be passed off to the valve guides through the valve stems. Valve guides are either integral (part of the head or cylinder block), or they are replaceable. The machined-in (integral) guides like integral valve seats have better heat transfer characteristics. However, they must be bored for oversize valve stems when serviced. The valve stem-to-guide clearance must be maintained close enough to have good heat transfer and large enough to prevent sticking. Valve guide lengths are a compromise between acceptable wear life and efficient lubrication. A short guide will wear rapidly and too long a guide causes heat due to friction.

A long guide is also difficult to lubricate. However, long guides allow the valves to run cooler, because they offer more area for heat transfer. To offset possible stem or guide wear, the guide may be bored larger than the valve stem a short distance in from the valve head end. This shortens the length of guide to be lubricated and acts as a heat shield. The counterbore also provides a relief for deposits to accumulate without causing valve-to-guide sticking. A groove is sometimes cut in the valve stem just below the head for the same purpose. The relief or groove will retain oil to lubricate the valve stem.

Valve Springs and Retainers

The valves are actuated and timed (in relation to piston position) by the camshaft, which changes rotary motion into linear (straight line) motion and transmits this motion to the valves through the valve train. They are closed by valve spring and combustion chamber pressures. Conventional valve springs are sometimes wound with the coils progressively closer near the stationary end to dampen vibrations occurring at higher speeds. High speed engines frequently use two springs per valve or spring dampers in an effort to control valve spring vibration or "surge."

Surge is one of the problems contributing to erratic spring behavior at high r.p.m. It occurs when vibrations set up by high speed cam and valve train movement excite the natural frequency characteristics of the valve spring. The spring then begins to vibrate and tends to stretch the valve opening, even though the cam is at maximum lift. Likewise, when the valve closes, the vibrating spring will lift the valve off its seat. Surge reduces the available spring load by opposing spring tension. To prevent surge, high-performance cam kits will include either inner springs wound in an opposite direction of the outer spring or damper coils. The inner spring prevents surge by vibrating at a different frequency, while the dampers actually rub on the inner surface of the valve spring coils to dampen the vibration.

Valve springs must be protected from corrosion by painting or plating. If surface damage starts, early fatigue and breakage will occur. Spring application is determined by rate and load; rate being the load in pounds that is required to deflect the spring a definite distance. Load is the maximum weight that the spring was designed to carry at a given height. Remember, valve spring height and tension are items which must not be overlooked when blueprinting a street or strip engine.

The valve springs are held in place on the valves by means of spring retainers and locks which fit into lock grooves machined into the valve stem. (See Figure 50.)

Seals are generally used on overhead valve stems to prevent oil from entering the cylinder between the stem and guide.

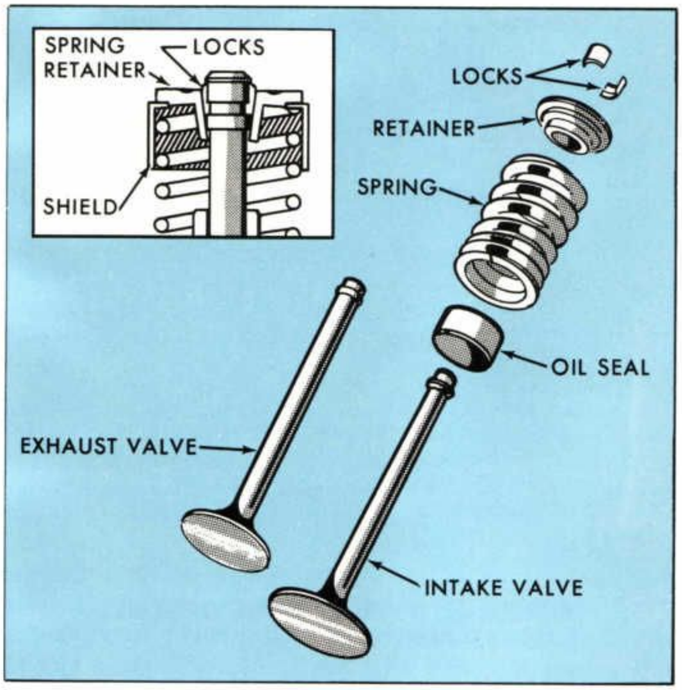


FIGURE 50. VALVE AND SPRING ASSEMBLY

ENGINE CAMSHAFT

The camshaft is, undoubtedly, the most frequently discussed component in the modern high-performance engine. It performs an extremely important function in the internal combustion process, yet it is probably the least understood of all the engine components. To the performance-minded, changes in carburetion, manifolding, valve size, cylinder volumes and compression ratios can be wasted effort if changes are not made in engine camming. Engines . . . stock or performance, are mechanical compromises and any modifications must, at best, be coordinated.

Camshaft Construction

The production engine of today uses a camshaft which is located in the center of the block directly above the crankshaft. (See Figure 51.)

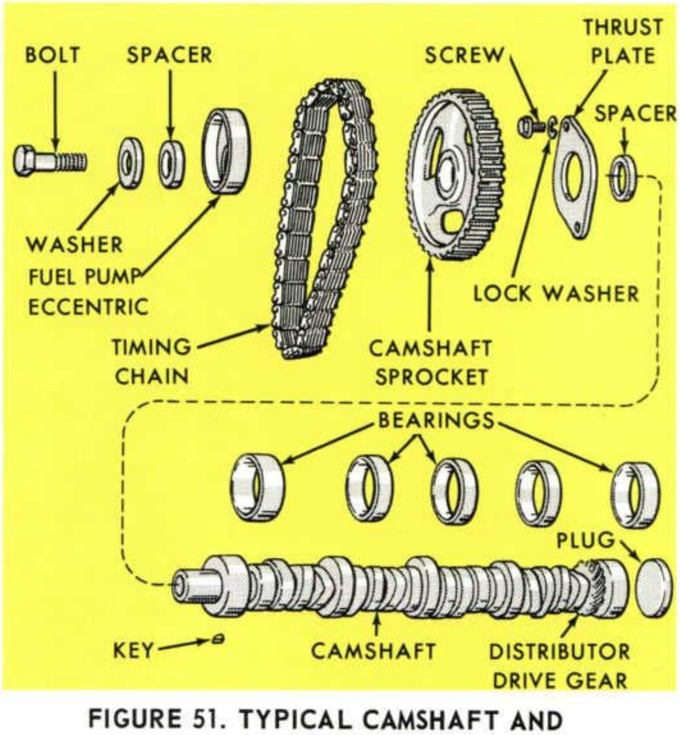


FIGURE 51. TYPICAL CAMSHAFT AND RELATED COMPONENTS

It is geared to the crankshaft and rotates in replaceable bearing inserts. Each bearing receives oil under pressure through a drilled passage from the main bearing immediately below it. Production cams can be made of either cast iron or cast steel. The camshaft consists of a number of lobes which open and close the valves, in relation to piston position, by means of lifters, pushrods and rocker arms in the O.H.V. engine.

Overhead Camshafts

Almost all current production automobile engines have overhead valves, but very few have overhead cams. The main reason for using an overhead camshaft (one located in the cylinder head) is to eliminate the need of reciprocating valve train parts. The positive cam/valve action allows for extremely high engine r.p.m.s with less possibility of valve float and virtually no possibility of high speed valve train failure. The idea of an overhead cam is not new, but dates back to the Peugeot racing car of 1912. However, overhead cams have come a long way since 1912. Today, you will read and hear about exotic full blown fuelers with DOHC or SOHC engines turning the quarter-mile at 6-second E.T.'s and speeds of 230 miles per hour. The DOHC (dual overhead cam) engine uses a total of four camshafts or two on each bank of cylinders. (See Figure 52.) The SOHC (single overhead cam) engine such as Ford's 427 uses one cam on each bank.

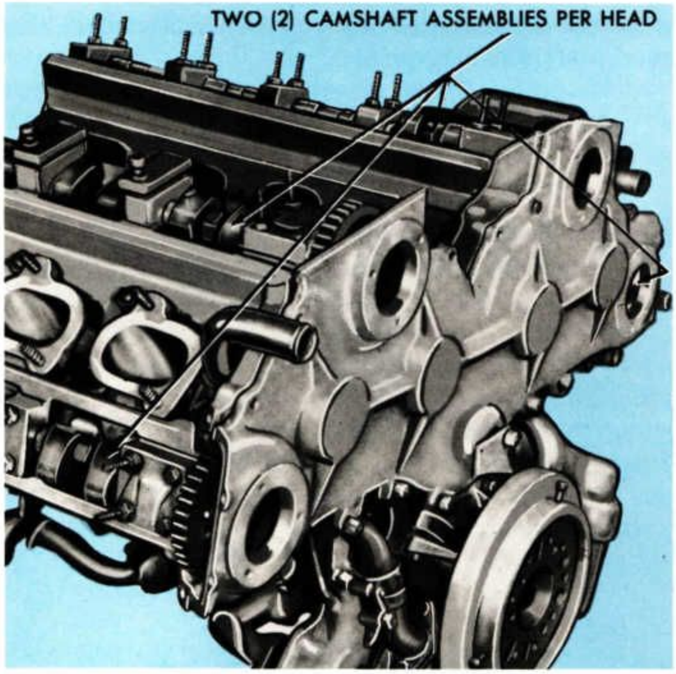


FIGURE 52. DOHC ENGINE WITH FOUR OVERHEAD CAMS

The overhead cam design has more than proven its worth in competition. This type of engine can develop from 600 to 1500 horsepower. However, for the average indivdual who's only interest is building a part time combination street/strip weekend warrior, the overhead cam engine is a bit too much. Even though, your girl friend or wife might get a kick out of hauling her groceries home in a 600-plus horsepower machine.

Camshaft Design Characteristics

In entering the world of performance, you will be faced with decisions regarding *cam profiles* or the amount of lift, rate of lift, duration and overlap. In order to make the right decision and pick the camshaft for the job, be it stock or all-out competition, you should have a basic understanding of cam design. We'll begin by recalling our earlier discussion on the four-stroke cycle. You may remember that the only time the air/fuel mixture could pass into the cylinder was when the intake valve was open; the only time burned gases could leave the cylinder was when the exhaust valve was open. These events were timed to occur with the intake valve opening at T.D.C. and closing at B.D.C. This was followed by compression, ignition and the power stroke. Then the exhaust valve was timed to open near B.D.C. and close at T.D.C. The exact timing of valve and ignition events in relation to piston position will largely depend on what is desired from the engine. Herein lies the function of the camshaft . . . to control the timing of these events in line with the final engine performance; be it fuel economy . . . smooth, efficient, low-end performance . . . or greater power output at high r.p.m.

There are three basic camshaft characteristics governing mixture flow, timing and overall engine volumetric efficiency. These three characteristics involve the design of the cam lobe or profile and are commonly referred to as lift, duration and overlap. Each has a vital effect on the incoming fuel charge as well as on the disposing of the exhaust gases after combustion has occurred. The difference in camshafts and engine performance involves these three characteristics. (See Figure 53.)

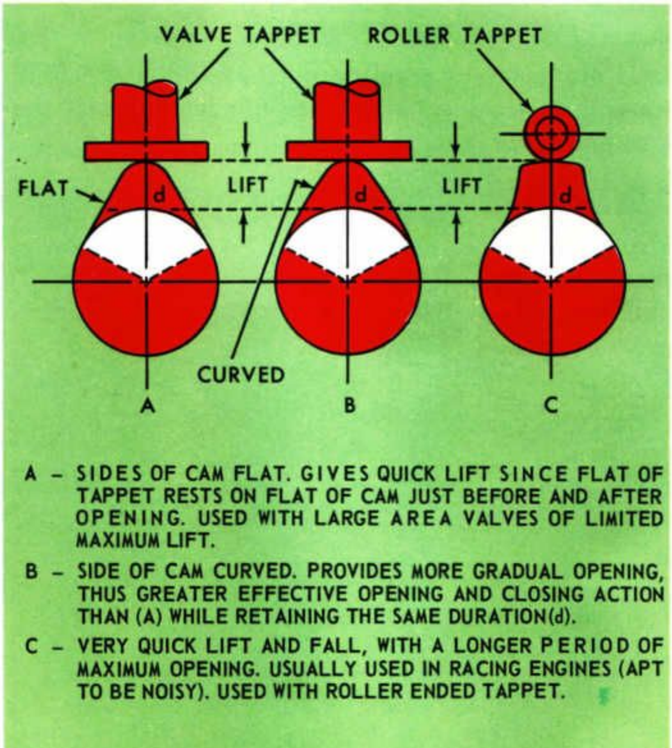


FIGURE 53. TYPICAL LOBE DESIGNS

VALVE LIFT

We'll start by discussing the first of these characteristics . . . lift. The distance that the valve travels off its seat is called the valve lift. It is normally expressed in decimal fractions of an inch (.426 for example) and can be physically measured with the engine assembled. Valve lift should not be confused with lobe lift. Lobe lift is a micrometer measurement of the cam lobe and is determined with the cam out of the engine.

Therefore, lift may be determined as either lift at the valve or lift at the cam lobe. Since overhead valve engines incorporate a rocker arm to actuate the valves, they create a lift which is more than the cam would cause by itself. To mathematically determine the lift at the valve, you must multiply the lift at the valve lifter (lobe lift) by the rocker arm ratio. For example, a stock 390 2V hydraulic cam has an intake lobe lift of 0.2470 and a rocker arm ratio of 1.73:1. Multiplying 0.2470 by 1.73, we get a theoretical valve lift of 0.4270. On engines with solid lifters, you would subtract the amount of valve lash from the lobe lift before multiplying.

RATE OF LIFT

A principle closely related to net valve lift is the concept of "rate of lift". Volumetric efficiency is influenced not only by net valve lift but by the rate of lift. For example, two camshafts may have the same net lift but the rates of lift may be different. (See Figure 54.)

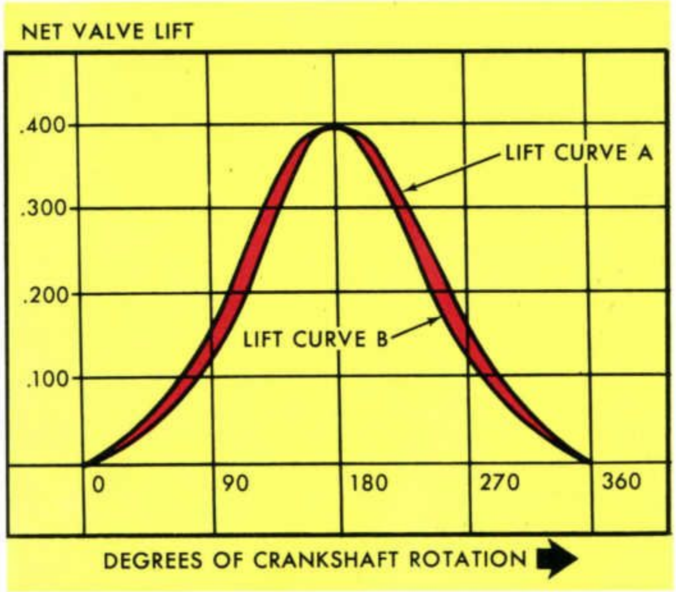


FIGURE 54. RATE OF VALVE LIFT

The graph in this illustration plots two sample cams having identical valve events with the exception of lift rates. From a theoretical standpoint, net lift and rate of lift both affect total gas flow into and out of the cylinder. In assessing the value of lift rates, one could turn to the recent finding that a noticeable volume of gas will flow only after the valve is several thousandths of an inch off its seat. Therefore, the increased area under the one curve in the graph indicates a possible difference in volumetric efficiency and engine performance, even though both cams have the same net lift. This quicker opening cam is difficult to detect in any kind of inspection short of tearing down the engine. Thus, there are some rodders running with these so called "cheater" cams which have a stock net lift but a faster rate of lift. In such cases, they are gambling on the possibility that the only thing the inspectors are going to check is the lift of the lobe. As a rule of thumb, however, high lift cams with a quick rate of lift improve engine volumetric efficiency at high r.p.m.

DURATION

The next design characteristic of the camshaft is known as duration and it occurs simultaneously with the lifting of the valve. Duration, or how long the valve is off its seat, is related to degrees of *crankshaft* rotation. The primary function of valve duration is to allow the incoming gases ample time to fill the cylinder with a fresh charge of fuel and air and more time to rid the combustion chamber of burned gases. To understand the meaning of duration, we'll consider the degrees of camshaft rotation in relation to crankshaft rotation. Remember, the camshaft controls timing events in relation to piston position. In the four-cycle engine, the camshaft is geared to the crankshaft and rotates half as fast as the crankshaft. This means that for every 360 degrees rotation of the crankshaft, the camshaft rotates 180 degrees. (See Figure 55.)

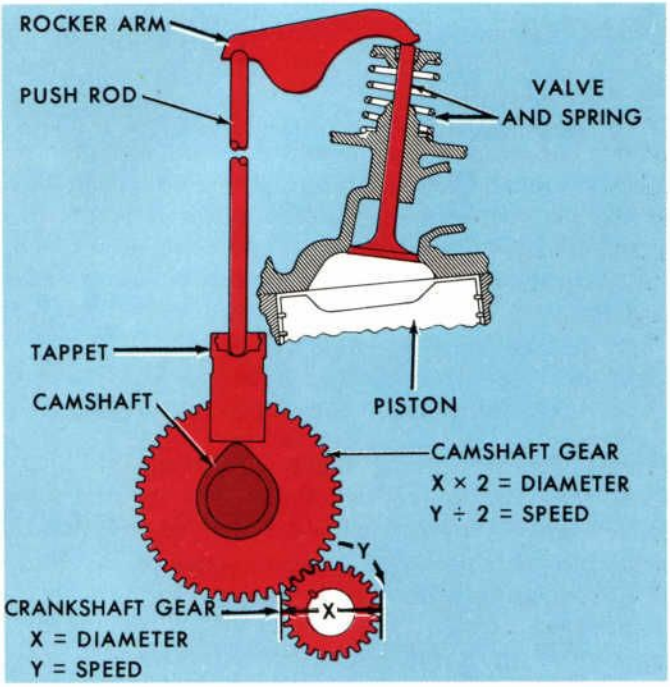


FIGURE 55. CRANKSHAFT-TO-CAMSHAFT GEAR RELATIONSHIP

When a camshaft is referred to as having 280° intake duration, this means that the intake valve will be off its seat for 280° of crankshaft rotation. Let's pause for a moment and reconsider the four strokes of our four-cycle engine.

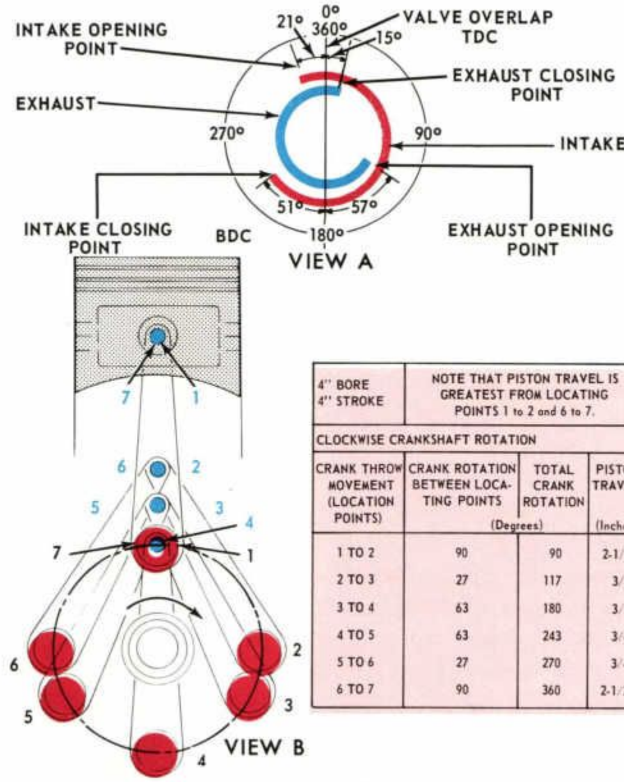
Review of Basic Valve Timing

Ideally, the intake valve would open when the piston is at T.D.C. and about to begin its intake stroke. It would close when the piston reaches the bottom of the stroke so that no intake mixture can escape when the piston starts up. The exhaust valve would open at bottom center after the power stroke and close at top center of the exhaust stroke. However, intake mixtures and the valve train parts possess static and dynamic inertia. This means that they are difficult to start in motion and also difficult to slow down, change direction, or stop, once they have started. Instead of trying to force the gases and valve train parts to attain their maximum speed immediately, valve timing events are started early in the cycle. This simply means that the intake valve gets a head start and opens before the piston reaches T.D.C. so it can be further open by the time the piston has actually started the intake stroke. The valve does not close until the piston passes B.D.C. because gas can still flow into the cylinder after the piston passes bottom center. The same conditions are true for the exhaust valve. This is the way valve events are actually timed in the modern automobile engine. This is also how valve duration can affect high speed engine performance.

Consider the fact that during high speed engine operation the in-rushing fuel mixture has a packing force or kinetic energy. If we can take advantage of this packing force by holding the intake valve open longer (duration), we could improve the engine's volumetric efficiency and power output at high engine speeds. This is why high-performance camshafts are designed with a longer duration . . . to provide more valve off-seat time and improve high r.p.m. mixture flow by taking advantage of the in-rushing, packing force of the fuel charge.

Overlap

Longer duration timing angles also bring into sharp focus the next cam characteristic. It is referred to as valve overlap. As previously explained, when camshaft profiles are changed for longer duration, it results in the opening and closing of intake and exhaust valves before and after T.D.C. and B.D.C. This, in turn, means that both intake and exhaust valves are going to be slightly off their seats at the same time during some period of crankshaft rotation. The period of crank rotation, when both valves are unseated is called valve "overlap". It is directly related to intake and exhaust valve timing (duration). If you change duration by opening or closing the valves earlier or later, the overlap period will be changed. (See Figure 56.) View A is a typical overlap schematic. View B relates piston travel to valve overlap.



4" BORE 4" STROKE	NOTE THAT PISTON TRAVEL IS GREATEST FROM LOCATING POINTS 1 to 2 and 6 to 7.		
CLOCKWISE CRANKSHAFT ROTATION			
CRANK THROW MOVEMENT (LOCATION POINTS)	CRANK ROTATION BETWEEN LOCATING POINTS (Degrees)	TOTAL CRANK ROTATION (Degrees)	PISTON TRAVEL (Inches)
1 TO 2	90	90	2-1/2
2 TO 3	27	117	3/4
3 TO 4	63	180	3/4
4 TO 5	63	243	3/4
5 TO 6	27	270	3/4
6 TO 7	90	360	2-1/2

FIGURE 56. VALVE OVERLAP AND RELATED PISTON TRAVEL

The primary function of valve overlap is scavenging residual or remaining gases by taking advantage of pressure variations existing in the cylinder at top dead center. Additionally, the outgoing exhaust gases help to "draw" in the next intake charge. Camshafts designed with a high lift, long duration and large overlap tend to work well in the high r.p.m. ranges, but they *can adversely affect low speed performance.*

The adverse low speed performance is understandable, since we know that horsepower is a function of pressure. And, effective cylinder pressures will decline in the low engine speed ranges due to the longer valve duration of high-performance camshafts. What actually happens is that at slow engine speeds the column of air and fuel is not moving as fast in the manifold and intake ports. So, the piston will push the mixture back into the intake ports when the intake valve opens before T.D.C. This is one of the reasons why a high-performance engine will lope and labor at idle with a sound that can make a hot rodder's blood churn with excitement.

As engine speed increases breathing ability is improved and the engine will "come to life" developing more power output at higher engine r.p.m. Some performance cams may have an overlap in excess of 70° and total valve opening time or duration of over 300°.

VALVE TRAIN ASSEMBLY

Up to this point, we've merely mentioned the valve train and pointed out its importance to high speed engine operation. However, when the time comes to choose a camshaft, you'll also have to decide on the type of lifter, pushrod and rocker arm to run in your modified engine. (See Figure 57.)

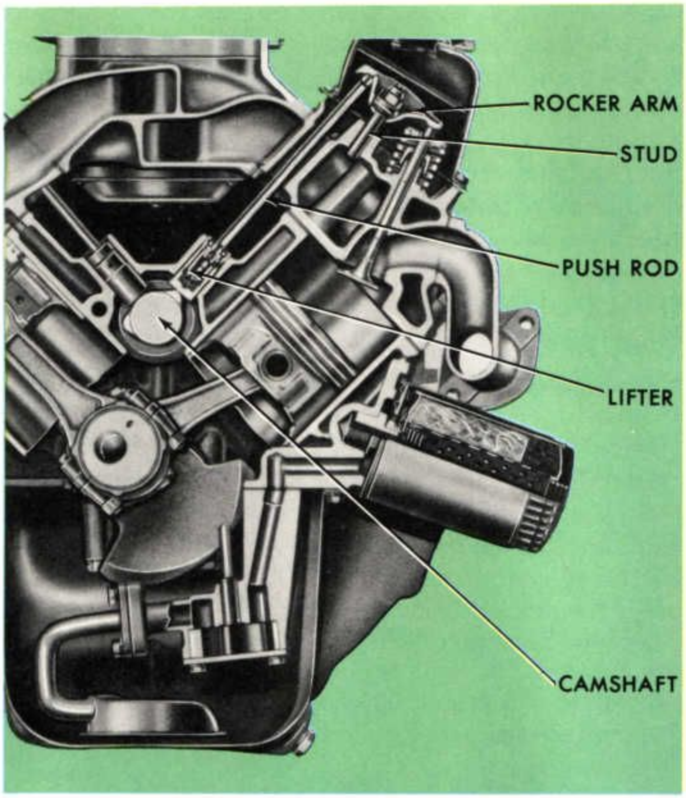


FIGURE 57. TYPICAL VALVE TRAIN

There are two basic requirements for an efficiently operating valve train. They are proper *weight* and *rigidity*. In a high-performance engine, the valve train should be light weight, yet rigid enough to withstand the increased r.p.m. The degree of rigidity needed is not only determined by engine speed, but also by the weight of the valve train components. If you are intent on modifying your engine for maximum performance, you must consider and compensate for the additional load which is likely to be placed on them. To make the right decision, you should have a fundamental understanding of valve train construction and operation.

Lifters

Lifters or cam followers are the link between the cam and the pushrod. They may be either solid or hydraulic, flat, convex, or a roller type. The shape and design depends on the design of the camshaft, the space available, and the type of engine performance required. For example, lifters may be designed with a spherical-shaped bottom which is about .002″ higher in the center than at the edges. This, in addition to a cam lobe designed with a taper of as much as .002″, will ensure even lifter wear. (See Figure 58.)

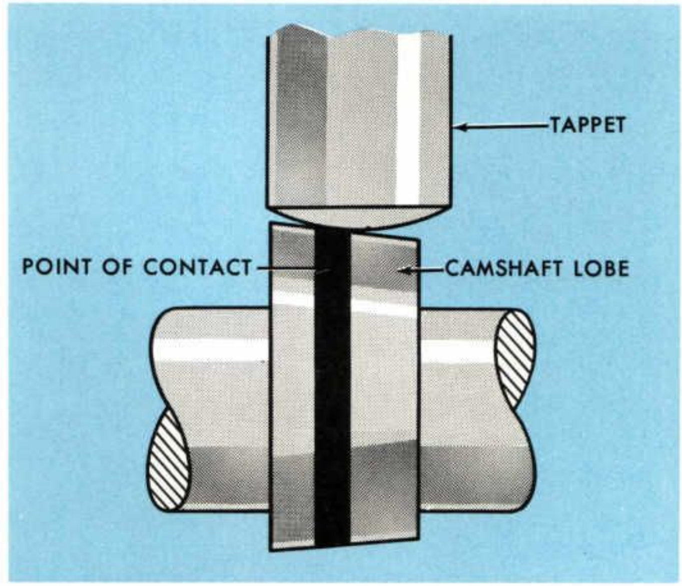


FIGURE 58. LIFTER AND CAM LOBE DESIGN

The tapered lobe causes the lifter to rub off-center and revolve in operation.

As the r.p.m. range of a high-performance engine passes the 5000 mark, a mechanical or solid tappet and camshaft set-up is generally used. Solids are more effective in maintaining proper valve lash and preventing high speed valve float than are hydraulic lifters. This is the primary difference between a solid and hydraulic cam set-up . . . the method of maintaining *valve lash.*

Valve lash is the provision which is made in an engine to allow for the heat expansion of moving valve train parts. The relative position of engine parts is changed by several thousandths of an inch as the engine warms up. If no initial clearance is built-in or provided by adjustment in the valve train, the valves will not seat when warm. This results in power loss and/or burned valves. With solid lifters, valve lash is adjustable and can be set periodically as valve and linkage wear progresses.

HYDRAULIC LIFTERS

The hydraulic lifter usually offers a self-adjusting means of maintaining the proper "lash" in the valve train. (See Figure 59.)

The hydraulic lifter consists of a body containing a plunger that is held up by a plunger spring. On the bottom of the drilled plunger is a one-way check valve, spring and retainer. The top of the plunger contains a cup in which the valve rocker arm pushrod rides. When assembled and in the engine, a channel and a hole in the side of the body matches an oil feed hole in the

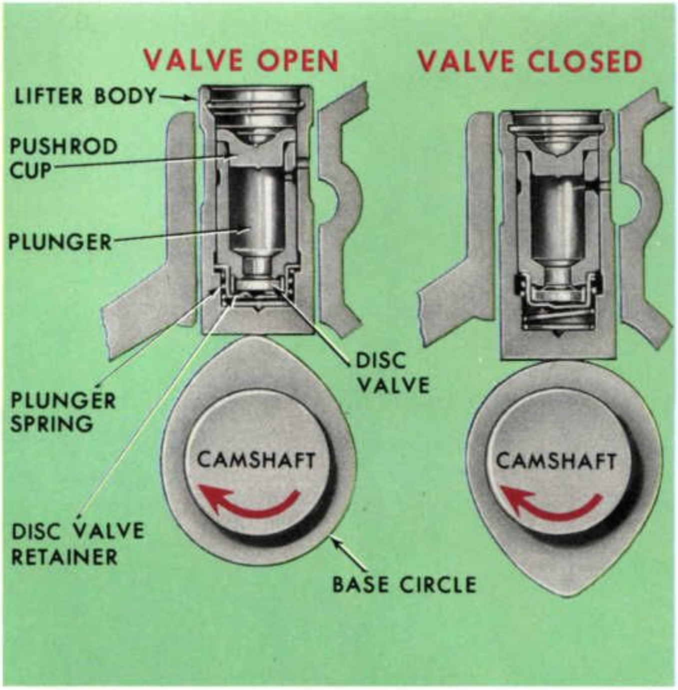


FIGURE 59. TYPICAL HYDRAULIC LIFTER

lifter bore in the cylinder block. During engine operation, when the valve is closed, the lifter is on the base circle of the camshaft lobe and the valve pushrod is in its lowest position. With the lifter in this position, the plunger spring expands, forcing the plunger upward, thus taking up any linkage clearance. As this occurs, the volume of the lifter compression chamber is increased, resulting in reduced oil pressure in the compression chamber. To equalize this pressure differential, the check valve moves off its seat to permit oil to flow from the supply chamber into the compression chamber of the lifter.

As the camshaft rotates, the lifter assembly is raised by the camshaft lobe. This increases the pushrod force against the lifter plunger and hydraulic pressure builds up in the compression chamber until it acts as a solid member of the valve operating mechanism. The lifter then becomes a hydraulic ram which forces the valve in the cylinder head to open. During this period, a slight leakage of oil past the plunger occurs (calibrated leak-down rate). As the high point of the camshaft lobe rotates and passes by the foot of the valve lifter, the valve in the cylinder head seats and the lifter assembly is forced downward. Reduced force on the lifter plunger at this time relieves the pressure on the lifter plunger and it is free to be moved upward by the plunger spring. This action allows oil to flow once again through the oil holes in the lifter body and plunger. The cycle is repeated every revolution of the camshaft. Zero clearance (lash) in the valve train mechanism is maintained at all times by the hydraulic force and expansion of the plunger spring between the lifter body and plunger.

The main disadvantage of hydraulics is their tendency to pump up (hold excessive trapped oil); thereby changing valve train adjustments (lash) at high engine speed. This results in a loss of compression and horsepower since valves are held off their seats too long during high speed operation.

Although hydraulic lifters may not maintain proper valve lash at high r.p.m., there have been improvements in hydraulic cam lobe profiles and lifter design which extend r.p.m. capabilities from the 5000 to 7000 range. The design changes usually involve an anti-pump up mechanism or relief port. When the lifters pump up from engine over-revving, the relief port opens allowing the release of excess oil trapped in the lifter compression chamber.

ROLLER LIFTERS

There is one other type of lifter occasionally used in high-performance engines. It is called the roller lifter. In general, rollers create less drag and impose less loading on cam lobes than do regular solid lifters. This permits more rapid and efficient valve operation at high speeds. Some cam manufacturers claim that rollers will allow engine revving well over 10,000 r.p.m. without valve float. The cam used with roller tappets generally has a very quick lift and fall rate with a longer period of maximum valve opening (duration). (See Figure 60.)

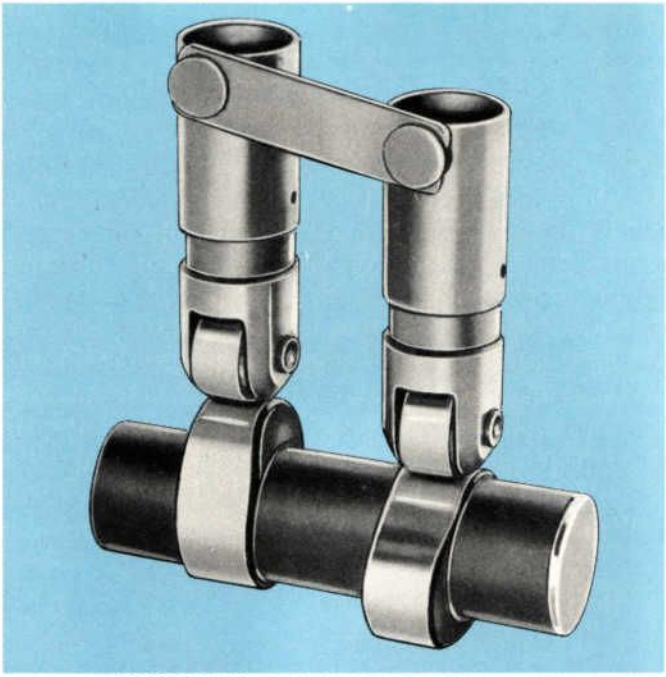


FIGURE 60. ROLLER CAM SET-UP

In addition, the cam lobes are not tapered, but are designed with the faces perfectly square with the shaft.

Pushrods

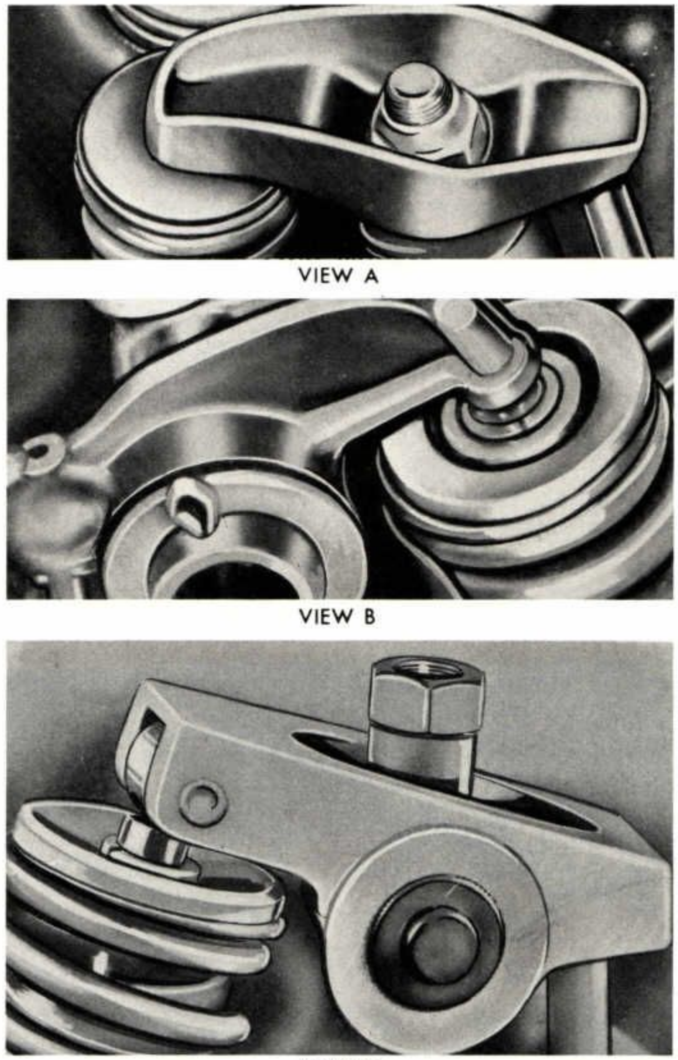
Pushrods can deflect under load and this must be taken into consideration when you lay out the plans for that high-winding weekend warrior of yours. Most high performance pushrods are a chrome-moly tubular steel design. This type of pushrod is both light-weight and rigid and subsequently offers good high speed operating characteristics. Pushrods may be either adjustable or non-adjustable. The adjustable pushrods are generally used when a hydraulic cam is replaced with a solid lifter cam.

Rocker Arms

The rocker arms used in most of today's O.H.V. engines serve a dual purpose. They receive the motion of the cam on one end and multiply it by the ratio of the rocker arm while transferring it to the valves. For those of you who plan to have a slide rule at hand when building your engine, the ratio of the rocker arm is the distance from the center of the pushrod contact point to the center of the rocker shaft. This distance is divided into the distance from the valve stem to the center of the rocker shaft. (Measurements are taken from the center of the stud hole on some engines). This ratio is approximately 1.5:1. Rocker arms may or may not be adjustable depending on the design of the camshaft and the type of lifter used. Most high-performance camshafts use adjustable rocker arms and a solid lifter cam to maintain proper valve lash at high engine speeds. Some rockers are pivoted on studs pressed or threaded into the head; others are supported by hollow shafts through which the oil supply is routed. (See Figure 61, Views A and B.)

For high speed engine operation, the pressed-in rocker studs should be replaced with threaded ones. If you are going all-out you may decide to use special high-performance rocker arms. These ultra high-performance rocker arms are usually made of a light-weight, high strength aluminum and feature a needle-bearing roller which contacts the tip of the valve stem. (See Figure 61, View C.)

An important point to keep in mind, when modifying or blueprinting an engine for performance, is rocker arm geometry or the rocker arm-to-valve tip relationship. Improper alignment can result in increased valve side loads, rapid wear of valve guides and other problems. So always check rocker arm geometry when blueprinting or whenever making any engine modifications affecting the valve train.



VIEW A

VIEW B

VIEW C

FIGURE 61. ROCKER ARM TYPES

RELATION OF CAMSHAFT TO VALVE TRAIN ACTION

Our coverage of the camshaft and valve train has been aimed at helping you develop a fundamental understanding of the various component designs and operation as they relate to engine performance and power output. In regard to camshafts, we can say that, in general, short valve duration and moderate lift are usually used when the desired engine characteristics are smooth idle, good low speed torque, and a reasonable but conservative top speed. On the other hand, long-timed (long duration), high-lift cams normally improve engine performance in the high r.p.m. range. *However, a word of caution is in order to those of you who are considering a quick swap to a wild grind cam for improved breathing at high r.p.m.* When any attempt is made to increase the duration of opening lift, or speed of valve lift, one or a combination of the following conditions may be encountered. The resistance of valve train components may be such that an oil film cannot be maintained between mating parts and metal surface damage can result. Inertia forces at high speed act to maintain the speed and direction of moving parts. For example, if the valve train parts weigh ¾ of a pound, a force of about 67 pounds is necesary to hold them against the camshaft at 3600 r.p.m. Any increase *in r.p.m. results in a corresponding increase in the force* required to hold the valve train intact. If the cam is changed to increase the engine r.p.m. range, and proper compensation is not made in the valve train . . . parts could fly away from each other and become damaged when they again come in contact. Acceleration forces of some cams could be great enough to bend or break pushrods, valves, rocker arms, shafts or supports. A common high speed failure is due to a valve not closing rapidly enough (valve float). When this occurs, it results in piston and valve interference and a possible unglued engine. In other words, *don't* use the valve lifters or other valve train components if a new shaft is installed . . . *don't* intermix parts such as using solid lifters and a hydraulic design cam, and *above all* . . . make sure that valves, springs, retainers, pushrods and lifters match the characteristics of the cam. *Don't* gamble on ruining the cam and possibly the entire engine just to save a few dollars. (See Figure 62.)

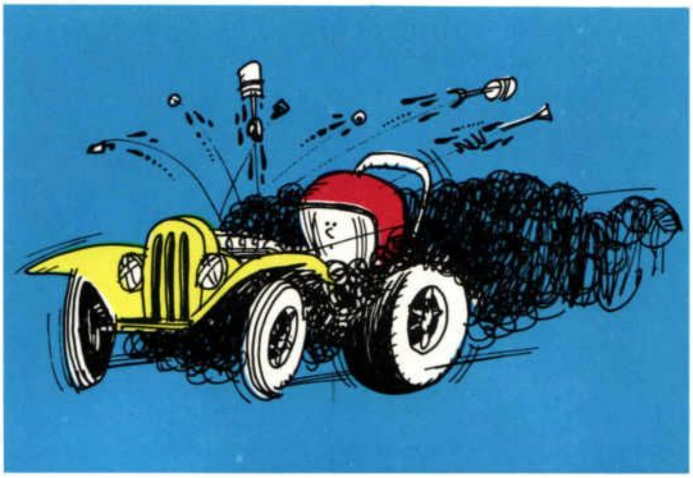


FIGURE 62. ECONOMIZING CAN BE COSTLY

Maintaining the proper relation between cam design and valve train components by coordinated modifications is important to overall engine performance and can mean the difference between winning or losing a competitive event.

PREPARATIONS FOR IMPROVED PERFORMANCE

CYLINDER HEAD PREPARATION

Proper cylinder head preparation is a necessary prelude to other service and modification operations involving the heads such as CC-ing, porting and polishing, milling and valve work. To begin with, the heads should be boiled out, sandblasted or scrubbed with a wire brush and visually inspected to check for cracks or casting defects. They should then be dried with compressed air to prevent rusting. All oil and water passages should be checked and cleared of obstructions. The next thing to check for is head trueness. Even new heads can be as much as .014-inch out of level from end-to-end. To make this check the heads should be smoothed and cleaned. A level bar should be used in conjunction with a .004″ strip gauge to test for clearance. (See Figure 63.)

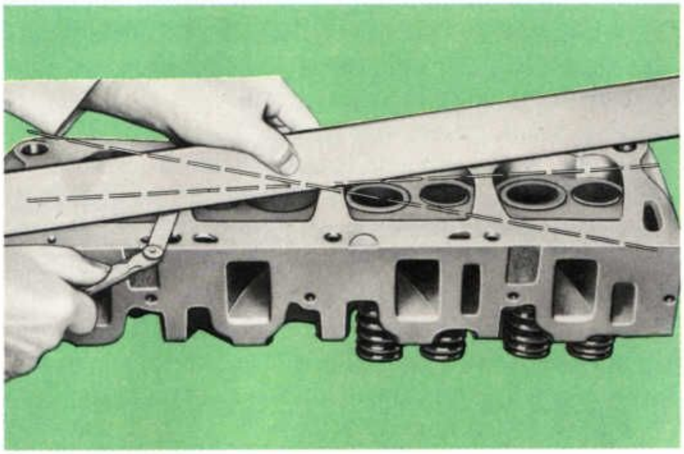


FIGURE 63. CHECKING CYLINDER HEAD TRUENESS

Normal head torquing will usually take up variations up to this limit. Head trueness should be checked, lengthwise, crosswise and in two diagonal locations. A flat head surface is essential to high speed engine operation and, if it proves necessary, a milling cut sufficient to true the heads should be performed by a qualified machine shop. Make certain that the combustion chambers are smooth and free of sharp edges which might hold heat and cause detonation.

CC-ing

CC-ing, or head spec-ing, is an essential part of blueprinting an engine. Equalizing combustion chamber volumes can mean the difference between winning or losing. It can also mean the difference between being legal and illegal for the class you're running in. Before you begin the actual CC-ing operation, you should make certain that the valves are seated and the spark plugs you intend to run are installed in the head. To CC the heads you'll need a piece of clear plastic and a burette. The plastic should be about ½-inch thick and large enough to cover the combustion chamber. The burette is graduated in cubic centimeters (most burettes break this down into tenths of a CC which is just right for head spec-ing). A burette is nothing more than a tube with a petcock at the bottom, which allows you to accurately dispense a measured amount of liquid into the combustion chamber. It should have a capacity of at least 250 CC. You can use any of a number of liquids combined with a little dye, such as kerosene, alcohol or a mixture of automatic transmission fluid and a solvent. Plain water with a touch of coloring can also be used. However, it does not flow readily into small spaces. The CC-ing operation itself is quite simple, as you will see when reading the following procedure. However, CC-ing can be tedious and will require a certain amount of patience. (See Figure 64.)

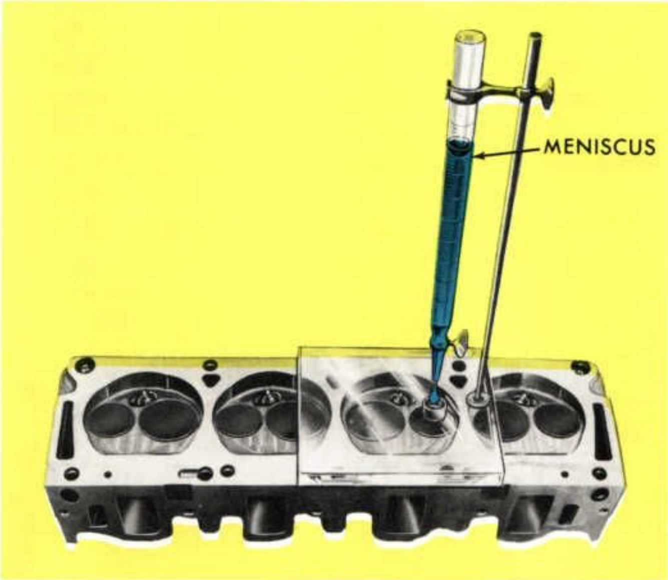


FIGURE 64. CC-ING

1. Secure the cylinder head on a work bench and make certain that it will not move during the measuring operation. Use a level to keep the head surface horizontal.
2. Drill a hole through the plastic. It can be tapered or made large enough to permit the entry of the fluid and the exit of air.
3. Use a light grease to coat the area around the chamber to be measured. This will provide a seal around the plastic. Make sure that the valves are in place and the spark plug is threaded all the way in. Then carefully set the plastic over the chamber.
4. Fill the burette with the liquid and position it over the hole in the plastic plate. Slowly open the petcock and fill the chamber with fluid, making sure that all air is out of the chamber before stopping.
5. Read the burette at the bottom of the meniscus (bottom of fluid) and record the amount of liquid used to fill the chamber. Repeat the entire procedure for each combustion chamber and record your results.

If you find a difference in volumes, there are a number of methods you can use to equalize the chambers. For example, the combustion chamber volumes can be equalized by milling the head, polishing the chambers or sinking the valves. However, valve sinking can disturb the air flow characteristics of the head and polishing can alter combustion chamber shape and cause disrupted flame travel. If you chose either of these methods, you should take care to avoid these complications.

Porting and Polishing

Like everything else about automotive engine modification, the time honored practice of enlarging or reshaping and polishing cylinder ports is being challenged by a scientific approach to port design. In the past, porting and polishing was a trial and error type of operation with the hot rodder hogging out the ports as far as possible and then polishing them to a mirror finish, all in the hope of increasing air flow and power output. Today, however, there are several schools of thought and a great deal of debate about the benefit of indiscriminately grinding out head ports. Stock cylinder heads are precision cast and the ports are scientifically designed, by using high-velocity flow testing equipment, to deliver the maximum possible mixture flow for a given R.P.M. range. Many people involved in engine air flow research or the investigation of internal aerodynamics will attest to the fact that enlarging ports and polishing runners can, in some cases result in a horsepower drop. For example, the little bumps or protuberances in the intake and exhaust passages have long been favorite areas of attack for the speed buff and his polishing stone. However, these little bumps or protuberances are often an intentional design feature of the passages to keep the incoming fuel atomized or suspended in the air. In such cases, a perfectly smooth finish might cause the fuel to cling to the port rather than being blown free immediately. On the basis of some air flow research, mixture flow can be significantly increased by a slight amount of grinding which does not drastically alter the basic port characteristics. All of these findings, however, do not completely discount the value of porting and polishing. If you've tried porting and polishing and felt the results when you hit the accelerator, then all the theories and arguments in the world won't change your mind as to the benefits of this type of engine modification. For those of you who are convinced that porting and polishing offers the solution to your search for additional horsepower, we have included the following service tips.

- If you don't intend to increase carburetion and compression or use a wild grind cam and larger intake valves, you should concentrate on enlarging and reshaping the exhaust ports.
- Use the new manifold gasket as a template and scribe the outline of the gasket port holes on the head. A blue dye painted on the port surface area will make the scribe lines visible.
- Make sure that you have a good idea of the port

wall thickness so that you don't remove too much stock and break through into the water passages.

- Use a hand drill and rotary files to remove large amounts of metal. Make certain that you stay within the scribe lines. The balance of the grinding down to the final polishing should be done with abrasive stones.
- When enlarging the ports, try to round the cross-section shape and make the passages as straight as possible. (See Figure 65.)

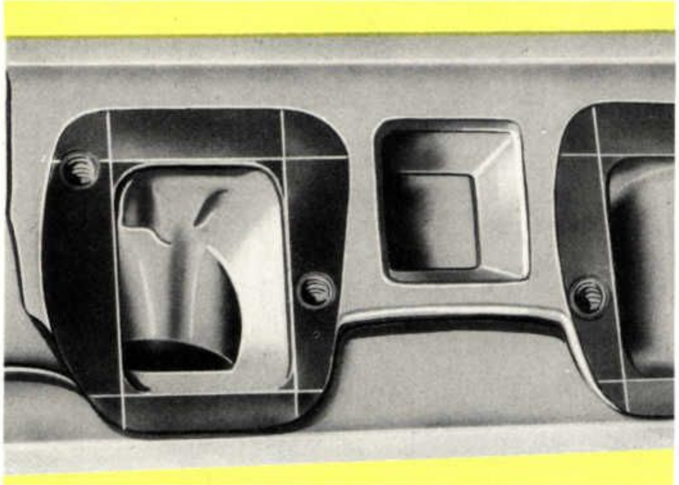


FIGURE 65. PORTING AND POLISHING

Rounding the corners of a rectangular port will help reduce turbulence and increase mixture flow.

Increasing Compression

Cylinder filling or volumetric efficiency is one aspect affecting engine horsepower output. However, horsepower can also be thought of as a function of cylinder pressure. Increase pressure and the result should be an increase in horsepower. The compression ratio is the obvious and most common way to evaluate cylinder pressure. If you can increase the engine's compression ratio, you will increase cylinder pressure and horsepower.

The three most common methods of achieving more compression are: (1) add special pistons with deflector domes; (2) mill the cylinder heads or block; and (3) use thinner head gaskets. (The first method of increasing compression will be discussed in detail later in the text.) The most popular and least expensive methods are the last two . . . thinner head gaskets, if available, or milling the cylinder heads.

Head Gasket Selection

In an engine built for high performance, the function and construction of the head gasket become items of extremely critical importance. A blown head gasket, besides costing a race, can result in severe engine damage. So if you're thinking of changing head gaskets to increase compression and performance, the starting point is to select the proper gasket for the job to be done.

When selecting a head gasket, you will find a wide range of types including fused aluminum steel and asbestos, solid copper alloy, stainless steel and steel shim, and the copper or steel O-ring gaskets used in some blown fuelers. If you are a part time performance enthusiast with a limited budget, the thin or steel shim head gasket offers an easy and inexpensive way to boost engine compression ratios. For example, a .010″ reduction in gasket thickness can result in an approximate 2.19 cc decrease in combustion chamber volume for a four-inch bore engine. This means that the air-fuel mixture will be packed into a smaller space with the net effect being an increase in compression ratio and engine output. Ford Motor Company offers a number of high performance steel shim head gaskets for their small and big block engines. These gaskets (one of which is illustrated in Figure 66) can boost compression by half a point or more.

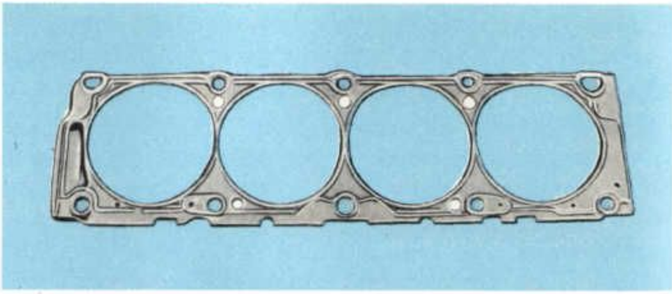


FIGURE 66. FORD STEEL SHIM HI-PER HEAD GASKET

The gasket illustrated is .030″ thick when installed compared to the stock gasket at .050″. It's recommended for use with standard as well as competition Hi-Per Ford heads. Whatever the case may be, whether you're building a "streep" machine or a full blown fueler, the head gasket you choose *must* provide both *strength* and *sealability*.

Head Gasket Installation Tips

- The most important thing to consider when installing head gaskets is *surface preparation*. Head and block mating surfaces must be smooth, even and free of foreign substances.
- Check intake manifold alignment when changing head gasket thickness. Manifold milling or different intake manifold gaskets may be required.
- Use a sealant recommended by the gasket manufacturer (non-hardening types are generally used). The gasket, head and block mating surfaces should be covered with a *thin* uniform coating. Care should be taken not to plug lubrication cham-

bers or water passages. After the sealant has been applied, carefully position the head gasket on the block.

- To aid in proper bolt torquing, it is advisable to clean the bolt holes by running a tap through them while the heads are off the engine. Install the head and follow the manufacturer's spec's and tightening sequence.

HEAD MILLING

Head milling can be another low cost, acceptable method of increasing compression and horsepower. In the past, shaving the heads was a quick and easy way to boost compression, add a few horses and get an extra bit of kick out of your engine. (See Figure 67.)

FIGURE 67. JUST "PLANE" HEAD MILLING

Most speed shops could easily handle the milling job, and all you needed to know was how to remove and install the heads. At the time, milling was a pretty good bet and an easy way to increase horsepower.

However, the modern OHV engine, with its wide variety of combustion chamber and piston designs, etc., makes head milling an operation requiring more careful consideration as to its consequences and final results. Normally, and in most cases, you would expect combustion chamber efficiency to increase after the heads are milled. *However, combustion efficiency could just as easily decrease because of altered or disrupted flame travel across the piston top.* Remember, control over flame travel is one of the many items considered in the design of the combustion chamber and the piston. Head milling can alter this design relationship. This is not to say that cutting a little metal off head surfaces won't result in a few extra horses. It is merely intended to remind you that any performance modification should be planned, coordinated and well thought out in advance. Remember, there are many high performance pistons available, designed to obtain results very similar to those of head milling. Namely . . . an increase in compression and horsepower.

Once you have considered all the alternatives and decided that head milling is the route to take, then the major problems facing you concern how much to cut and with what consequences. The milling process itself is a very exacting operation, which can only be performed by an automotive machine shop equipped with the proper machinery. (See Figure 68.)

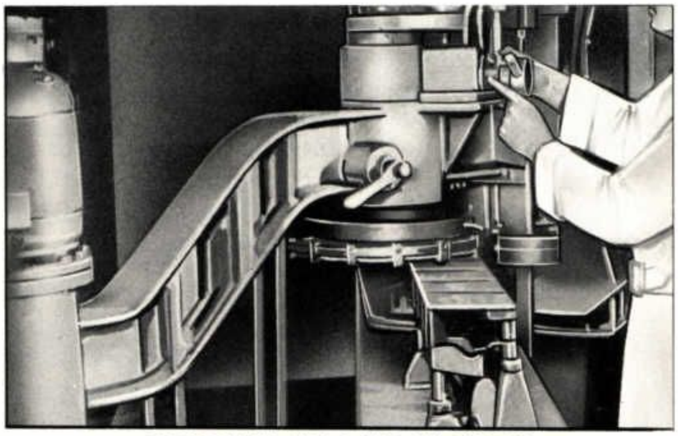


FIGURE 68. MILLING MACHINE

It is a common practice to mill cylinder heads from .010 to .040″ and more. There are, of course, physical limitations to the amount of stock that you can mill from a particular head, such as deck or casting thickness and valve-to-piston clearance. If the cut is to be a minor clean-up pass, as may be the case when equalizing chamber volumes or trueing the heads, then you need not be too concerned about changes in combustion efficiency or alignment problems. However, if the cut is of major dimensions (.010″ and more) you should know what the consequences may be in terms of combustion efficiency, manifold, port and bolt alignment problems, cam loading, piston/valve clearance, and changes in valve train geometry.

CONSEQUENCES OF HEAD MILLING

The following items should be taken into consideration when milling heads and, in some cases, when using thinner head gaskets:

- Compression should not be increased on an engine that is not in top mechanical condition.
- Make certain that the head casting is basically

true. The cylinder heads should be thoroughly cleaned and prepared, before the milling operation is undertaken.

- Generally speaking, it is not advisable to mill cylinder heads in excess of .050". Too much of a cut can result in head flexing under combustion pressures.
- When milling cylinder heads or block surfaces, it may also be necessary to mill the intake manifold or the manifold-side of the head to bring port and bolt holes into alignment and insure a good gasket seal. If the cut is minor, port and bolt alignment could possibly be corrected with a thicker or additional gasket between the intake manifold and heads and/or slight elongation of intake manifold bolt holes.
- On engines having hydraulic lifters with non-adjustable rockers, make certain that the lifters are not over-loaded. If the heads are brought closer to the cam by milling or using thinner gaskets and the pushrod length is not altered, the hydraulic lifter inner bodies could be shoved deep into the lifter's main case. This could result in lifter failure and possible engine damage.
- Valve train geometry is altered whenever the heads are moved closer to the cam. On engines having rocker arm shaft supports, the rocker arms can be set to the proper attitude by adding steel shims under the supports. The shim should be approximately the same thickness as the amount milled from the head. If you use shims make certain that they do not block the oil passage provided in the head and rocker arm supports.
- When using thinner head gaskets or milling the heads on a solid cam setup, make certain that you check and adjust valve lash to specifications.
- One of the *must* operations when milling cylinder heads is to determine the valve-to-piston clearance. This operation should be performed on *all* cylinders in accordance with the procedures covered in this manual under the heading "Checking Valve-to-Piston Clearance." Don't panic if the clearance doesn't meet specifications in some cylinders, In many cases, piston tops can be eyebrowed or cut to allow for proper clearance.
- Increasing compression may necessitate a change in spark plug heat range to insure proper ignition. Heat range selection is covered in detail under the Ignition Section of this manual.

Determining how much to mill from the heads can be a perplexing problem. In making this decision, remember that too much of a cut could not only result in various complications but it could also make your engine "illegal" for its class.

Head milling charts are provided in the Appendix Section of this manual for your convenience in determining the correct amount of stock to remove.

ALTERED COMPRESSION RATIO

Once you have shaved the heads or switched to a thinner-than-stock head gasket, you can forget about the original "stock" compression ratio. This also holds true for alterations of combustion chamber volumes, cylinder boring, crankshaft stroke changes and changes in piston design. To accurately determine the new compression ratio, two measurements must be made. The first is cylinder volume and the second is combustion chamber volume. Once these measurements have been made the *new* compression ratio can be determined by using the formula discussed in the Introduction of this manual.

VALVES

In most cases, the average individual will leave a valve job to the skill and competency of an experienced machinist. This is probably the best and safest thing to do when building your engine. However, for those who are interested in what it's all about, we have included the following information on valve jobs. We haven't included the entire story, however, since many of the operations such as checking valve seat/face runout, valve stem clearance, push rod runout, etc., are all part of normal engine service. Instead, we have decided to cover those operations which are of particular importance to engine blueprinting or modification for high performance.

REFINISHING VALVE SEATS

Refinishing the valve seat should be closely coordinated with the refacing of the valve face so that the finished seat and valve face will be concentric and the specified interference fit will be maintained. This is important so that the valve and seat will have a compression-tight fit. Be sure that the refacer grinding wheels are properly dressed. For high-performance application, some Ford blueprint spec's call for an intake valve seat and face angle of 30° and exhaust valve seat and face angles of 45°. When grinding valve seats, remove only enough stock to clean up pits and grooves or to correct the valve seat runout. On the valve seats of most Ford engines a 60° angle grinding wheel can be used to remove stock from the bottom of the seats (raise the seats) and a 30° angle wheel can be used to remove stock from the top of the seats (lower the seats). (See Figure 69.)

On *stock* engines, the finished valve seat should contact the approximate center of the valve face. However,

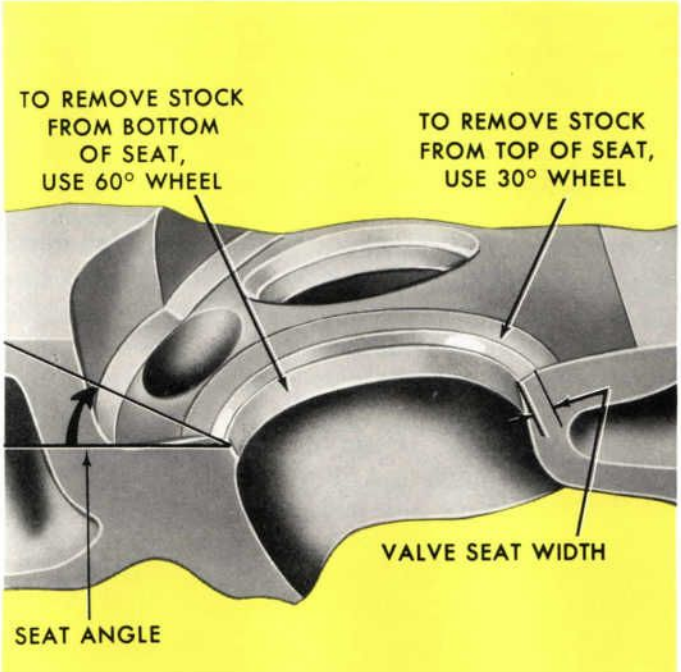


FIGURE 69. VALVE SEAT REFINISHING

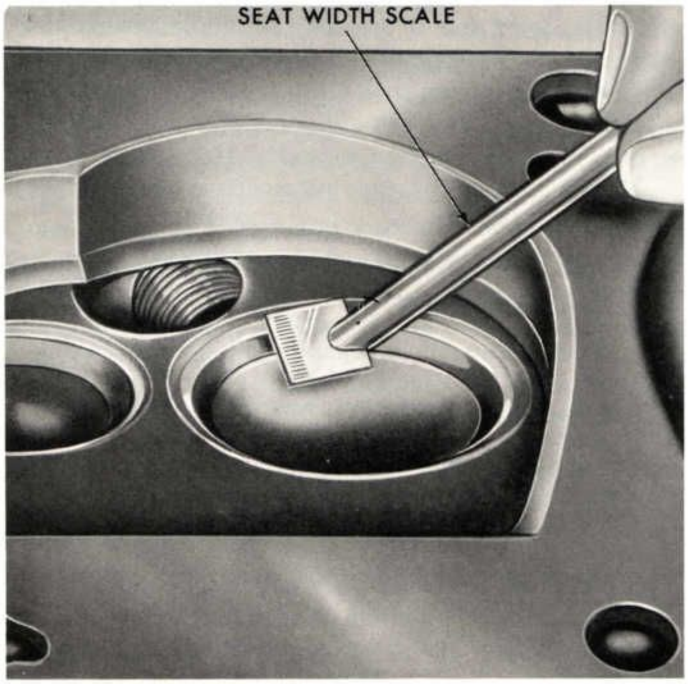


FIGURE 70. MEASURING VALVE SEAT WIDTH

for high-performance engines, valve seats should contact the valve face as far out on the edge of the valve as possible. This will provide a larger effective valve opening and improve engine breathing. The point of valve seat and face contact can be determined by using machinist bluing. Coat the seat with bluing, set the valve in place, and rotate it with light pressure. The bluing will transfer to the valve face giving you a visual means of determining the point of contact.

VALVE SEAT WIDTH

After the seat has been refinished, use a seat width scale or a machinist scale to measure the seat width. (See Figure 70.)

Stock seat widths generally run from between .050"-.080". This allows for more efficient heat transfer during periods of engine idle and low speed operation. Blueprint spec's for Ford engines specify an intake seat width of .035" and an exhaust width of .050" *for drag strip racing only*. Remember, valve seat width is critical. A valve seat that is too wide can cause carbon deposit accumulation in valve pockets; a seat which is too narrow won't dissipate valve head heat adequately.

REFACING VALVES

If the valve face runout is excessive and/or to remove pits and grooves, you should reface the valves. Remove only enough stock to correct the runout or to clean up the pits and grooves. If the edge of the valve head is less than 1/32-inch thick after grinding, replace the valve as the valve will run too hot in the engine. *The interference fit of the valve and seat should not be lapped out.*

Remove all grooves or score marks from the end of the valve stem, and chamfer it as necessary. Do not remove more than .010-inch from the end of the valve stem. The valve stem from the valve lock groove to the end must not be shorter than the minimum specified length.

If the valve and/or valve seat has been refaced, it will be necessary to check the clearance between the rocker arm pad and the valve stem with the valve train assembly installed in the engine.

REAMING VALVE GUIDES

If it becomes necessary to ream a valve guide to install a valve with an oversize stem, a reaming kit is usually available from the manufacturer. Many engine builders prefer to knurlize the guides prior to the reaming operation. Knurlizing will actually decrease the diameter of the valve guide bores, making is possible to restore worn guides.

When going from a standard size valve to an oversize valve, always use the reamer in sequence. Always reface the valve seat after the valve guide has been reamed, and use a suitable scraper to break the sharp corner (I.D.) at the top of the valve guide.

INSTALLING LARGER VALVES

Using larger valves may or may not improve engine breathing ability. Larger valves run hotter than smaller ones and they are heavier as well. This could mean burned valves or high speed valve float if the proper precautions are not taken. In addition, you are apt to encounter valve shrouding by the combustion chamber walls. So, don't rush to larger valves and expect enormous gains in horsepower. In many cases, increasing valve size will necessitate other modifications such as chamfering or boring the cylinders and using deflector or dome type pistons to achieve the best results. If you do decide to install larger valves, keep the following points in mind:

- Use a hand-operated reamer to remove large amounts of stock.
- Measure the face of the new valve and stop reaming when the diameter of the reamed hole equals the smallest diameter of the valve face.
- It may be necessary to remove some stock from the combustion chamber walls to reduce valve shrouding and improve mixture flow.
- Check piston-to-valve clearance.

VALVE SPRINGS

For satisfactory high-speed engine performance, it is important that valve springs be tested and properly installed. The valve springs should be tested before installation to insure that the spring tension meets specifications. A spring testing fixture should be used to measure "full open" pressure and "seat" (fitted dimension) pressure. When checking the inner spring on a dual spring set-up, remember that the inner spring rides on a stepped portion of the spring retainer. (See Figure 71.)

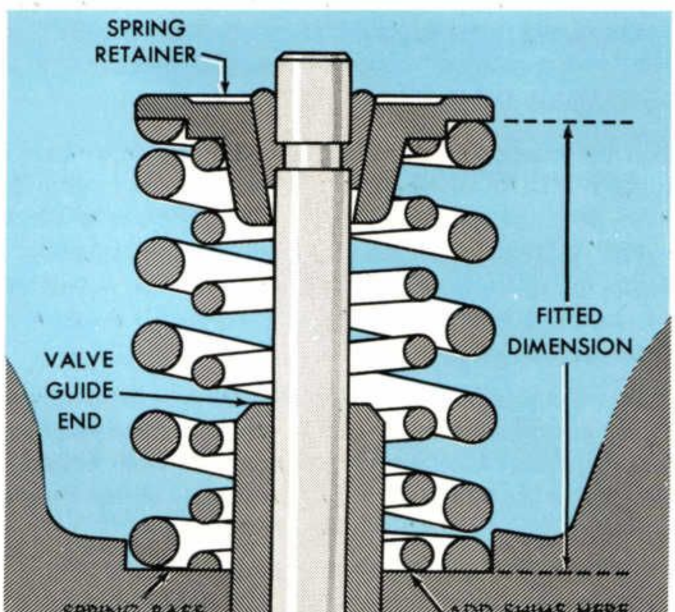


FIGURE 71. SPRING AND RETAINER

You will have to allow for this by compressing the inner spring more than the outer spring. For example, if the step measures 1/16-inch, the inner spring must be compressed 1/16-inch more than the outer one. When the spring is at "full open" pressure, you should also check for coil stacking or coil bind. Coil bind can ruin the valve train. If you can slip a .010 to 012" feeler between each coil, you will have an ample safety margin of approximately .060" at maximum lift. On some high-performance cam kits with inner and outer valve springs, it may be necessary to reduce the diameter of the valve guides to permit installation of the inner springs. In addition, the outer spring seats may have to be enlarged to accommodate the larger spring diameter. This can be accomplished by using a special counterboring tool available from most speed shops. Once the springs are installed, you should check the "fitted dimension." (Refer to Figure 71.) Measure the spring proper only, and do not include the thickness of the retainer. If your measurement is *less*, you will have to counterbore the difference in spring seat depth. If your measurement is *more* than the specified fitted dimension, you will have to use spacer washers to make up the difference.

Another important item which should be checked is spring retainer to valve guide clearance. Proper clearance is of critical importance when you switch to a high-lift cam. This operation should be performed with the valve train assembled and adjusted to specifications. Rotate the crank, until the valve spring is completely compressed and the valve is in the full open position. With the valve in this position, there should be a 1/16-inch to 1/8-inch safety margin or clearance between the valve guide end and the spring retainer. (See Figure 72.)

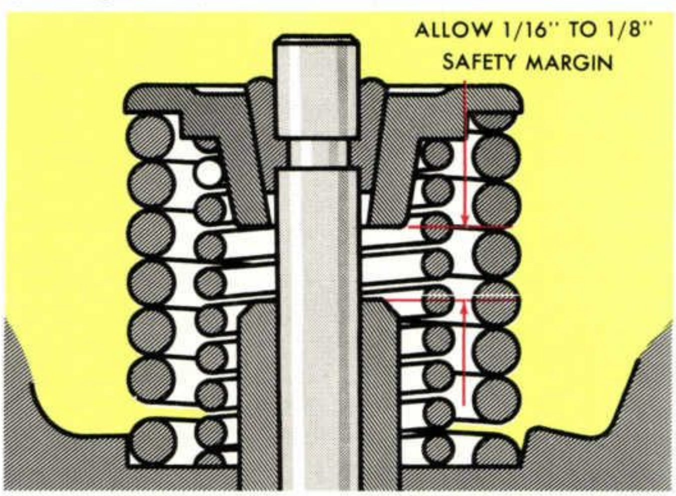


FIGURE 72. CHECKING SPRING RETAINER-TO-GUIDE CLEARANCE

In some cases, it may be necessary to machine the valve guides slightly to obtain proper clearance.

ROCKER ARM GEOMETRY

Correct rocker arm geometry will allow for longer engine operation at high r.p.m.s with little valve guide bore wear. To check for correct geometry, the valve should be positioned at 40% to 50% of maximum lift. The rocker arm tip radius should coincide with the centerline of the valve stem, when the valve is in this position. If the two centerlines coincide at less than 40% of total lift, the push rod should be shortened by the amount of the difference between the two centerlines. In the case of a rail type adjustable rocker, the rocker arm geometry can be off if the adjusting screw is screwed in to the limit of its travel. A longer pushrod should be used to correct for this situation.

ROCKER ARM-TO-STUD CLEARANCE

If you install a high-lift cam, exceeding approximately .450-inch lift, you should check for rocker arm-to-stud clearance on an engine equipped with ball-type rocker arms. (See Figure 73.)

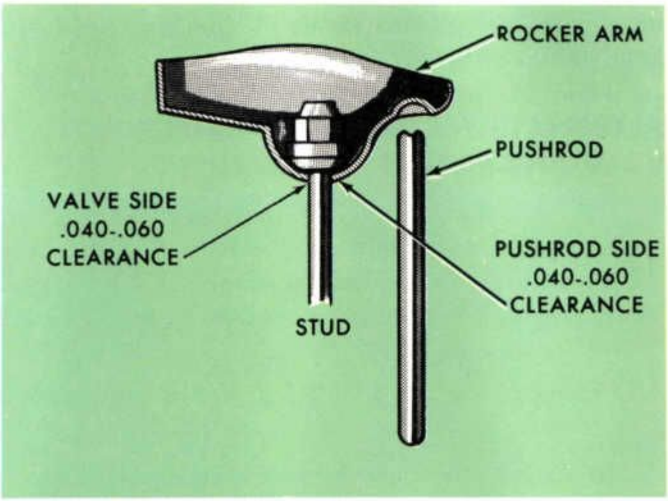


FIGURE 73. ROCKER ARM-TO-STUD CLEARANCE

You should have about .040-.060″ clearance on both sides of the rocker arm stud when the valve goes through a complete opening and closing cycle. One method of checking for clearance is to use a piece of solder about six inches long and 1/16-inch (.062″) in diameter. Form a hook in the solder so that it will fit between the slot in the rocker and the stud. Then, rotate the crankshaft until the valve has gone through a complete cycle. If you have sufficient clearance, the rocker arm should *not* make an impression in the solder. You should check for clearance on both sides of the stud. If you find that the clearance is insufficient, you must be careful only to elongate the slot in the rocker arm and not widen it.

SELECTING A CAM

Overcamming an engine is a common and all too frequent problem. Plan your engine modification beyond the installation of a camshaft. Coordinate your efforts to obtain the best results from a given combination of high performance parts.

If your interests lie in building a street "only" machine, concentrate on moderate increases in net valve lift. Depending on your engine displacement, a cam with durations from 260°-300° should improve volumetric efficiency at street crank speeds. The big problem is one of compatibility or of selecting the proper cam for the engine and the specific driving conditions. Generally speaking, cams with mild or medium duration and overlap should be used with cars equipped with automatic transmissions.

Street/strip or "streep" cars offer a little more flexibility in cam selection than do strictly street machines. Again, depending on engine displacement, look for net lift figures of from .500-.515 inch and durations extending a bit beyond 300°.

For all-out competition, the decision is yours. Net valve lift can reach heights of .600-inch with duration hitting exotic figures exceeding 330°. Whatever the case may be, Ford Motor Company offers a wide selection of competitively priced, race-bred, high performance parts. There's a Ford Hi-Per cam for every degree of performance improvement desired . . . from the Street 'n Strip Hydraulic to the wild Strip Tripper engineered and designed for the 7000 r.p.m. plus range. (See Figure 74.)

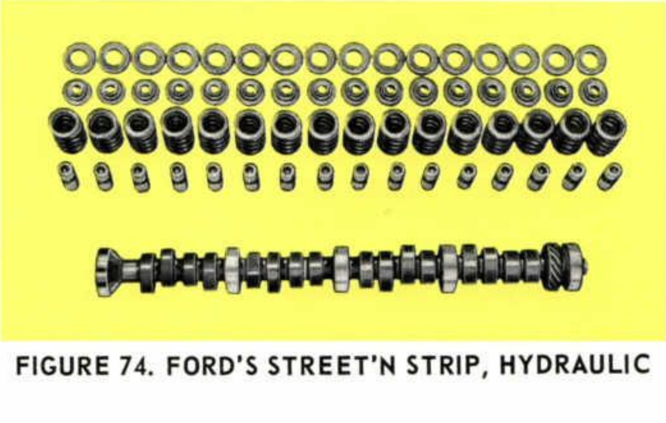


FIGURE 74. FORD'S STREET'N STRIP, HYDRAULIC

CAMSHAFT INSTALLATION TIPS

- When replacing a stock cam with a high performance cam, always replace related components such as lifters (pushrods, rocker arms, valve springs and spring retainers, etc. This will insure that the proper relationship is maintained between camshaft design and valve train components.
- Never install a cam dry. Always use additional lubricant on wearing surfaces of the cam, tappets and other valve train components. Much of the cam's wear comes within the first few minutes of its operating life. Lubrication will prevent galling (frictional wear) when the engine is fired up for the first time. Most manufacturers will specify

or recommend the use of a particular type of lubricant.

- The timing chain and gear should always be replaced to help insure proper cam timing. Extra precautions should be taken when installing and tightening the camshaft sprocket, since high speed engine harmonics can cause bolts to loosen.
- Never use old lifters on a new cam and do not intermix parts using solid lifters on a hydraulic cam. Hydraulic lifters do not require clearance ramps as do solids. (See Figure 75.)

Note.

The solid lifter cam lobe has a clearance ramp allowing the cam to rotate a few degrees off the base circle to take up this clearance. Since the hydraulic lifter maintains zero lash, the cam has no clearance ramps ground into the lobes. Using solids on a hydraulic cam will result in a pretty hard slap of the lifter and valve.

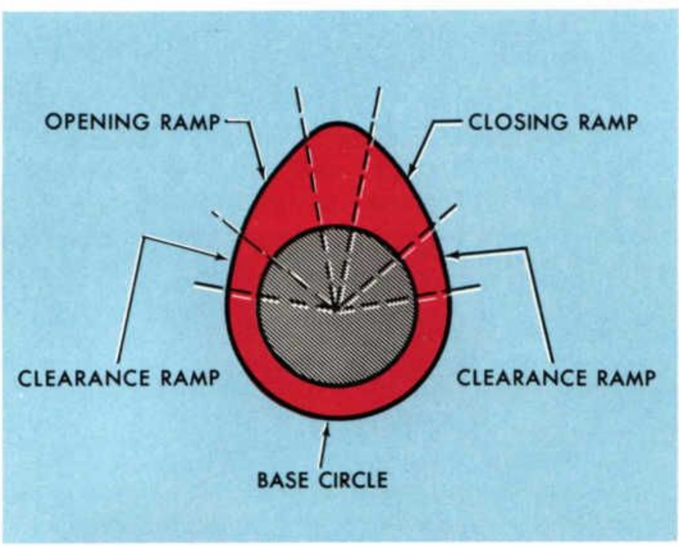


FIGURE 75. NAMES OF SOLID CAM LOBE LIFT AREAS

CHECKING VALVE-TO-PISTON CLEARANCE

Always check for ample clearance between the valves and piston head, particularly when installing a cam with an increased net lift. If the proper clearance is not maintained, it could result in piston/valve interference and severe damage to the engine. To check piston-to-valve clearance, lay small soft strips of clay across the top of the piston in the area of valve proximity. With the cam, valves and valve train installed, bolt the head into place (remember the head gasket). Hand rotate the engine through a complete four stroke cycle (two complete revolutions of the crankshaft). This will assure that both valves (intake and exhaust) move through their complete patterns. Remove the head and measure the thickness of the impressions left by the valves in the clay. A number of engine builders agree that the impressions or valve clearance should run around .060-.080 inch minimum. Blueprint specs for Ford engines, however, call for a minimum valve-to-piston clearance of .120″. This operation should only be performed when the cam has been degreed-in. Remember that variations in cam timing (the advance or retard of a particular shaft or the amount of valve lash) can alter the piston/valve relationship. Clearance checking before the cam is degreed-in can be useless and costly. Checking valve-to-piston clearance in a *must* operation whenever any engine modification is carried out which could alter the valve-to-piston relationship. Engine modifications, which call for valve-to-piston clearance checking include; camshaft changing or regrinding, head and block-milling, and increasing engine compression ratios by changing head gaskets, crankshaft, rods or pistons.

ALTERNATE METHOD FOR CHECKING VALVE-TO-PISTON CLEARANCE

To eliminate the necessity of an extra "R&R" of the cylinder head, the following procedure requires only a dial indicator (or mechanic's scale) and a small pry-bar . . . with head installed. Follow these suggested tips:

1. Bring piston No. 1 to T.D.C. on its compression stroke.
   - Adjust valve lash to specified dimension.
2. Rotate crank 360°. This will place both valves in their overlap position (lightly off their seats).
3. Position dial indicator on top of valve spring retainer.
   - A mechanic's scale beside the spring will also work.
4. Wedge a small pry-bar under rocker arm.
   - Depress valve until it touches piston.
   - Read dial indicator or scale.
   - Compare to specification.
5. Repeat procedure for each cylinder, according to engine firing order.

FINDING TOP DEAD CENTER (T.D.C.)

Timing of a camshaft has long been considered a simple matter of aligning the markings on the cam and crank sprocket. However, when setting up a high performance engine, which involves camshaft replacement, it is possible for the crankshaft-to-camshaft relationship to be several degrees off, either advanced or retarded.

Therefore, it is important that a new cam be *degreed-in* to insure maximum performance. To accomplish this you must first make an accurate check for top dead center. There are several methods used to check for T.D.C. The two most common methods involve the use of either a positive piston stop or a dial indicator and a degree wheel. We will cover the piston stop method since it is probably the most popular of the two.

1. The crankshaft, pistons, camshaft, cam gearing and lifters should be in place. Rotate the crank until number one piston appears to be at T.D.C. The lifters for No. 1 should be on the base circle of the cam.
2. Mount a degree wheel (360° protractor) on the nose of the crankshaft and fasten a suitable pointer to the block. Align the degree wheel so that the pointer indicates T.D.C. and tighten the degree wheel to the crankshaft.
3. Rotate the crank opposite to its normal direction to lower No. 1 piston enough to allow for the installation of the piston stop. (See Figure 76.)

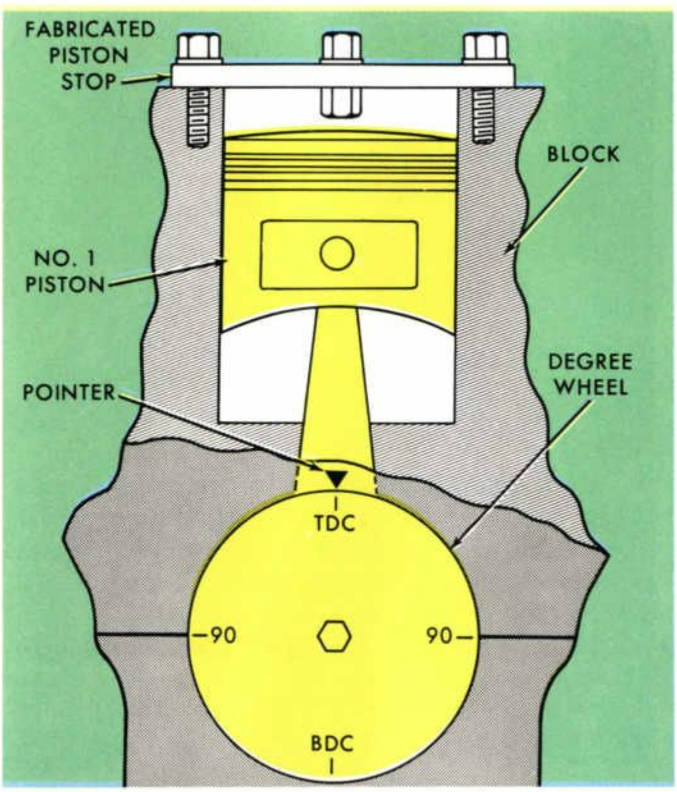


FIGURE 76. LOCATING TOP DEAD CENTER

4. Install the stop on the cylinder block and slowly rotate the crank in its normal direction until the piston is against the stop. Record the reading on the degree wheel.
5. Rotate the crank opposite its normal direction until the piston again touches the stop. Record the reading on the degree wheel.

Note:

Reversing crankshaft rotation will take up any clearance in the con rod bearings, which could otherwise affect the second reading of the degree wheel.

6. If you are lucky and both degree readings on either side of T.D.C. are the same, you have the pointer reading the exact position of T.D.C. and no correction is required. Otherwise, you will have to remove the piston stop and rotate the crank until the pointer is exactly aligned half way between the two degree readings. This point is T.D.C. You should make the necessary correction on the damper by making a scribe mark to indicate exact T.D.C. This will insure that future checks with a timing light will be properly oriented. Without disturbing the crank, carefully loosen the degree wheel and adjust it so the pointer aligns with T.D.C. Then tighten the degree wheel in place.

TIMING THE CAMSHAFT

With T.D.C. established and the degree wheel showing the correct location of T.D.C., you are now ready to check valve timing or *degree-in* the cam. There are various methods of checking valve timing. You can, for example, use a dial indicator to check the accuracy of each individual cam lobe. However, for our purpose, we will assume that the cam is correctly ground and our only concern is to find out if the valves are opening and closing in correct relation to piston position. In other words, we want to determine if the cam is correctly phased (timed). The procedure which follows involves the determination of the cam lobe center line or point of maximum lift in relation to T.D.C. and degrees of crank rotation.

1. Install the camshaft, sprocket and chain. With the camshaft in place, insert a tappet for the *intake* valve of #1 cylinder.
2. Place a dial indicator on the tappet with the cam at maximum lift. Make certain that you are working with the intake cam lobe and tappet for #1 cylinder. The degree wheel, with the correct location of T.D.C., should still be installed on the crank.
3. The next step involves the use of the timing card received with the camshaft from the manufacturer.

   For illustration purposes we'll assume that we are working with Ford's all-out competition cam—the Strip Tripper. In this case the card should read as follows:

Intake Opens	60° BTDC
Intake Closes	90° ABDC
Exhaust Opens	94° BBDC
Exhaust Closes	56° ATDC
Total Intake Duration	330°
Total Exhaust Duration	330°

Using the information from the timing card, you can compute the cam centerline or point of maximum lift, which is always ½ the duration. From our example, the point of maximum lift is ½ of 330° or 165°. Next, we determine when maximum lift (cam centerline) should occur in relation to T.D.C. We know that the intake opens 60° BTDC. Subtracting this from our point of maximum lift, we get 165° −60° or 105°, the point of maximum lift after T.D.C. on the degree wheel. *Think about this as it is fundamental to your understanding of cam timing.* 105° is the point on the degree wheel or degrees of crank rotation where maximum lift should occur if the cam is correctly installed and timed.

4. This step involves the physical determination of the cam centerline or point of maximum lift in relation to T.D.C. Assuming that we are working with a chain-driven camshaft, turn the engine over (clockwise) until the dial indicator reads .030″ before reaching maximum lift. (View A, Figure 77). Stop, read the degree wheel and record the number of degrees. Continue rotating the engine in the same direction until the dial indicator once again reads .030″. (View B, Figure 77). Stop and record the degree reading on the degree wheel.

   Add the two readings and divide by two. The answer is the point where the cam centerline (maximum lift) is. If your result is the same as that computed in step 3 (105°) then the cam is correctly timed.

Note:

The .030″ was used for illustration only. Any measurement above .015″ is acceptable.

Example:

Suppose you install Ford's Strip Tripper cam and follow the preceeding procedure. The first degree wheel reading (before maximum lift) is found to be 94° of crank rotation. The second (after maximum lift) turns out to be 119°. You add the two together 94° plus 119° equals 213°. Divide by two and your answer is 106½°. Compare this with your computed point of maximum lift 105° and you find that maximum lift is reached 1½° too late in terms of crank rotation. You must correct for this retarded

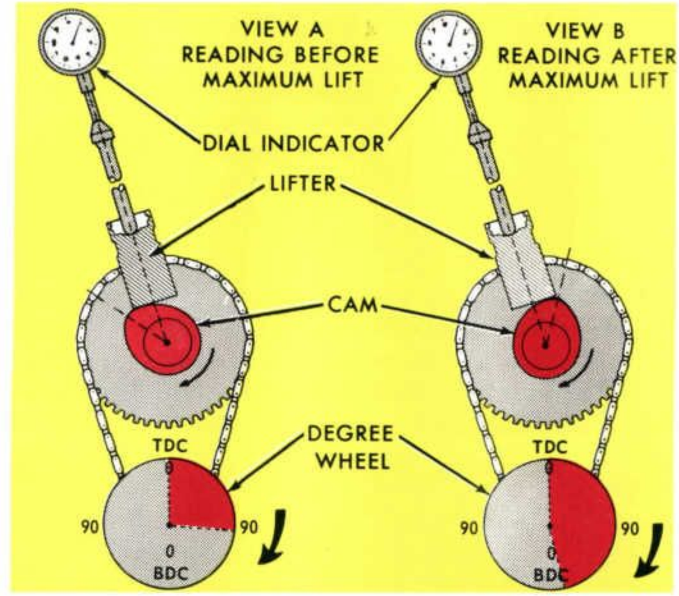


FIGURE 77. CAM DEGREEING

condition by changing the phase or timing of the cam. To do this the cam must be advanced (moved forward in the direction of cam rotation) 1½°. This can be accomplished by using an off set key or eccentric bushing in the timing gear or crank gear. Since timing figures are expressed in crankcase degrees, correcting the timing at the crankshaft is perhaps the easiest method. To determine the amount of offset, first find the circumference of the crankshaft nose using the formula $C = d\pi$. Then divide the answer by 360° (number of degrees in a circle) to find the number of inches per degree. You would then multiply this by the number of crankshaft degrees you were off. This will give you the amount of offset. The entire timing procedure should then be repeated to insure that the cam is correctly timed.

5. An alternative method of timing the camshaft may be used with the valve mechanism for No. 1 cylinder in place. The dial indicator in this case would be placed on top of the valve stem.

EFFECT OF VALVE LASH ON CAM TIMING

One final point should be covered before leaving the subject of camshafts. Total valve duration (timing) can be effectively altered by changes in valve lash settings. Increasing valve lash will shorten duration, since more crankshaft rotation will be required to close the gap between the rocker arm and valve stem and open the valve. Tightening the lash will effectively lengthen duration and may increase engine output at higher r.p.m. Generally speaking, .010″ of valve lash difference will be about 1° of cam advance or retard. You may try to vary valve lash, but be careful, remember it will affect valve timing and can be extremely hard on the valve train.

Cylinder Block Assembly

DESIGN AND OPERATING PRINCIPLES

CYLINDER BLOCK

Whether you decide to build a house, a bridge, or an automobile engine, a solid foundation must be provided. The foundation in the case of an automobile engine is the cylinder block. A typical block is shown Figure 78.

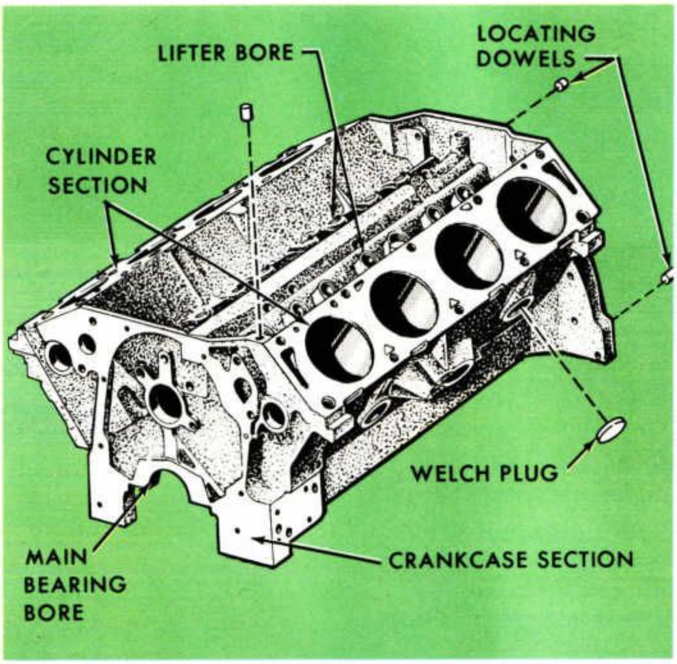


FIGURE 78. CYLINDER BLOCK (TYPICAL V-BLOCK SHOWN)

When considering a high-performance engine, some of the basic design requirements of any cylinder block become even more critical. High on the list of these requirements, we'd have to include rigidity, minimum weight, good machining characteristics, and the ability to withstand temperature changes and resist wear. Overshadowing this list of requirements and controlling the quality level to a certain extent is the competitive need for economical manufacture. In effect, regular production design is aimed at the best balance of quality and cost under mass production conditions. For this reason, blueprinting becomes a mandatory step if the ultimate in high-performance potential is to be attained.

Before we get into cylinder block blueprinting and modifications, let's review some fundamentals. First, the block is a metal box containing a series of holes or cylinders. These cylinders are cast either in-line, horizontally opposed (pan-cake), radially (aircraft-type), or in a V-shaped configuration. The planes of the bores in most current production eight-cylinder engines are V-shaped . . . a design which gives great strength and rigidity. The portion of the block beneath the cylinders is called a *crankcase* and along with the oil pan forms an oil-tight housing in which the rotating and reciprocating parts operate. All of the major parts of the engine depend on the block for support. It contains, in addition to the cylinders, water jackets for cooling purposes and drilled oil passages (oil galleries) to direct lubricants to the moving parts. It also provides machined surfaces for the attachment of heads, oil pan, clutch housing (scatter-shield), and other bolt-on accessories. The lower portion of the block (immediately beneath the cylinders) is the webbing (reinforcing ribs) or crankshaft supports. Particular attention is given to this area in block design, inasmuch as the webbing forms the upper half of the main bearing supports and is the point of greatest stress, both in construction and in operation. (See Figure 79)

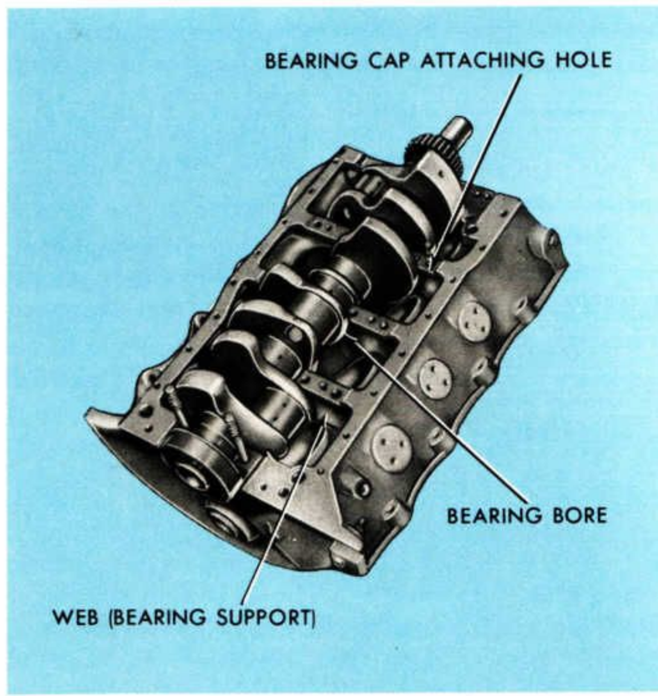


FIGURE 79. CYLINDER BLOCK WEBBING

Types of Castings

The cylinder block is an intricate casting with a variety of thicknesses in its total cross-section. These variations, by design, both accommodate and contribute to the stress characteristics with occur during the period when the casting is being cooled. Faced with the engineering problems this involves, manufacturers have resorted to several types of construction and component materials. The conventional block castings are now tending more toward a "thin wall" type of cast iron block which, in addition to being a weight-saver, reduces the need for extensive machining operations after the casting has been made.

Even though cast iron is now the predominant choice of manufacturers, more and more attention is being given to aluminum alloys as a component material for the block. The alloys are solving the original problems related to excessive wear and high porosity associated with aluminum. From a high-performance standpoint, the improved weight and strength factors will allow development of engines with better power-to-weight ratios.

The Short Block

The major assemblies and sub-assemblies housed in the cylinder block include:

1. Crankshaft
2. Camshaft
3. Bearings
4. Oil Seals
5. Pistons
6. Piston Rods
7. Piston Rings
8. Valve Lifters

This assembly is known as a SHORT BLOCK. (In the complete engine assembly, every component attaches directly or indirectly to this short block.) Now let's direct our attention away from the design and functional responsibilities of the cylinder block and consider similar background information as it relates to crankshafts, bearings, and piston and connecting rod assemblies.

CRANKSHAFT DESIGN AND OPERATING PRINCIPLES

The purpose of the crankshaft is to convert reciprocating (up and down) motion into rotary motion. It is often referred to as the "backbone" of the engine. The crankshaft revolves in main bearings whose bores are machined into the bottom of the block. Piston and rod assemblies provide a direct connection to the power source. The crankshaft must carry the entire load of the power developed by the engine.

Design

The crankshaft is a one-piece casting or forging of heat-treated iron or steel alloy of considerable strength. A well designed crankshaft will have a large journal radii, thick cheek section (area between main and rod journal), a large journal overlap (See Figure 80), high quality material, and carefully controlled heat treating. The number of bearing journals used, depends upon the design of the engine. As far as main bearing journals are concerned, it is generally acknowledged that the more used, the better for reasons of both better support and vibration control. Some manufacturers have gone so far as to place a main journal between each rod journal. The rear main journal is usually longer than the other main journals because of the additional weight of the attached flywheel.

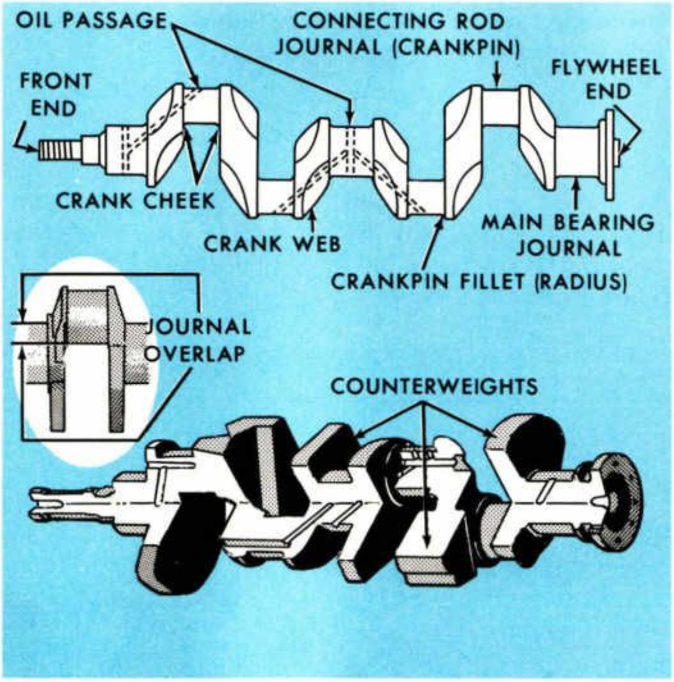


FIGURE 80. TYPICAL CRANKSHAFT DESIGN

The connecting rod (crankpin) journals are positioned about the centerline of the crankshaft at different angles (planes) to more evenly distribute the load applied. A four-cylinder engine will normally have cylinders 1 and 4 on the same side and 2 and 3 on the other side, spaced 180 degrees apart. (See Figure 81)

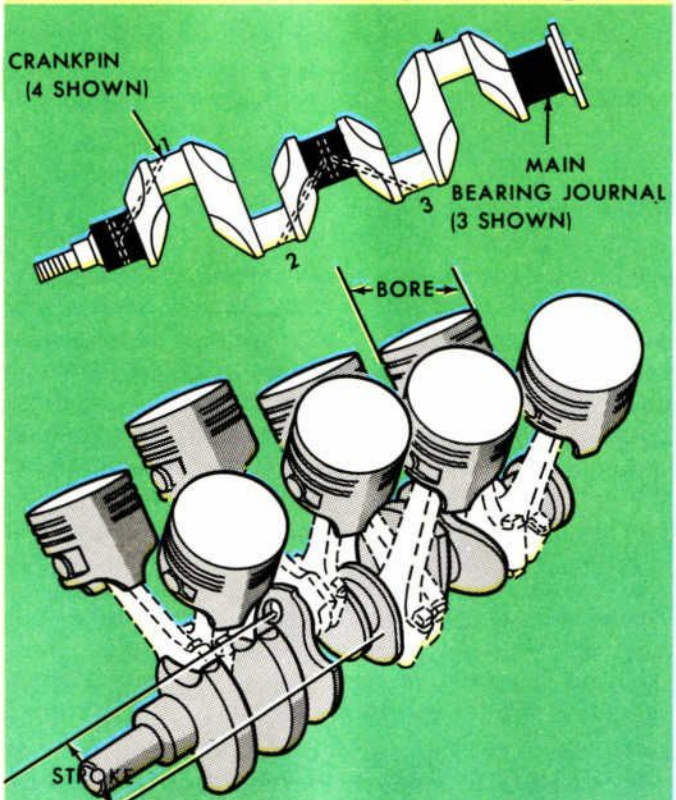


FIGURE 81. CRANKPIN AND MAIN BEARING JOURNAL PLANES

The six-cylinder crank throws are spaced 120 degrees apart (as viewed from either end of the crankshaft) and cylinders 1 and 6, 2 and 5, and 3 and 4 are paired to share the three planes. In the case of a V-8 design, we find four throws; one for each of the two opposing cylinders. This means that two connecting rods share the same journal. The positioning of the throws is similar to that of the four-cylinder crankshaft, or may be varied so that the throws are in two planes, each 90 degrees apart. (Throw is a term used to describe the crank journal and its side supports.) (See Figure 82)

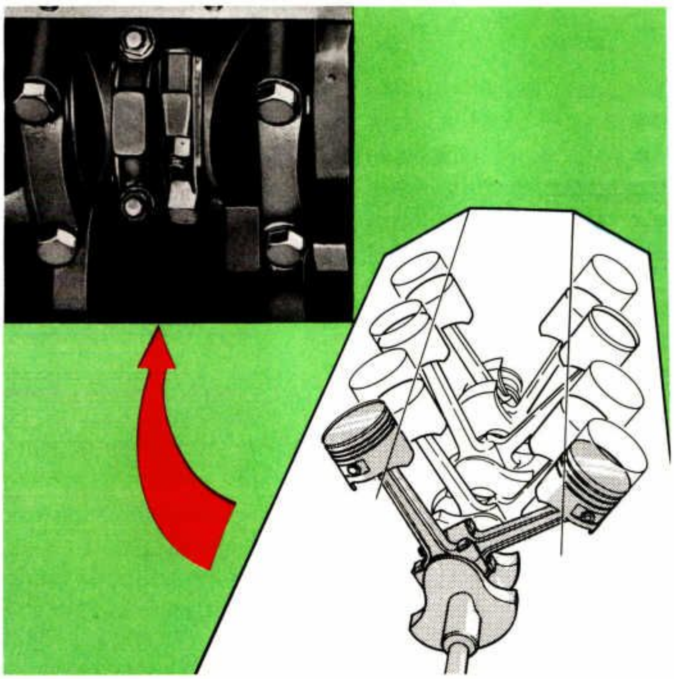


FIGURE 82. TYPICAL V-8 CRANKSHAFT AND CONNECTING ROD ASSEMBLY

To provide balance, counterweights are designed opposite the crank throws. Proper balance is one of the most critical factors of crankshaft design because of centrifugal forces and forces of inertia. We'll cover this in greater detail later in this section. Oil passages are drilled from main to connecting rod journals to provide proper lubrication to the bearings. A flange is provided at the rear for attaching the flywheel; and machined surfaces are made at the front for attaching a camshaft drive gear and vibration damper.

Operating Principles

The flow of power from the engine cylinder is not smooth. The sequence of the power impulses is controlled by the firing order. On a four-cylinder engine, piston number one goes down on a power stroke, while number four is moving downward on its intake stroke. While one and four are going down, numbers two and three are moving up; one on its exhaust stroke and the other on its compression stroke. This means a power impulse is transmitted to the crankshaft every half-revolution or two impulses per revolution. (See Figure 83)

Since the six-cylinder crank throws are spaced 120 degrees apart, you get a power impulse every third revolution. With the V-8 design, there is more overlap of power impulses since more than one cylinder is delivering power at any given instant. The objective is to alternate power strokes at each end of the crankshaft and on opposite sides of the block. This will reduce the amount of force concentrated near any one point on the crankshaft and allows for a smoother running engine. Several firing order sequences are possible and are applied to current production engines.

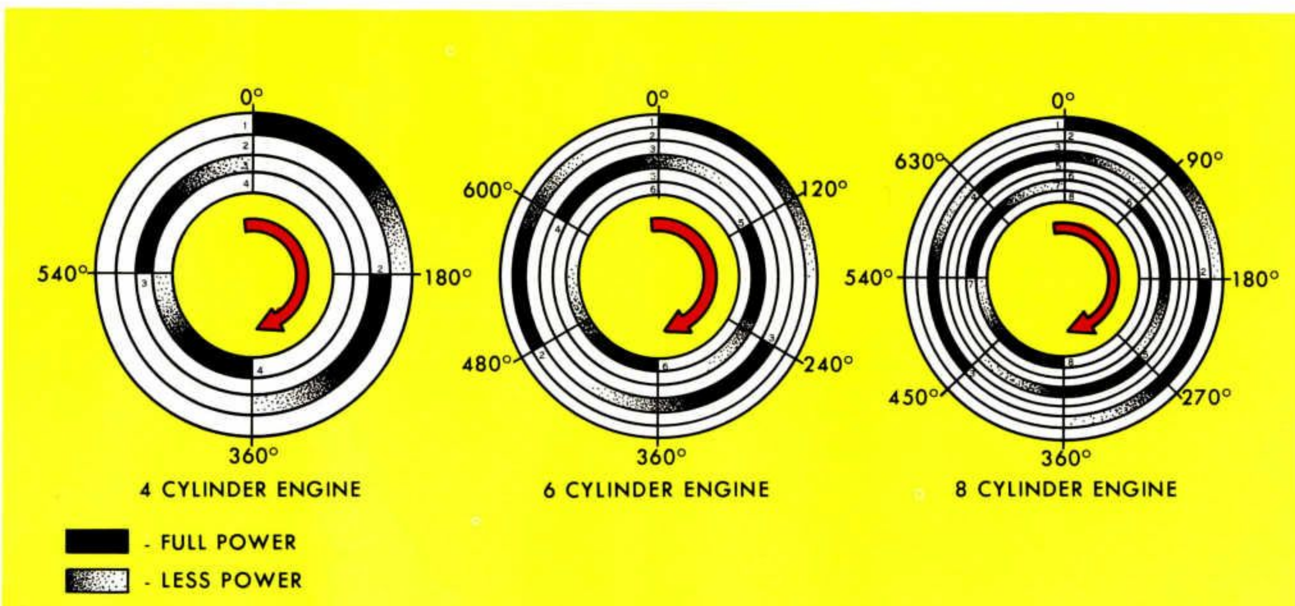


FIGURE 83. POWER IMPULSE OVERLAP

To further the smoothness of operation, a flywheel is attached to the rear of the crankshaft. Its function is to keep the engine running evenly between power strokes. The inertia of the flywheel tends to keep the crank turning at a constant speed. The flywheel absorbs power as the crankshaft tries to speed up and releases power as the crankshaft tries to slow down. Additionally, a ring gear is bonded to the outer circumference of the flywheel to mesh with the starting motor pinion; the rear face of the flywheel serves as the driving member of the clutch on engines coupled to standard transmissions. Flywheels used on high r.p.m. engines are of lighter construction than those used on its normal-duty counterparts; this is true also of flywheels used with automatic transmissions.

Vibration is the major enemy of the crankshaft. It can be caused by centrifugal forces or by the forces of inertia. The inertia forces come from the connecting rods and other attached parts. When a piston moves down on its power stroke, the force which can exceed two tons tends to twist the crankpin ahead of the rest of the crankshaft. An instant later that force is relieved and the crank tends to untwist. This vibration is rarely felt in the vehicle, but can often result in a broken crankshaft. It can be partially compensated for by a rubber and steel damper fastened to the front of the crankshaft. (See Figure 84)

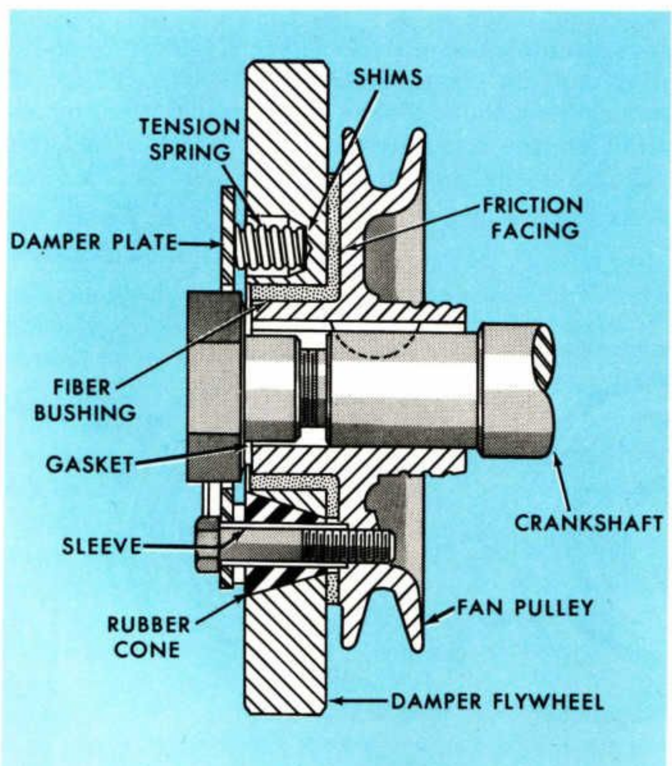


FIGURE 84. VIBRATION DAMPER

The vibration damper adds mass or inertia to the end of the crankshaft opposite the flywheel; this, in turn, minimizes the effects of twisting. The fastening and insulating material is usually of bonded rubber.

ENGINE BEARINGS

Types

Bearings are used in various places throughout the engine where there is relative motion between parts. These bearings are called the sleeve-type because they surround the bearing journals. Main and connecting rod bearings are split and, therefore, known as half-sleeve type bearings. A full-round bearing (such as found on the small end of the connecting rod) is called a bushing.

Camshaft bearings are of the full-sleeve design and are usually replaced as a result of wear factors, rather than any tendency to produce noise. Camshaft bearings, like crankshaft bearings, rely on rigid oil clearance tolerances to properly maintain a specified oil pressure.

Bearing-to-Shaft Oil Clearance

Bearings are manufactured so that an oil hole mates or matches with an oil supply hole in the block and/or bearing journals. Some bearings have grooves or slots machined into their surfaces to more evenly distribute the lubricating oil. The amount of available lubricating oil is critical to any engine, but even more so in high performance work because of the heavy demands made on the engine. The amount of oil is determined by the clearance or working space between the face of the bearing and the bearing journal. (See Figure 85)

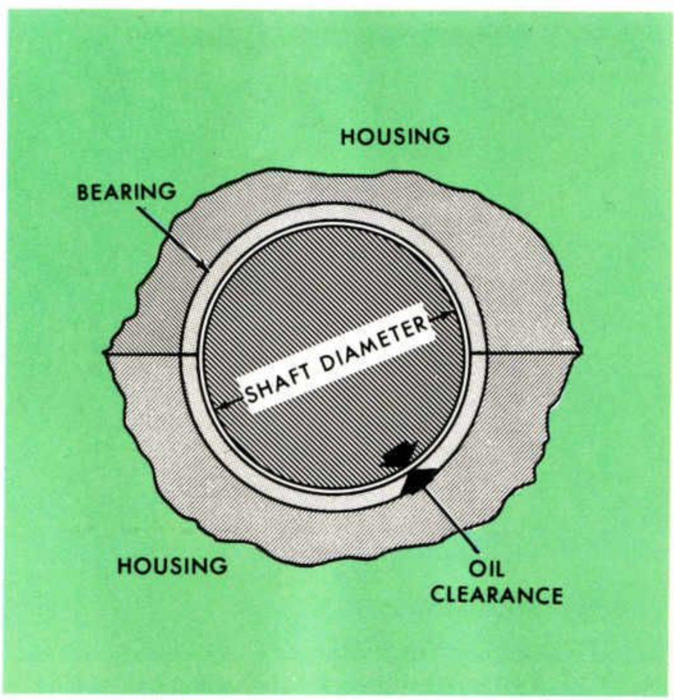


FIGURE 85. BEARING-TO-SHAFT OIL CLEARANCE

This critical factor of oil clearance is best explained by observing the following example:

1. Recommended clearance (.0015″) provides normal oil supply.
2. Double clearance (.003″) provides five times normal oil supply.
3. Double clearance again (.006″) provides twenty-five times normal oil supply.

As excessively large clearances are approached, the danger of oil starvation is introduced. This is a result of the bearings nearest the oil pump receiving *all* of the supply and the bearings further away not getting enough.

CAUTION:

From the above example, you can see the importance of strict adherence to recommended specifications. Even though the specified oil clearance may have been raised for the high performance engine—don't get carried away.

Design Requirements

There are several requirements a properly designed engine bearing must meet to give satisfactory performance. These requirements are:

1. Embedability—the characteristic of allowing a foreign material to embed itself in the bearing material; thus, allowing the bearing to protect itself from scratching and gouging.
2. Conformability—The ability of the bearing material to conform or distribute itself according to alignment and shape of the journal.
3. Load-carrying Capacity—The ability to support loads of the high compression engines which approach 3000 p.s.i. or more.
4. Fatigue Resistance—The ability to withstand constant flexing, caused by various load applications.
5. Corrosion Resistance—The ability to tolerate and operate in an atmosphere of corrosive elements resulting from by-products of combustion.
6. Wear Resistance—By careful selection of balanced ingredients, the design engineer must choose materials that produce strong bearings that don't wear out too fast; yet retain their embedability and conformability characteristics.

Bearing Terminology and Dimensioning

With the aid of the illustration, you can "zero-in" on the terminology used to describe the various parts of the engine bearing. Some bearings do not have the annular grooves for oil distribution; others are designed with thick side walls (such as the one typically used for center main bearings) or thrust faces to compensate for crankshaft end-play. (See Figure 86)

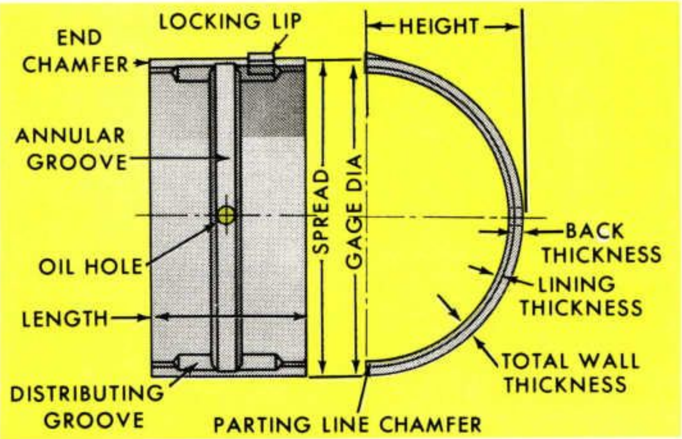


FIGURE 86. TYPICAL SLEEVE – TYPE BEARING HALF

Component Materials

The bearing backs are usually made of steel. The lining material is a matched combination of alloys to meet the requirements of a given engine. These alloys can be various combinations of lead, tin, copper, antimony, cadmium, and silver.

PISTON AND CONNECTING ROD ASSEMBLY

A piston and connecting rod assembly, as shown in Figure 87, includes the piston, connecting rod (with

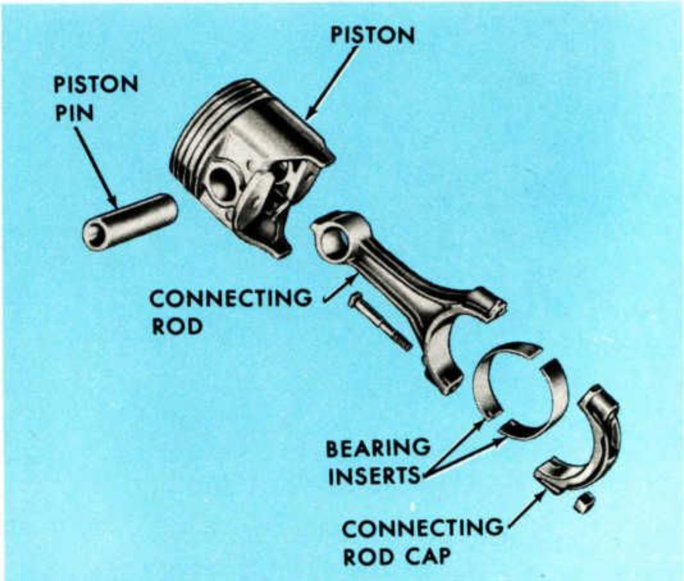


FIGURE 87. TYPICAL PISTON AND CONNECTING ROD ASSEMBLY

cap), connecting rod bolts, bearing inserts, piston pin, and piston rings.

In high-performance engines, particular attention must be given each of the components mentioned. The piston assembly constitutes the major reciprocating mass and is, therefore, subjected to heavy forces of inertia and centrifugal, mechanical, and thermal (heat) forces.

The functions of the piston include:

1. Sealing the combustion chamber.
2. Acting as a moveable bottom wall of the combustion chamber—allowing it to increase and decrease in volume.
3. Acting as a crosshead to transmit the expanding gas forces to the connecting rod, as well as controlling side thrusts to the cylinder walls.

These functions are accomplished by the combined contributions of each of the components that make up the piston assembly, as well as, piston design itself.

Piston Design

Inasmuch as the function of the piston is to transmit the force generated by burning fuel to other components, it is desirable to make the piston as light as possible—yet, strong enough to withstand the tremendous forces to which it is subjected. Power loss must be prevented by a close fit between the piston and cylinder wall to prevent expanding gases from leaking past the piston into the cylinder (a function of the piston rings which will be discussed separately).

Most modern engines use aluminum pistons of the controlled expansion (autothermic) type. (See Figure 88).

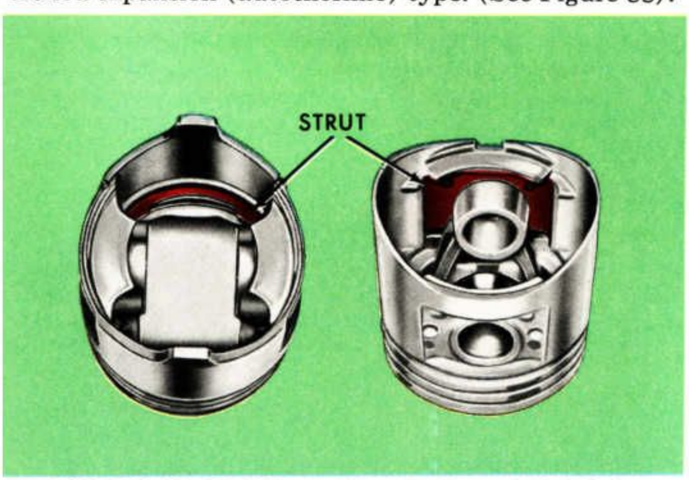


FIGURE 88. TYPICAL AUTOTHERMIC PISTON

The expansion is controlled through the use of steel struts cast into the pistons. If a bar of steel and a bar of aluminum are the same length at room temperature, then, at any greater temperature, the aluminum bar will be longer. Due to the same action, the steel struts will prevent excess expansion of the aluminum piston.

The die cast method of manufacture is used in most cases, although a few special pistons are sand cast or forged. Some pistons have domed or contoured heads. The reason for this is to form a portion of the combustion chamber shape; to arrive at designed compression ratio volume; and to provide the necessary valve and cylinder head clearance. (See Figure 89.)

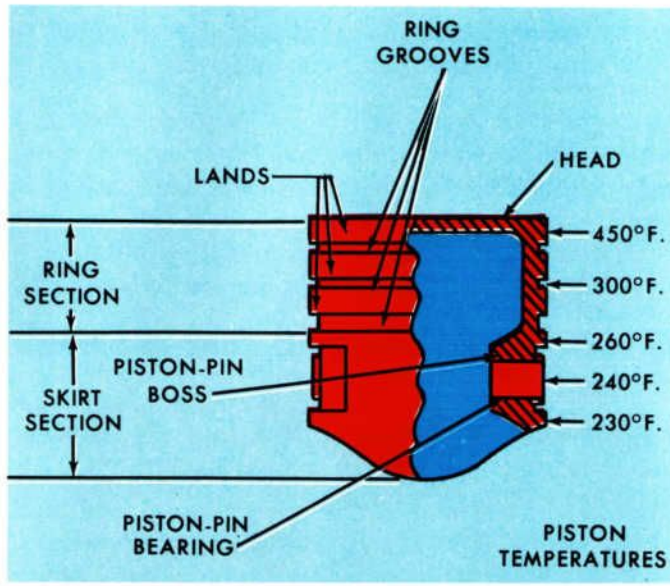


FIGURE 89. PISTON TERMINOLOGY AND OPERATING TEMPERATURE RANGE

Most of the heat absorbed by a piston is through the dome or top. It will expand more in this area than any other; so the upper diameter is made smaller to allow for this expansion. The diameter is gradually tapered larger toward the bottom until a maximum is reached just below the piston pin. The piston is also ground to be larger on the thrust surfaces than on the piston pin end surfaces to assist in friction reduction. (See Figure 90.)

This is known as a "cam-ground" piston. When cam-ground pistons are cold they have an elliptical (oblong) shape; when warm, they assume a round shape by expanding in a direction parallel with the piston pin axis. This design allows normal clearance in a small area when the piston is cold (to help control piston slap). When the piston gets hotter, the area of normal clearance increases. Keep in mind that there is never an actual metal-to-metal contact between the piston and cylinder wall. Proper lubrication provides a film of oil between the two.

The shape of the skirt, or portion of the piston below the piston pin, depends on the engine application. The end result of piston skirt form should: (1) give fairly constant skirt-to-cylinder-wall clearance between cold and warm engine conditions; (2) provide enough strength and resistance to wear for all expected operating conditions; (3) not be excessively heavy; (4) have acceptable friction resistance.

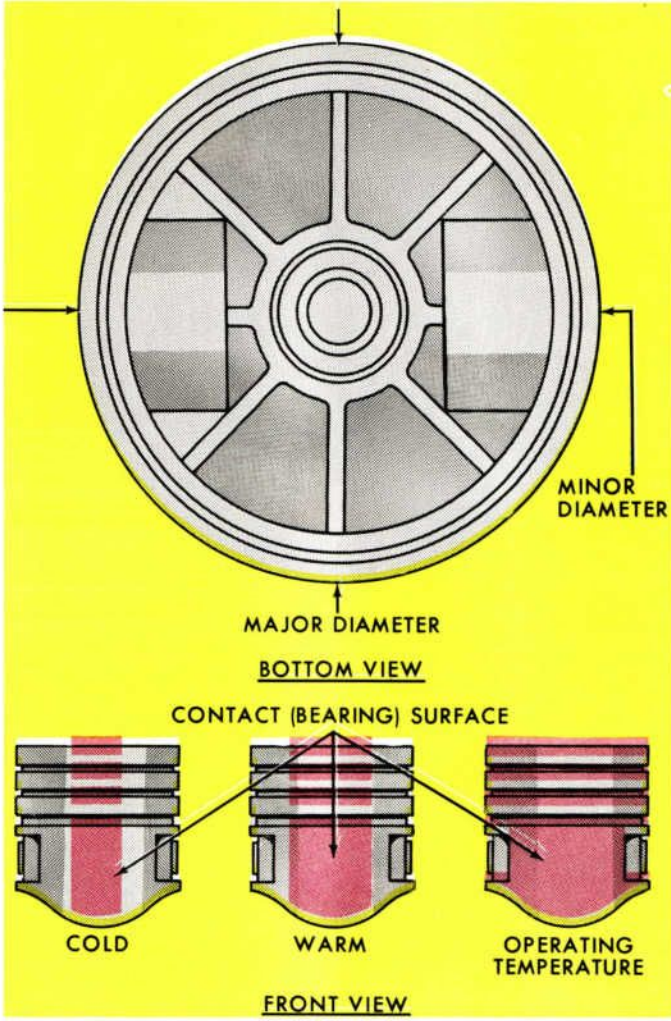


FIGURE 90. CAM-GROUND PISTON

Piston Rings

Piston rings are used to seal the space between the piston and cylinder wall. They are made of either cast iron or steel. The top (compression) ring is sometimes chromium plated to resist abrasion from foreign matter in the intake air. Rings must seal against the piston ring grooves as well as against the cylinder wall.

Aluminum pistons frequently have steel or iron guides cast into them for the compression ring to ride. The compression ring gets very little oil and runs hot. These guides help to prevent excessive wear. Some of the many compression ring designs are shown in Figure 91).

The second ring from the top (on a three ring piston) is a combination compression and oil ring. It has some

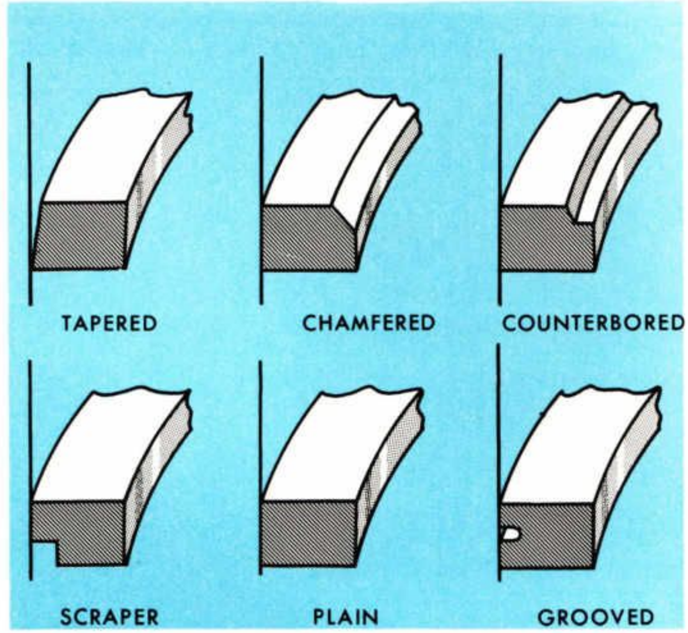


FIGURE 91. TYPES OF COMPRESSION RINGS

features of both the top and bottom rings. Its oil groove is closed at the ends to prevent the escape of oil through the gap.

COMPRESSION RING ACTION

A stroke-by-stroke study of the action of the compression ring reveals the following:

1. Cylinder walls are lubricated on upward piston strokes; excess oil is wiped away by rings on downward strokes.

2. On the INTAKE STROKE, the pressure differential (partial vacuum in the combustion chamber and atmospheric pressure in the crankcase) tends to force oil upward, past the rings into the combustion chamber (See Figure 92).

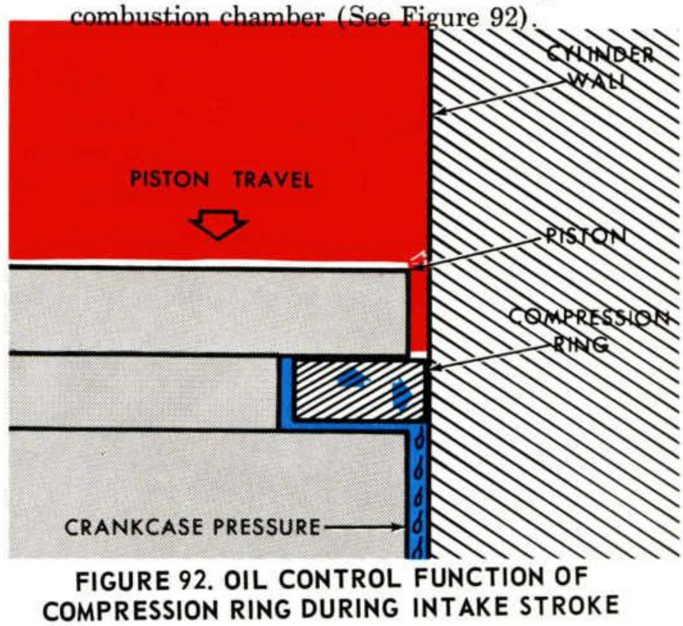


FIGURE 92. OIL CONTROL FUNCTION OF COMPRESSION RING DURING INTAKE STROKE

As the piston continues downwards, the top compression ring rests against the upper surface of its ring groove, causing the lower, outer edge of the ring to wipe oil from the wall.

3. On the COMPRESSION STROKE, the ring is forced downward against the bottom surface of the groove. Compression pressure is applied to to the back of the ring, which in addition to its normal tension, forces the ring outward to form a more perfect seal. (See Figure 93).

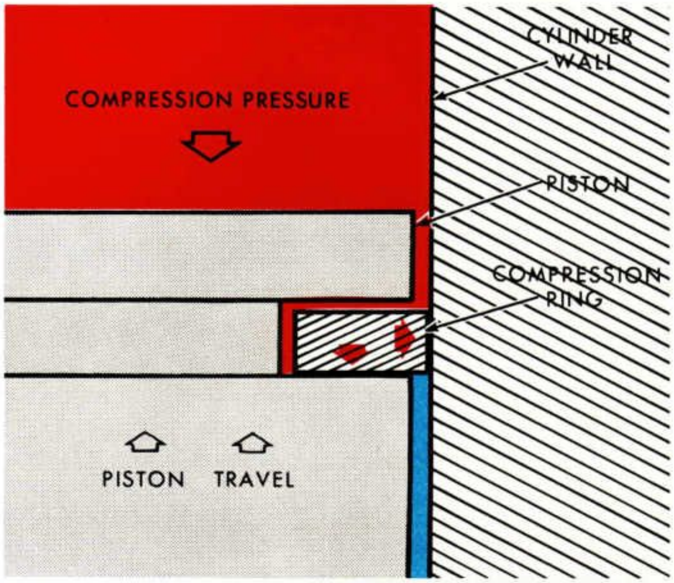


FIGURE 93. SEALING FUNCTION OF COMPRESSION RING DURING COMPRESSION STROKE

4. On the POWER STROKE, this sealing effect is even greater as the combustion chamber pressure rapidly increases. The very high pressures at the back of the ring combine with ring tension to effectively seal combustion gases above the piston.

5. To insure an even greater sealing, many high performance engine builders specify the use of a compression ring that incorporates a long overlapping feature where the ring ends normally butt together.

6. On the EXHAUST STROKE, the piston is moving upward, of course, and the ring wipes part of the carbonized surface from the oil film. Any gritty material that is left is passed over by the ring, and is the major cause of cylinder wear. It has been proven that an *extremely fine* film of oil slows wear rates, while thicker oil films trap abrasives and contribute to more rapid wear.

OIL RING ACTION

Oil rings are of open construction. The volume of oil to be handled is too great to squeeze between the piston and cylinder wall, so some of it must pass through the ring and through the piston. Holes are drilled in the groove behind the oil ring to allow the oil to pass through. Oil control rings of segment type construction are used in most engines. They are highly flexible, can change position more readily, conform to cylinder wall shape and are less susceptible to carbon fouling than the one piece type. (See Figure 94.)

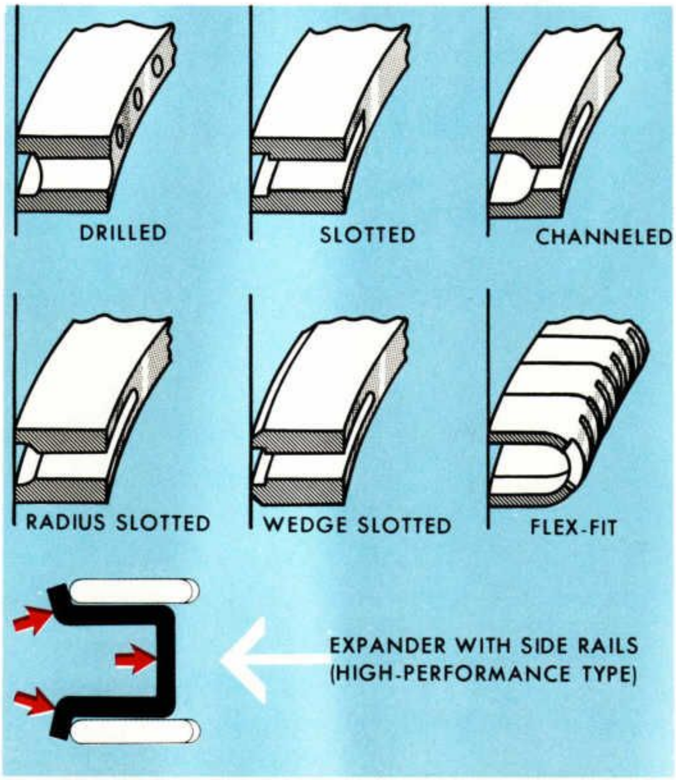


FIGURE 94. TYPES OF OIL CONTROL RINGS

Piston ring manufacturers specify the use of chromium-plated rings on most passenger car engines. This is usually meant to be the top compression ring only. Lab tests prove, however, that an engine equipped with chromed top compression rings only will last twice as long as one not so equipped; whereas, an engine with *all* rings chrome-plated will last up to four times as long.

Piston Pins

Piston pins—often called "wrist" pins—are hardened steel, tubular shafts used to secure the piston to the connecting rod. They are highly polished to provide the necessary bearing surfaces that contact the rod bushing and piston bosses. The pin may be secured in one of three ways. (See Figure 95.)

The wrist pin end of the rod is sometimes locked to the pin and in other engines it has a bushing in the rod and bears on the pin. The pin usually is free to rotate

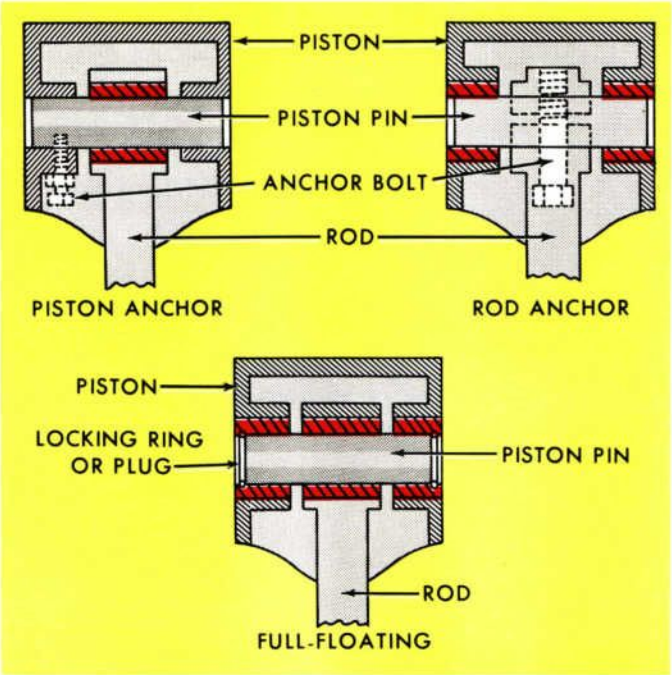


FIGURE 95. METHODS OF LOCKING PISTON PINS

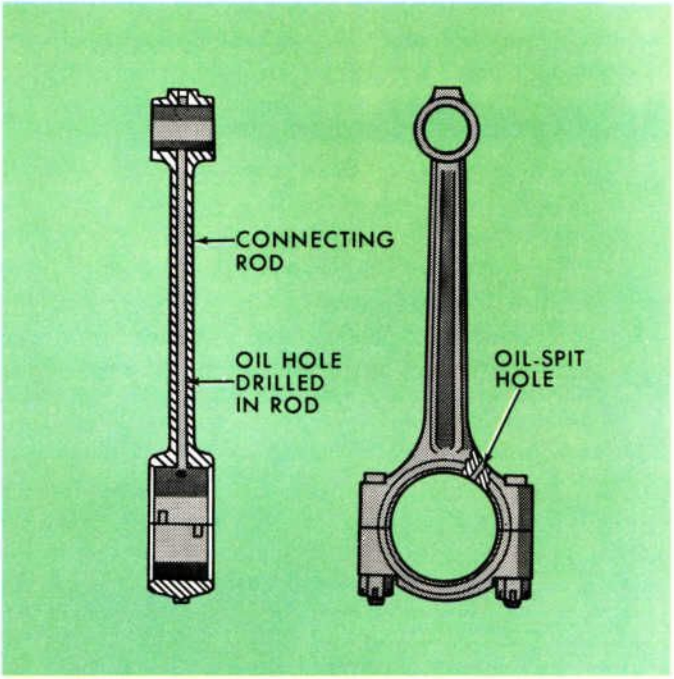


FIGURE 96. ROD LUBRICATING FUNCTION

in the piston. When the piston pin is locked in the connecting rod or piston by either a bolt or a pressed fit, no other pin locks are necessary. Pin locks of round or rectangular section are usually used when the piston pin is not locked in the rod or piston. Some high speed engines use plugs on the piston pin ends as a means of retaining the pin.

Piston pins that are press-fitted into the rod are approximately .001 inch larger in diameter than the rod bore. The pins that float or rotate in the rod bushing or piston have a clearance of approximately .0003 inch. The pin-to-rod clearance will stay about the same when hot, whereas the piston-to-pin clearance will become slightly greater because the aluminum piston will expand at a greater rate than the steel pin.

High-performance engines, for the most part, use the full-floating pin. As shown in Figure 95, this design provides maximum bearing surface.

Connecting Rods

The connecting rod must have considerable strength, be rigid, and yet be as light as structurally possible. Its function is to transmit power thrusts from the piston to the crankpin. A split-type bearing and cap secures the large-end of the rod to the crank.

To provide adequate lubrication, some rods incorporate a drilled passage from the crankpin journal bearing to the wrist pin bearing. Also, some have a drilled "spit" hole which is aimed at the cylinder wall. (See Figure 96).

Other engine designs simply rely on splash and spray from the revolving crankshaft. Connecting rods currently in use are made of forged steel to withstand the inertia and gas loads. The upper and lower halves are machined together to provide a perfectly matched circle to enclose the crankpin. For this reason, the rod caps are marked and should never be interchanged during assembly. A constantly varying I-beam section connects the piston pin end to the crankpin end.

PREPARATIONS FOR IMPROVED PERFORMANCE

CYLINDER BLOCK

To orient our thinking toward the high-performance angle, the contributions of the block itself are largely confined to the areas of:

1. Strength and rigidity.
2. Cylinder (BORE) size.
3. Cooling and lubricating functions.
4. Alignment factors.

We'll discount the bore size momentarily, as it is generally understood and accepted that the cylinder diameter is directly related to the power output of the engine. From a practical standpoint, you may think there isn't actually a lot that can be done in the areas cited, once the design of the block is in your hands in the form of a finished product. Let's take a look at the procedures recommended by professional engine builders. Their experiences have proven that a little work, patience, and common sense pays off in terms of high-performance RELIABILITY.

The recommended procedures are as follows:

1. Before disassembly of components from the block, check the deck height. This is the distance from the top of the piston (at T.D.C.) to the top or deck surface of the block. This is a critical dimension as it relates directly to compression ratio. It must be held constant to ensure a proper balance of combustion chamber volumes when the head is installed. (See Figure 97.)

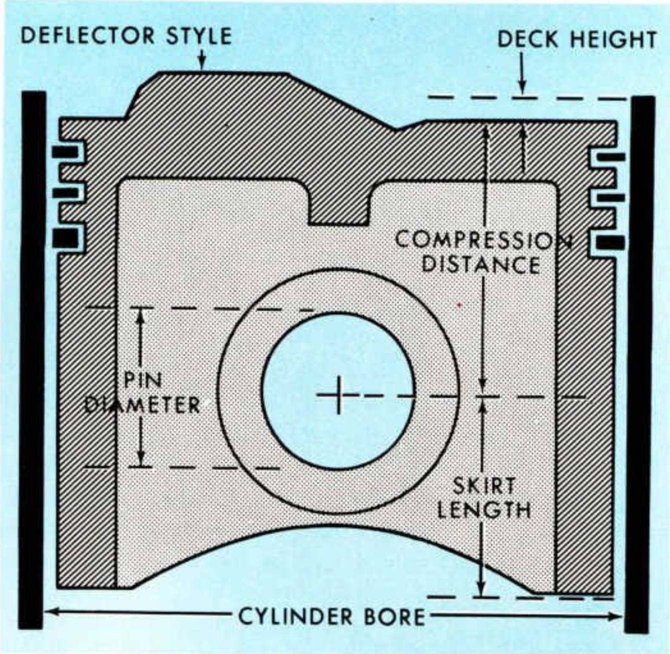


FIGURE 97. CHECKING DECK HEIGHT

2. Now, with all components removed and the useability of the block certified by a magnaflux text, check the main bearing bores for specified diameter and alignment with each other. (Detailed assembly procedures are provided in Appendix I to this manual.) (See Figure 98.)

3. Check the deck surfaces of the block to see that they are parallel with the crankshaft axis. The distance from the centerline of the crank to the deck surface of the block must be the same at the front and rear. If they are not the same dimension, the head surfaces on the block will have to be sent out to a specialty shop. *They should be cut a minimum amount necessary to produce a true, flat surface for accurate decking.*

4. Remove casting burrs and slag with a small hand grinder. This will help to ensure that these protrusions (flashings) don't break away and close-

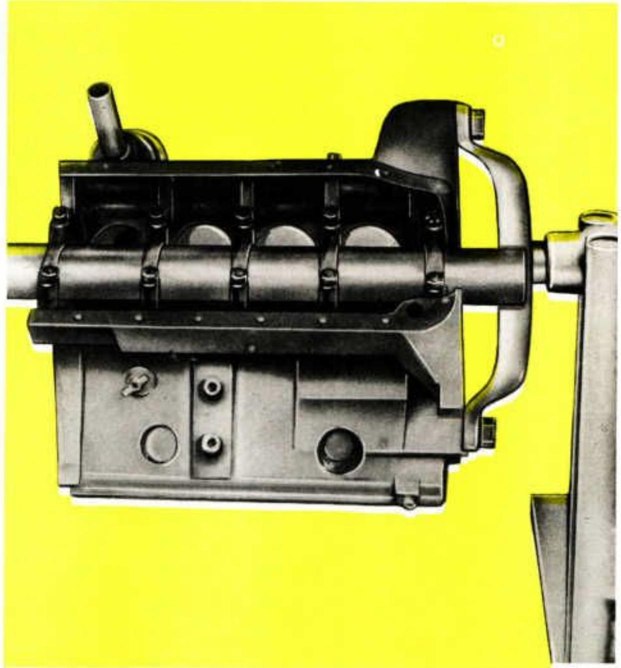


FIGURE 98. CHECKING MAIN BEARING BORE ALIGNMENT

off a critical oil passage or scuff moving surfaces. This grinding operation also aids in reducing stress areas where cracks are most likely to start.

5. Run a bottoming tap down all bolt holes to clean out any foreign deposits. A small chamfer on the head bolt holes is a good idea to prevent the top thread from pulling up when it is torqued.

6. Check all dowel pin heights. If any are longer than their receiving or mating hole—a proper seal cannot be attained.

7. Polish tappet bores with fine grit sandpaper to remove rough spots.

8. Rough-up rear main oil seal machined surface with a center punch. This will aid in preventing the seal from slipping in the groove at high r.p.m.

9. When replacing cam bearings, make sure the oil holes in the bearing and block are aligned.

10. Run a small bottle brush or drill through all oil passages.

11. Check and refinish cylinder walls, as required.

    A. Visually inspect the walls for scores, cracks, spotty wear, etc. . . . .

    B. Measure the bore for taper or out-of-round conditions. Either inside "mike", telescoping gauge, or dial indicator may be used.

    C. If cylinder wear dictates, or oversize pistons are to be used, bore the cylinders with a boring bar. Leave approximately .002" stock for the honing operation. Again, boring is an operation usually done by specialty shops.

D. Hone the cylinder walls to their final dimension. Honing is recommended both to remove "glaze" when installing new rings, and as the final step of the boring operation. If a considerable amount of metal is to be removed, start with a coarse stone and finish with a fine stone. Although dry honing has been done—it is highly recommended that a cutting fluid be used. The cylinder must be finished to the specified size for the piston and rings to be installed.

The recommended surface finish to produce the 60° pattern shown in Figure 99 is best achieved by frequent cleaning of the stones. The rate of the vertical strokes (up and down movement) of the hone should be increased as the r.p.m. of the hone is increased.

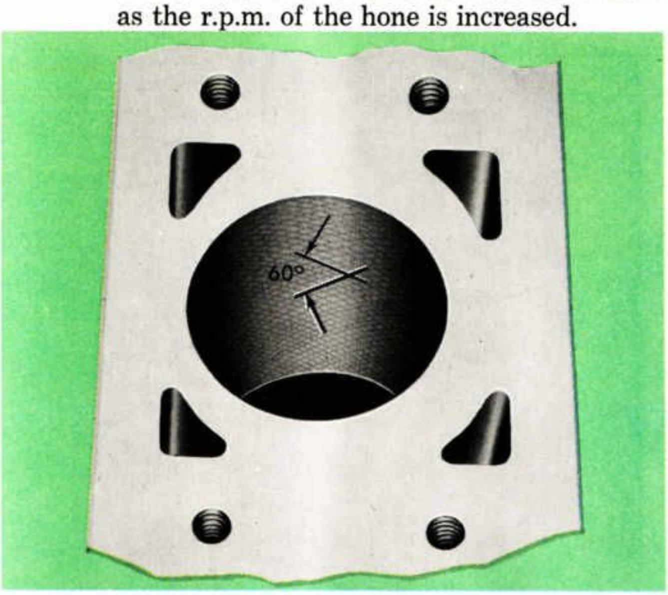


FIGURE 99. CROSS-HATCH PATTERN

12. Break all sharp edges with a small file. (Around cylinder bore chamfers, main bearing bore chamfers, etc. . . .)

13. Clean the block thoroughly and coat its machined surfaces with a light oil film, as previously recommended, and store it in a clean area until you are ready for assembly.

CRANKSHAFT

In addition to selecting the crankshaft which provides the proper stroke, the following suggestions are offered to assist you in your efforts to build a high-performance engine. (It is advisable to certify that the crankshaft is structurally sound with a magnaflux test.)

1. Check journals for taper or out-of-round condition with a micrometer. Measurements should be taken at several places along the length of the journal to check taper. Rotate the shaft by quarter-turns to check for out-of-round conditions. Regrinding is generally recommended if either condition shows as little as .0015″ variation.

CAUTION:

Some high-performance crankshafts are only surface hardened and the regrinding operation will produce a soft crank. These cranks will have to be replaced.

2. Polish-out nicks or scratches from bearing surfaces by hand. Use extremely fine sandpaper designed for this purpose.

3. Chamfer journal oil passages and break sharp edges with a wet oil stone.

4. Check crankshaft alignment using "VEE" blocks and a dial indicator. Straightening is necessary if it is more than .003″ to .005″ out-of-line. An alternate method is sometimes permissible if "VEE" blocks are not available; install the crank in the block and torque only the front and rear main bearing caps. (Bearing inserts installed). Take a dial indicator reading at center main bearing journal.

5. Before assembly, clean the crankshaft thoroughly —including internal oil passages.

CRANKSHAFT BALANCING

Crankshafts are balanced in production at the factory; however, in building a high-performance engine, it becomes an even greater critical factor. This is especially true if other modifications have been performed. Balancing work is a highly specialized area and is only performed in specially-equipped shops. It involves removal of metal at heavy spots and the addition of metal at light spots. (See Figure 100.)

We are concerned both with STATIC and DYNAMIC balance. Static balance is attained when the weight of the crankshaft is equal in all directions from the center when the crankshaft is at rest. Each engine design has its own balance requirements. (For example, an in-line, six-cylinder crank, supported on knife edges by the front and rear main bearing journals, should not rotate when set at any given position.)

Dynamic balance means balance in motion. It is obtained when the centrifugal forces of rotation are equal in all directions at any given point. To obtain dynamic balance, metal is removed from the crankshaft counterweights by either grinding or drilling. Although more rare, sometimes metal must be added to the coun-

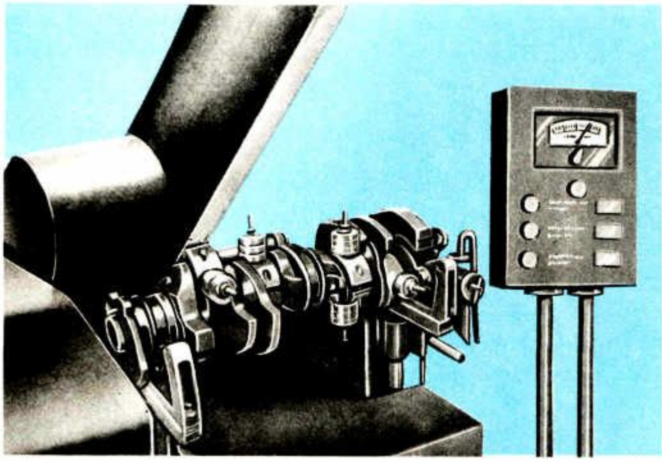


FIGURE 100. CRANKSHAFT BALANCING

terweights by welding, bolting-on, or filling a drilled hole with a heavier substance.

Not only must the crankshaft itself be balanced, but in production, the entire rotating assembly is balanced together. The whole assembly includes flywheel, vibration damper, fan pulley, and timing gears.

More importantly in high-performance work, however, is the strict adherence to the specified weights of the piston and connecting rod assemblies. This assembly includes rods, pistons, pins, rings, and bearings. These parts must be carefully balanced with one another so that the rotating mass will produce as little vibration as possible.

PRECISION INSERT BEARINGS

The connecting rod and main bearings are called PRECISION INSERT bearings since they are inserted directly into the main and connecting rod bores without machining or fitting. Most engine manufacturers make the bearings available in various sizes to compensate for both crankshaft journal wear and the use of undersize crankshafts. These undersize bearings are usually made available in undersize increments of .001″, .002″, .010″, .020″, and .030″. For high-performance engine applications, bearing inserts in increments of .0005″ are also available for more precise clearances. The bearings recommended by Ford Motor Company for high-performance applications are a copper-lead alloy with S.A.E. 1010 steel backs. They offer maximum durability for both street and strip.

PISTON AND CONNECTING ROD ASSEMBLY

Pistons

Figure 101 shows pistons which are typically used in high performance engines. They incorporate most of the features of improved piston design that have evolved through the years. They combine strength and durability and light-weight characteristics with controlled heat expansion features, along with skirt and dome configurations that permit proper working clearances. Pistons are selected to provide a compression ratio which is compatible with other design features and output requirements of the engine.

FIGURE 101. TYPES OF HIGH-PERFORMANCE PISTONS

Piston Rings

In racing engines, the use of chrome rings is a *must!* The balanced combination of ring sets that provide good wear characteristics with good sealing and oil control features (tension, shape, size, etc. . . .) can mean a great deal in terms of horsepower gains and losses. At least one authority claims an additional 19 horsepower was gained through careful selection of piston rings.

Connecting Rods

Connecting rods used in all-out competition engines incorporate scientifically-designed reinforcement contours that coincide with the strain pattern developed during high-stress, high r.p.m. operation. These connecting rods weigh only slightly more than conventional-design rods, but have much greater fatigue resistance. (See Figure 102-A.)

Balance is super-critical with connecting rods, as it is with all parts that revolve at high speeds. Weight mill-

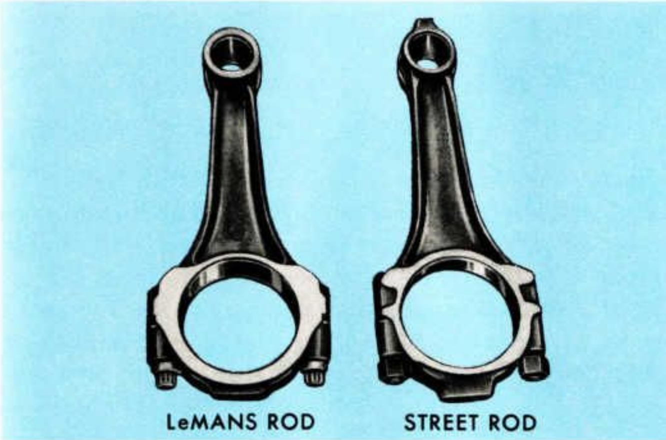


FIGURE 102-A. HIGH-PERFORMANCE CONNECTING RODS

ing pads are located on a vertical centerline at both ends of the rod for balancing purposes. Engine builders, when blueprinting, pay particular attention to the specified weight (measured in grams) of the connecting rod. (See Figure 102-B.)

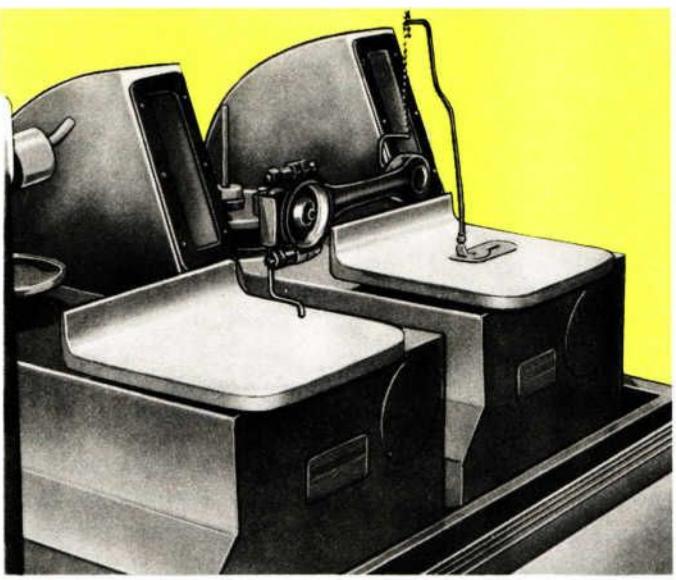


FIGURE 102-B. CONNECTING ROD BALANCING

In engine build-up, the following steps are recommended to ensure the bottom half of the mill doesn't come unglued. *Again, magnafluxing should be used to ensure that the connecting rod is structurally sound.*

1. De-burr with a small file. (See Figure 102-C.)
2. Hand-sand with fine sandpaper to provide a smooth bore.
3. Hand-sand sides on a flat surface. Be careful not to exceed specified oil clearance.
4. Check the rods for alignment (special fixture required). (See Figure 103.)

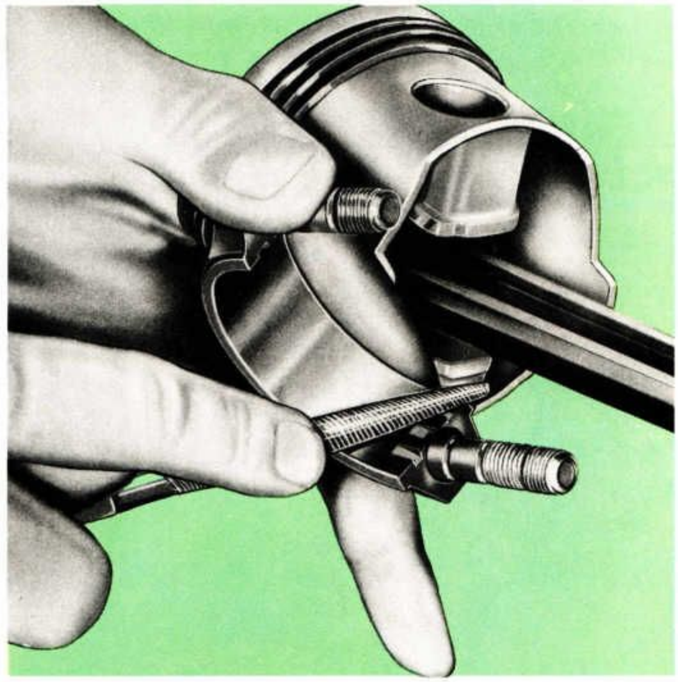


FIGURE 102-C. DE-BURRING CONNECTING ROD

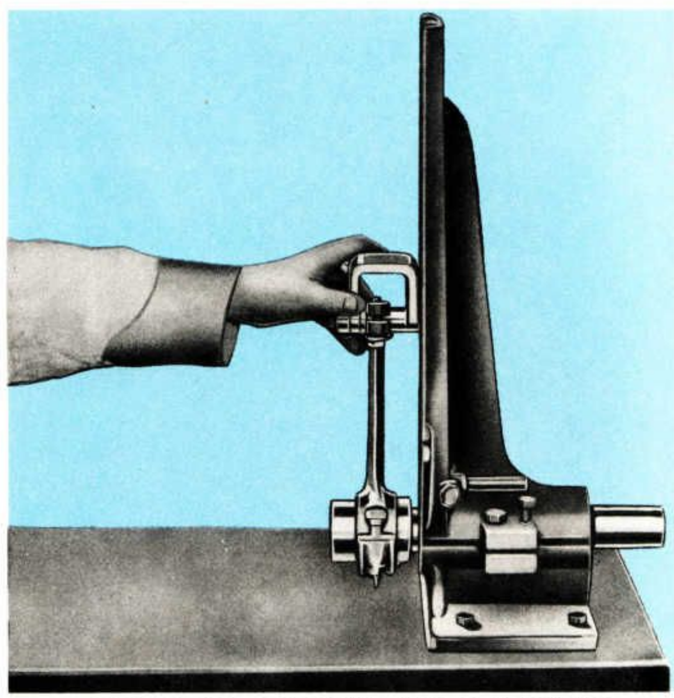


FIGURE 103. CHECKING ROD ALIGNMENT

5. When installing the rods to the crankshaft, torque the caps to specification, rotate the shaft, remove the bearing cap and visually inspect it for burrs on the bearing surface. This is an extra precaution before final assembly.

Speed shops that specialize in balancing operations normally perform the alignment checks as well. About all you need, in addition to normal hand tools and measuring devices, are patience, fortitude, and a good pair of eye-balls.

Engine Cooling and Lubrication

MAJOR FUNCTIONS OF COOLANTS AND LUBRICANTS

COOLANTS

The coolant used in a liquid-cooled internal combustion engine may be plain water or various anti-freeze solutions. The main function of the coolant is to dissipate heat from the combustion chambers (about 4,000° F.) to the surrounding atmosphere, and yet maintain engine temperature at around 200° F. to prevent the parts from expanding to the point where a ruined engine could result.

Part of the heat is transferred from the cylinder to the water in the water jackets. The outer surface of the water jacket will dissipate some heat to the surrounding air, however, most of the heat is carried by the coolant to the radiator, where it is dissipated into the air.

LUBRICANTS

Oil in the engine lubrication system performs these four important functions: (See Figure 104.)

1. Sealing–A film of oil fills clearances caused by unequal heat expansion of moving parts.
2. Cleaning–Dirt and abrasive deposits are constantly picked up and carried in suspension in the oil.
3. Cooling–Oil acts as a cooling agent by continually absorbing, transferring, and dissipating heat to parts of the engine cooled by water or air.
4. Lubricating–Oil acts as a lubricant because of its ability to stick to metal, to make the surface slippery, and to maintain a film between moving parts.

The importance of using high quality oil cannot be over-emphasized. Careful and time-consuming refining methods are used to produce good oil; therefore, its cost may be slightly higher. Some of the properties of engine oil to be considered are: sludge and varnish formation tendencies that block oil flow and cause parts to stick; film strength or load carrying ability; the rate of viscosity change due to temperature; the amount of sulphur or acid-forming ingredients; and the presence or absence of detergents. Engine oils used in racing engines contains anti-foam ingredients to prevent the oil from aerating at high r.p.m.s

Engine oil must be contained in the engine. This is accomplished by the use of various types of gaskets and seals. Modern sealing material makes use of synthetic rubber and plastics. Sometimes they are bonded to metal, fiber, or cork when used in critical areas. Most crankshaft seals are graphited asbestos but a few one-piece rubber and metal lip type seals are used. Regardless of the quality of gaskets and seals, they require proper installation, bolt torque.

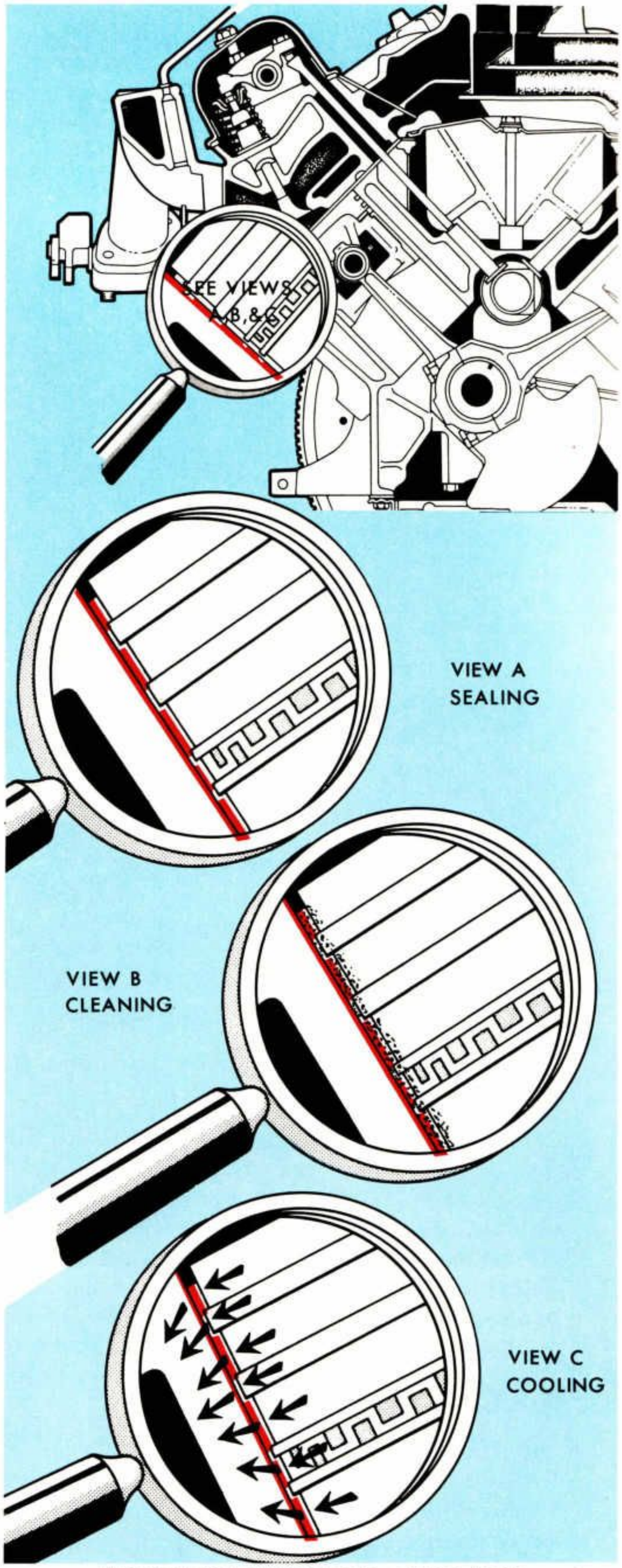


FIGURE 104. ENGINE OIL FUNCTIONS

and clean, matching surfaces. Excessively high internal pressures, worn bearings, shaft runout, and rough surfaces can contribute to seal or gasket leakage.

REVIEW OF COOLING AND LUBRICATING SYSTEM OPERATION

COOLING SYSTEM

The component parts of a typical liquid-cooled system are the radiator, radiator cap, water pump, thermostat, fan assembly, fan drive belt, and coolant passages (with distribution tubes) in the block and head which are subjected to extreme heat. (See Figure 105.)

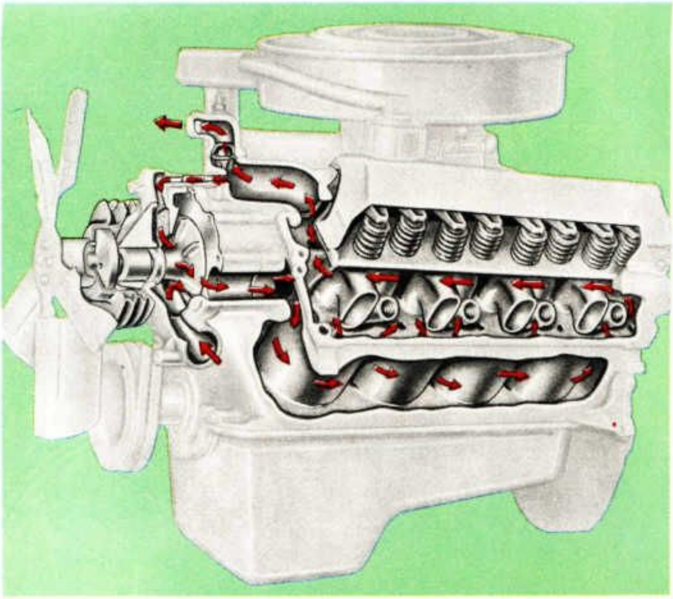


FIGURE 105. TYPICAL COOLING SYSTEM

Water or coolant is heated in the engine. When sufficient heat is generated, the thermostat opens, allowing the liquid to circulate to the top of the radiator. The coolant drops through the radiator where air, passing through the radiator takes most of the heat away. After being cooled in the radiator, the coolant enters the pump and is forced through the engine. Either a hole in the thermostat or a by-pass tube allows a slight water circulation when the thermostat is closed. The purpose is to eliminate steam or hot spots until the thermostat does open and complete circulation starts.

The water jacket is part of the cylinder block and only on large industrial engines can the jackets be opened for cleaning and inspection.

Water pumps are mostly of the centrifugal type because the delivery volume of this pump closely follows the circulation requirements of the piston engine. Sealed bearings are used on the impeller shaft and the water seal is usually formed through the use of face seals. Water pumps are normally belt driven from the crankshaft at or near crankshaft speed. (See Figure106). The fan that draws air through the radiator is usually attached to the front of the water pump. Fans vary widely in diameter and number of blades, depending on engine speed, radiator area, shrouding, noise limitations, etc.

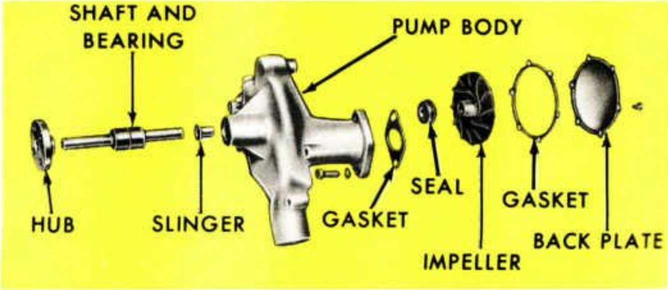


FIGURE 106. TYPICAL WATER PUMP

After flowing through the entire length of the cylinder block, the coolant flows up into the cylinder head through rear passages, then continues on through the entire length of the cylinder head, from back to front, cooling the combustion chambers, valves, and valve seats. The ports which carry the coolant from the block to the head can be seen when the cylinder head is lifted. (See Figure 107.)

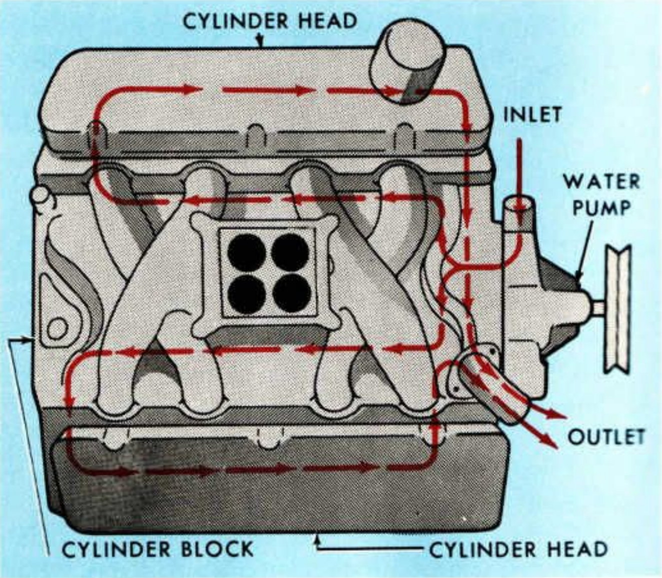


FIGURE 107. PATH OF COOLANT THROUGH ENGINE

It is very important to keep exhaust valves properly cooled. At their high operating temperature, exhaust valves, if not properly cooled, will warp, burn, or even melt. To keep the exhaust valves properly cooled, the coolant flows around the valve seats and valve guides. (See Figure 108.)

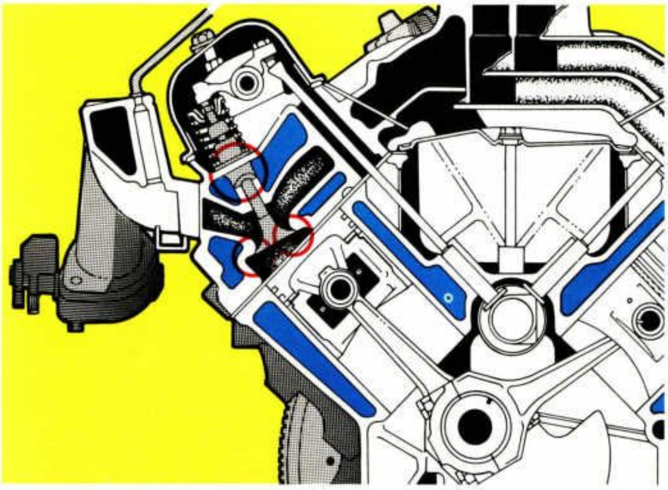


FIGURE 108. VALVE COOLING

An expansion or surge tank is located on the top of the radiator or in the high point of the cooling system. It serves as an air separator, reserve tank, and expansion chamber.

The entire cooling system is usually pressurized to raise the boiling point of the coolant. A valve, located in the filler cap, controls the pressure to approximately 14 pounds per square inch. This pressure will also show up any weak spots or leaks in the cooling system especially when permanent anti-freeze is used, because permanent or ethylene glycol anti-freeze is of high density and will flow through a very small hole. Various types of anti-freeze solutions have been used but practically all of the original manufacturers recommend the ethylene glycol base type because of its high boiling point. Alcohol base solutions have a low boiling point, and present a fire hazard.

Thorough sealing of the cooling system is necessary to prevent serious damage in the engine, not only due to excess heat, but in the event permanent anti-freeze gets in the engine, an undesirable gum is formed.

LUBRICATING SYSTEM

The most common system consists of an oil reservoir or pan located on the bottom of the engine, a pump, a filter, and passages leading to the parts to be lubricated. A pressure relief valve, usually located in the pump, maintains constant pressure in the system. (Some specially-designed race engines locate the relief valve in the oil galley in the block.)

Any excess oil that passes through the relief valve is returned to either the pump inlet or to the sump or reservoir. Parts that receive full pressure lubrication are the crankshaft main bearings, connecting rod bearings, and the camshaft bearings. Reduced pressure is necessary to some parts to reduce the possibility of excess oil consumption and to prevent starving the crankshaft and camshaft bearings. Parts that receive reduced pressure lubrication are hydraulic lifters, push rod ends when used with stud pivoted rocker arms, shaft pivoted rocker arms, and some distributor shafts. Areas that are lubricated by splash, squirt or drip are cylinder walls and piston rings, timing gears or chains, cam followers, and piston pins. (See Figure 109.)

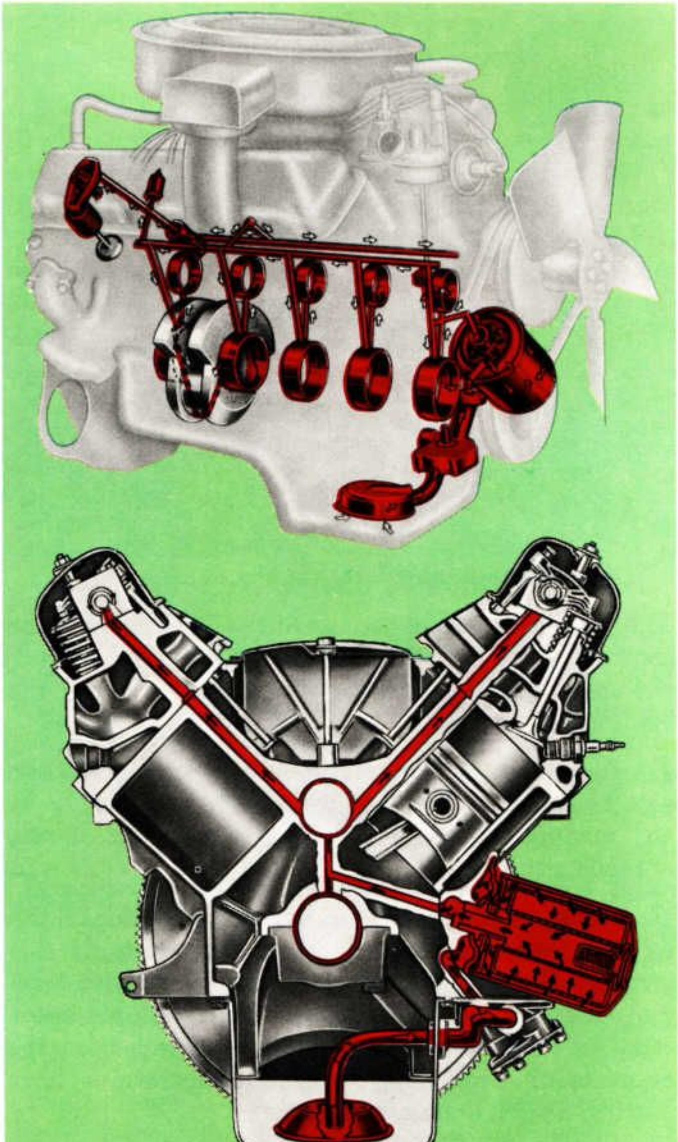


FIGURE 109. TYPICAL ENGINE LUBRICATION SYSTEM

DRY SUMP LUBRICATION SYSTEM

Another engine lubrication system is the dry sump type. In this system the reserve oil is stored in a tank away from the engine. Two or more pumps must be used; one to supply pressure to the engine and one or more to return the oil to the tank. This system has advantages in that the oil can be cooled easier and better, more reserve oil can be carried, air bubbles and oil foaming in the engine are reduced, and the rotating parts do not have to combat a crankcase full of oil.

In racing circles (both strip and track), the dry sump system is gaining in popularity. The horses gained as a result of this system's design may prove to be worth the extra cost involved.

PREPARATIONS FOR IMPROVED PERFORMANCE

COOLING SYSTEM COMPONENTS

Many of the steps necessary in preparing the engine cooling system for high-performance operation will have already been accomplished by performing the cleaning operations described under cylinder head and block preparations. Rust and lime deposits are inherent enemies of the cooling system, in that they form barriers to the system's function of heat dissipation. Normal service operations include:

1. The use of a rust inhibiting solution in the coolant.
2. Flushing foreign deposits from the system.
3. Testing the system for:
   A. Leaks
   B. Thermostat temperature range
   C. Adequate anti-freeze protection

The balance of operations involved in preparing the cooling system for high performance is largely dependent upon the type of driving you expect to do with the vehicle.

A vehicle prepared for both street and track operation will have all of the components recommended by the manufacturer. That is, thermostat, anti-freeze, shrouds, etc. . . .

The exact opposite end of this scale would be the vehicle prepared exclusively for the drag strip. In this instance the entire cooling system is sometimes removed, and no coolant is used at all. If you are interested in one "all-out" run down the strip, then the event is all over before engine temperatures have reached a point of destruction.

In between the two extremes cited above, we find that modifications to the cooling system are possible in the areas of:

- System capacity—Larger radiators are sometimes selected to provide additional coolant.
- Water pump design—Since cooling system pressures in some high-performance engines often approach 90 p.s.i., the impeller vanes have a reduced diameter to allow for sustained high r.p.m. operation.
- Sealing—High pressures also require the use of threaded water jacket plugs, rather than the usual press-fit Welch plugs.
- Component removal—Shrouds are often removed to accommodate blower, carburetor set-ups, or other modifications. Scoops or air ducts are added on other installations to increase air flow through the engine compartment; thermostats are sometimes removed to reduce any restrictions to coolant flow.
- Fan blade design—Since fan blades are required to operate at high r.p.m., and can use up as many as 6 to 8 horsepower, special attention is given them in high-performance applications. They must be designed to provide adequate air flow through the radiator under all operating conditions. Here, we are concerned with:
  - Number of blades
  - Speed of rotation (Some applications call for a clutch—controlled blade that "free-wheels" at high r.p.m.) (See Figure 110.)

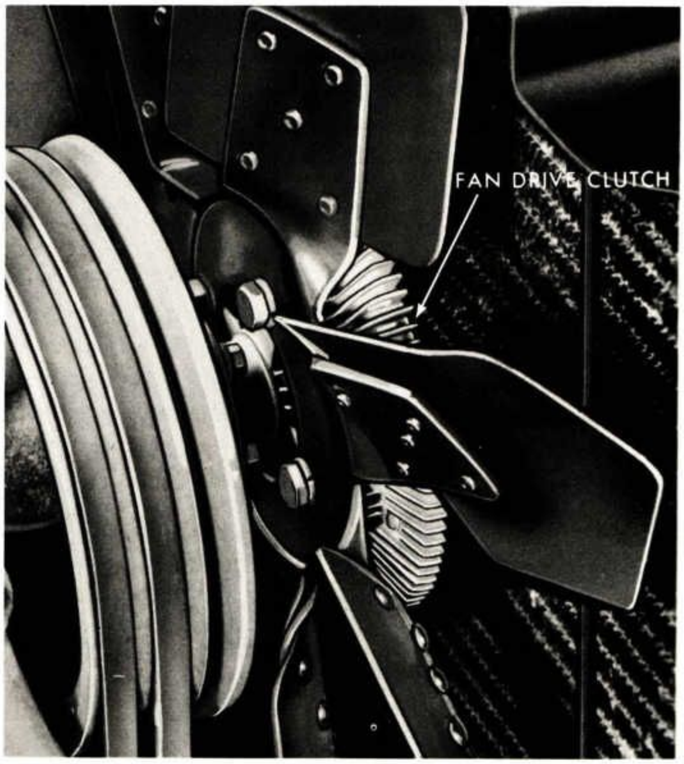


FIGURE 110. FAN DRIVE CLUTCH

  - Dynamic balance—All blades are balanced to reduce noise and vibration.
  - Length of blade—Blades are often shortened to reduce wind friction.
  - Shape of blade—Curvature, pitch, and blade angle determines the rate of air flow.
  - Material—Fan blades are often constructed of aluminum for weight reduction.

As a rule of safety—don't experiment on your own. For example, bending or removing a blade would throw the assembly out-of-balance, and vibration could lead to water pump damage or even worse . . . another blade may come unglued and fly through radiator, hood, your hand, etc. . . . Use only fan assemblies that have been tried and tested for your particular application.

FIGURE 111. SAFETY PRECAUTIONS

One final word of caution—Never add coolant to an overheated engine. Wait until it cools off. Adding coolant to an extremely hot engine can result in a cracked cylinder head or block.

LUBRICATING SYSTEM COMPONENTS

• Oil Pumps—Oil pumps are either of the gear or rotor type. The rotor type is used almost exclusively on high performance applications because of its higher capacity capabilities. (See Figure 112.)

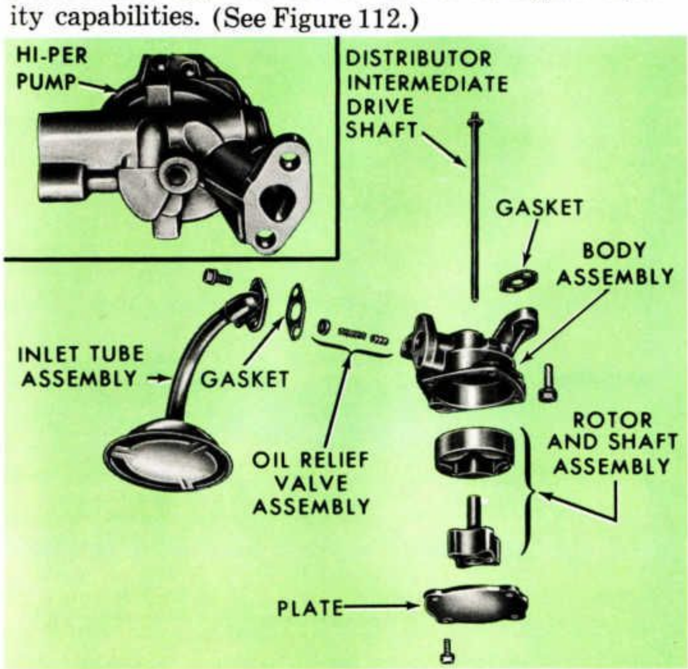


FIGURE 112. ROTOR TYPE OIL PUMP

The oil pump is driven by a drive gear on the camshaft or an extension-type shaft from the distributor. High performance (high capacity) pumps deliver approximately 22 g.p.m. with 70-80 p.s.i., at 4000 r.p.m.

• Oil Filters—From the oil pump, oil is pumped to the oil filter. Since one of the functions of the oil is to keep the engine clean, the oil itself must be kept clean. (See Figure 113.)

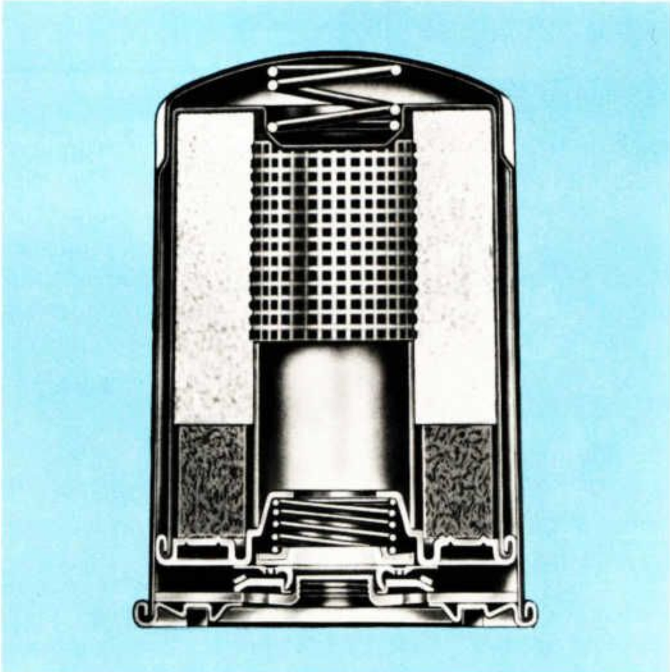


FIGURE 113. FULL-FLOW OIL FILTER

Lab tests indicate that most engine wear is caused by abrasive particles in the 10-20 micron range. (One micron=1/39 millionth of an inch.) Filters are designed to filter out these harmful abrasives. The filter materials are bonded with resins that will not breakdown under adverse conditions like sludge, varnish, or exotic fuel mixture contaminents.

Competition filters differ from conventional filters, in that they are constructed to withstand more severe service. Street type filters use a thin wall steel casing which is adequate for average pressure surges. High performance filters are constructed of heavy gauge (one-third heavier than conventional) metal.

The contour of the can is such that no weak points occur during the stamping process and can tolerate pressures up to 400 p.s.i. The base plates are similarly constructed of heavier gauge steel to prevent warpage (thus oil leakage) caused by high pressure surges. The gasket (which rests on the base plate) is seated in a deep channel to assure maximum sealing. The ports on the base plate are engineered for maximum oil flow; thus, maximum engine protection is assured and oil pressure remains high in top r.p.m. ranges. The type of filter shown in the illustration shows the full-flow characteristics; that is, all of the oil from the pump must pass through the filter before passing on to the rest of the system. The filter incorporates a by-pass valve that lifts off its seat to allow oil into the system, should the filtering material become clogged.

• Oil Pans—Stock oil pans, which are more than adequate for normal driving needs, may have insufficient capacity for high-performance requirements; one of which is to maintain oil temperatures below 275°. Another requirement is to keep oil away from rotating parts. This is accomplished by baffle plates welded inside the oil pan. (See Figure 114.)

One application of a baffle plate is called a "windage tray". Its function is to keep the mass of oil in the sump—away from the rotating crank assembly. For any strip or track competition, the deep sump oil pan is recommended. It provides the additional capacity to meet the requirements of cooler oil and less friction of dragging moving parts through the oil. Some top notch competition mechanics claim 15-20 horsepower gains by use of these specially-designed oil pans.

• Oil Sump Pickup—Any time a deep sump pan is used, an accompanying special oil pickup tube is required. It uses a large-diameter tube to provide for unobstructed oil flow at high r.p.m.

FIGURE 114. DEEP SUMP OIL PAN AND PICKUP

Ignition Systems

INTRODUCTION

Peak performance depends upon completely burning the highly compressed air-fuel mixture at precisely the correct time to obtain peak efficiency. The burned mixture must produce the highest possible temperatures and pressures in order to take advantage of any engine modifications that have been made. The voltage necessary to jump the air gap at the spark plug increases as compression pressures increase. High engine r.p.m.'s also tend to cut down coil saturation time and make it more difficult to produce a strong, hot spark at the plug. There are two basic ways to improve ignition output for high performance engines. One way is to improve the performance of the conventional ignition system. The other way is to use a transistorized ignition system. Let's talk about the conventional ignition system first.

CONVENTIONAL IGNITION SYSTEM

Replacing the single breaker point with the dual breaker point distributor or adding a dual point breaker plate to the present distributor enables the ignition coil to produce higher voltage at high engine r.p.m. (See Figures 115 and 116 respectively.)

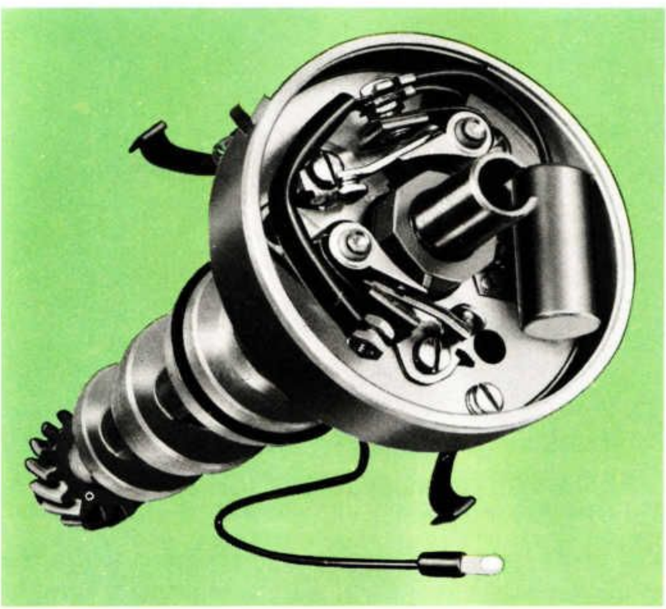


FIGURE 115. DUAL POINT DISTRIBUTOR

With one set of points closing to complete the circuit and the other opening to break the circuit, it is possible to obtain a longer dwell or coil saturation time. This enables the ignition coil to build a stronger magnetic field and produce both a hotter and higher voltage secondary spark. The use of a dual breaker point distributor also makes it possible to use lighter weight ignition points with spring tension designed to reduce the possibility of point bounce at high r.p.m.

FIGURE 116. DUAL POINT KIT

Point bounce is a condition that exists when the distributor cam is rotating at high speed and the breaker points actually hit and bounce rather than make a good solid contact. This causes an erratic build-up of the magnetic field in the coil and results in less secondary voltage at the spark plug. Care must be used when determining point spring tension to avoid another possible high speed problem . . . point float. If the spring tension is not sufficient to close the points at high speed, they will tend to "float" or stay open. When this happens, coil saturation time is drastically reduced and the secondary spark does not have enough voltage to jump the plug gap. So we can see that the selection of breaker points and the point spring tension adjustment are vital to the high performance distributor.

It is also possible to obtain a hotter spark by using a metal core secondary wire to the spark plugs, rather than the resistance-type wire used on conventional passenger cars. This allows both the starting (capacitive) end and the trailing (inductive) end of the spark to be utilized in firing and sustaining the spark in the cylinder. A radio suppression kit is recommended for street use.

A distributor for a high performance engine most often utilizes only centrifugal advance to control the timing. A vacuum control would have little use at high r.p.m.s. It is also much easier to tailor the ignition advance curve requirements with a centrifugal advance distributor. It is recommended that the advance curve be checked on a distributor test bench to be sure that it conforms to specifications. (See Figure 117.)

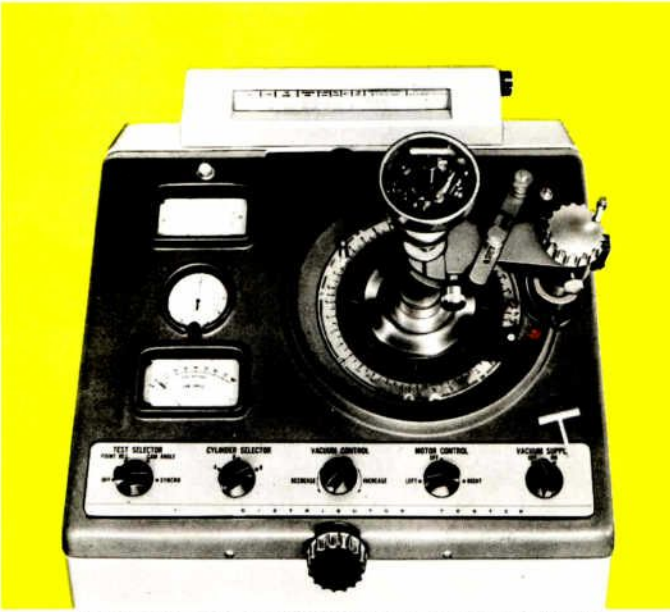


FIGURE 117. DISTRIBUTOR TEST BENCH

The Autolite distributor, either the original equipment or a high performance replacement, is adjustable by controlling spring tension on the centrifugal weight springs. Some other distributors are non-adjustable and the springs or weights must be replaced if the advance curve is not within specifications. Figure 118 illustrates the advance curve of a typical Hi-Performance distributor. In a combination "STREEP" (street and strip) vehicle, it is desirable to use both the centrifugal and vacuum advance distributor to obtain acceptable performance at lower speeds. The

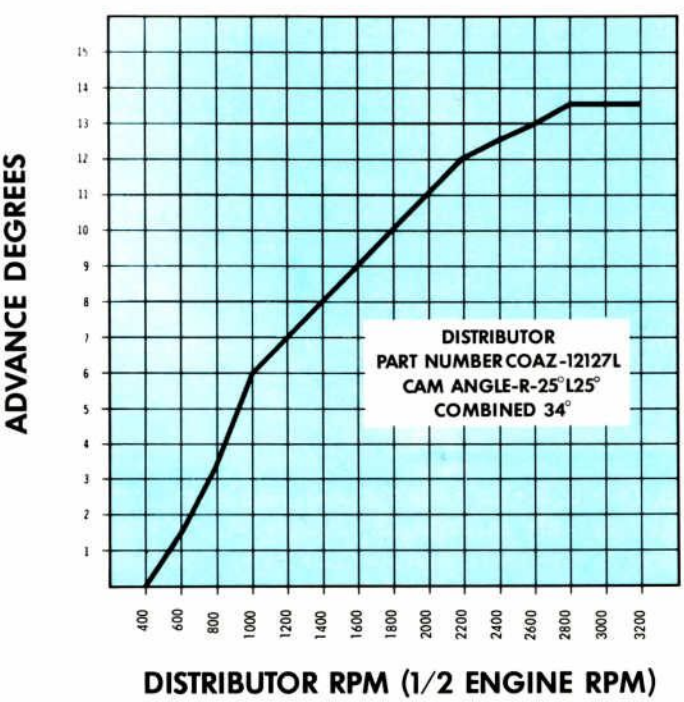


FIGURE 118. CENTRIFUGAL ADVANCE CURVE

vacuum advance diaphragm is designed to control ignition timing in relation to the load applied to the engine and, of course, the engine is more sensitive to load at lower speed.

TRANSISTOR IGNITION SYSTEMS

There are two types of transistor ignition systems used by the automobile industry at the present time.

One type, the transistorized system, uses a conventional distributor with breaker points to "trigger" or control the system. (See Figure 119.) The other type, called capacitor discharge, uses a special distributor with a magnetic cam and an induction coil inside the distributor housing. There are many similar advantages to each type of transistor ignition system. As we mentioned before, the entire ignition system is designed to allow sufficient time for the coil to build up a strong magnetic field so that it can produce a secondary voltage high enough to ionize (change from a non-conductor to a conductor) the spark plug gap and "fire" the compressed air-fuel mixture in the cylinder.

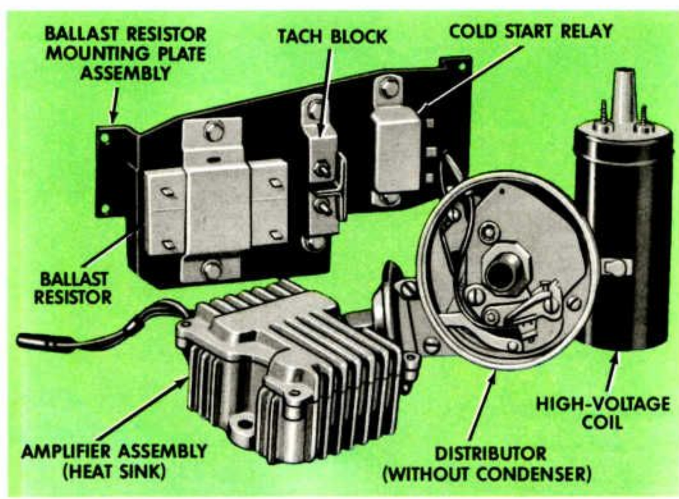


FIGURE 119. TRANSISTORIZED IGNITION SYSTEM

The point-type transistorized ignition aids ionization by allowing the use of a coil with more primary turns of wire; thus, it has more current draw than the conventional system. Due to the design of a transistor, it has the ability to carry a strong current in its emitter-collector circuit with a small amount of current flowing in the base circuit. (See Figure 120.) Therefore, the base circuit is connected to the distributor breaker points to act as a "trigger" or control, and the ignition coil is connected to the emitter-collector circuit. With the ignition points closed, a small amount of current flows through the base circuit and the points to ground. This allows a larger amount of current to flow through the emitter-collector circuit and the ignition

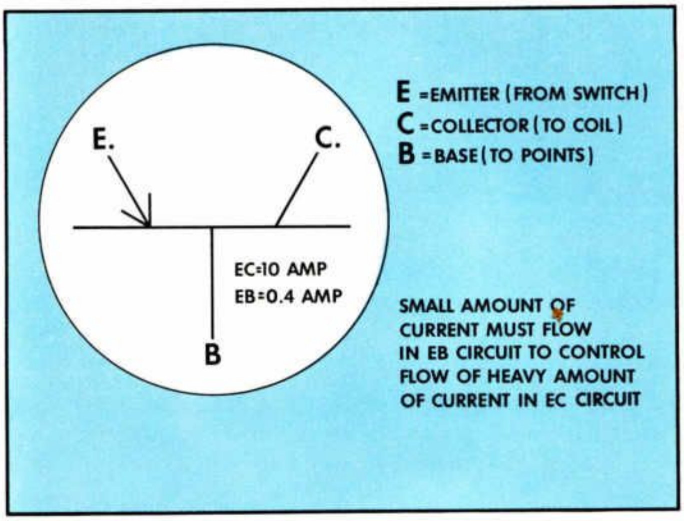


FIGURE 120. POWER TRANSISTOR SYMBOL

coil to ground, causing a strong magnetic field build-up within the coil. When the points open and the base circuit is interrupted, the current stops flowing in the emitter-collector coil circuit. The magnetic field then collapses and a high voltage current is induced in the secondary winding of the coil to "fire" the spark plug. Even at the extreme high speeds of a high performance engine, this type system helps provide the necessary spark. Of course, the ultimate in transistor ignition systems is the capacitor discharge type. By eliminating the ignition breaker points, one of the common high speed ignition problems is overcome . . . that of point bounce. As we discussed previously, in a conventional breaker point system, the points tend to bounce at high speed.

The capacitor discharge system also has another important advantage. Less time is needed to build up a high voltage secondary spark after the circuit is interrupted than is needed with a point-type transistorized system or a conventional ignition system. The capacitor discharge system reaches maximum voltage in 1-2 micro-seconds or millionths of a second. Conventional ignition systems and point-type transistorized systems take from 80 to as high as 210 micro-seconds to produce maximum secondary spark intensity. We can also see from these figures that a capacitor discharge system could fire a partly fouled spark plug. In the other systems, the additional time required to build up the spark could allow that spark to bleed off to ground through a partly fouled plug before the system could produce its maximum output . . . or even high enough voltage to jump the gap. Both types of transistor ignition systems can be credited with the ability to extend the life of the spark plugs because of the sustained high voltage to the plug and the ability of the transistor to rapidly stop the flow of current to the ignition coil when the base circuit is opened—either by the capacitor or the breaker points.

This rapid interruption of the flow of current causes a high voltage secondary without the inductive, or plug eroding tail-end portion of the spark. (See Figure 121.)

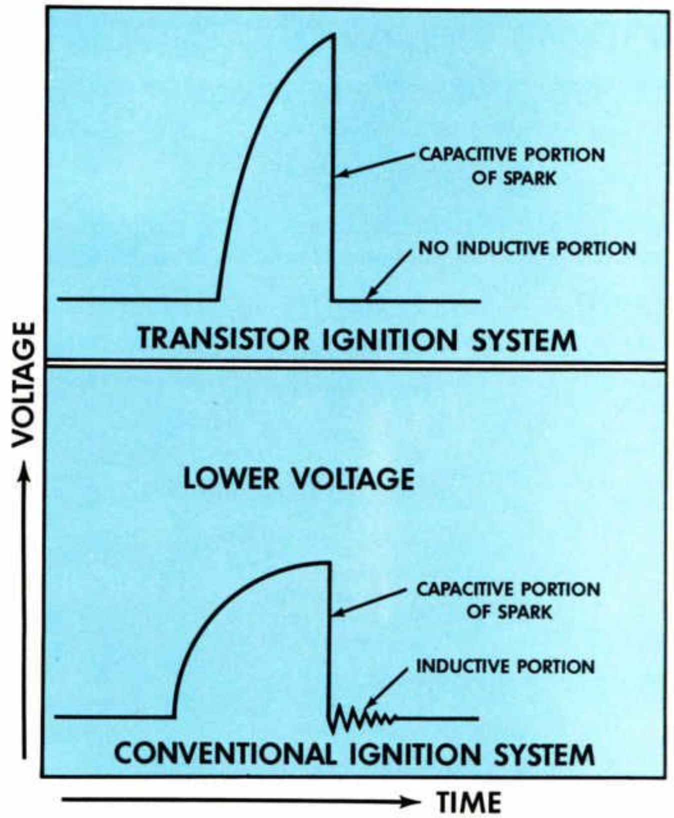


FIGURE 121. TRANSISTOR VS. CONVENTIONAL SYSTEM

In street use this could mean up to 50,000 miles of plug operation. In the point controlled transistorized system, the ignition points have almost an unlimited life. The only reason for changing points would be rubbing block wear, and that is reduced by using a highly polished cam and special lubricant to insure a minimum amount of rubbing block wear and little timing change. As far as the contact surface is concerned, the very small amount of current needed to "trigger" the base circuit would never burn the points. The fact that the base circuit is entirely separate from the emitter-collector circuit means that there is no possibility of induced current in the primary winding of the coil being discharged through the breaker points. This is why the condenser for a transistorized system is in the collector circuit rather than in the base circuit.

The advantages in using transistor ignition systems for either street or strip can be grouped into two categories—performance and economy. In the area of performance, the advantages are a rapid build-up of secondary voltage; a spark of ample intensity, as well as voltage to sustain ignition in the cylinder without the need for the inductive portion of the spark; and last but not least, the ability to produce this voltage and current at most any speed. In the area of economy, the advantages are prolonged spark plug and ignition breaker point life and no condenser needed in the circuit.

MAGNETO IGNITION

There is one other type of ignition system used in racing . . . the magneto. Because of its waning popularity, this publication will not deal with the magneto except to say that about the only time that this system is used is when the race car has a weight problem. Because the magneto is a self-contained unit, no outside current supply is needed, so the battery and charging system can be eliminated with the resulting weight savings. The disadvantage in this type of system is the horsepower required to turn the magneto. Quite often the horsepower requirement disadvantage is greater than the weight saving advantage and the magneto system is not used. (See Figure 122.)

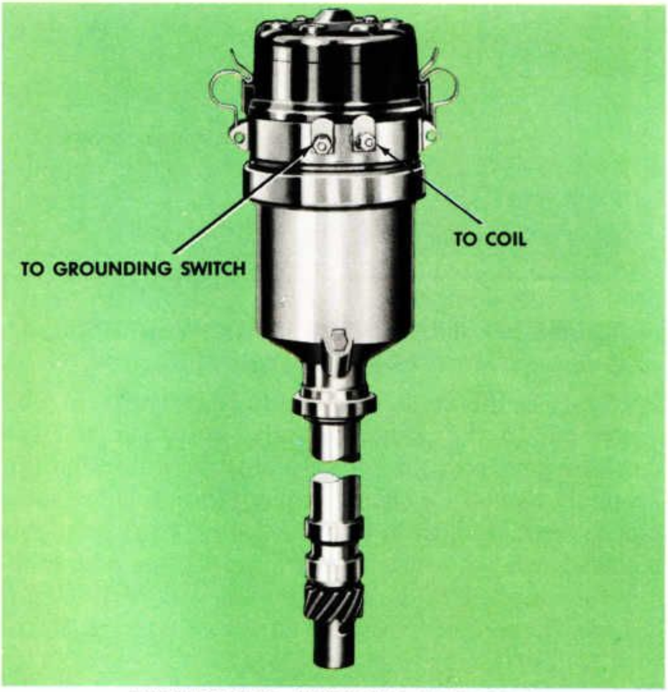


FIGURE 122. TYPICAL MAGNETO

The operation of the magneto is really quite simple. A powerful magnet is rotated within or around a coil or series of coils of wire to produce a primary current which is boosted in voltage by a transformer coil. Because of the fact that the primary current is produced by the magneto itself, no external current source (battery) is needed. As mentioned before, the faster the magneto turns, the more horsepower it requires to develop a primary current sufficient to energize the booster transformer coil. Balancing the moving parts of a magneto at the increased speeds of the high performance engine sometimes becomes a problem. Because of these problems and the fact that most high-performance vehicles require a battery to supply starting motor energy, the magneto is not the most popular type of ignition system.

SPARK PLUGS

Selecting the proper spark plug is, without a doubt, one of the most important factors which affect the outcome of a competition event with a high-performance vehicle. The best engineered car at the track will not win if any plug fails to fire. Unfortunately, this is an area in which trial and error are about the only "specifications" that can be used. Other than *reach* and *thread diameter* the spark plug selection must be made on an individual basis (See Figure 123.) The heat range of a plug, or the ability to withstand the intense temperatures inside the combustion chamber, depend on many factors. C.I.D., compression ratio, compression pressure, type of fuel, air-fuel ratio, type of camshaft, spark advance setting, elevation, humidity, cooling system, carburetor and intake manifold design, header design, and, of course, the type of race event are but a few of these factors. Unfortunately, the

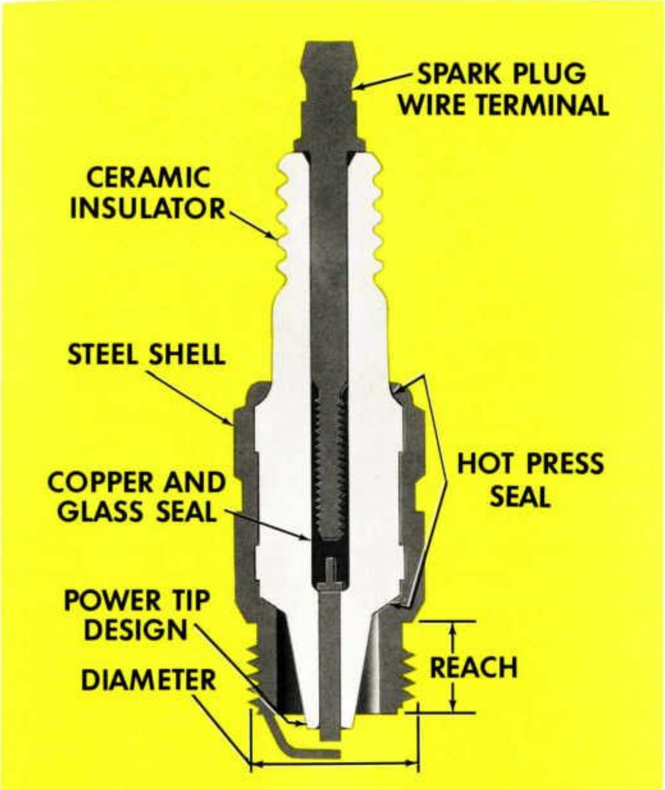


FIGURE 123. SPARK PLUG REACH & DIAMETER

wrong spark plug heat range can cause, not only the loss of a race, but also the loss of an engine.

There are four types of spark plug designs in common use. (See Figure 124.) The two-cycle gap design

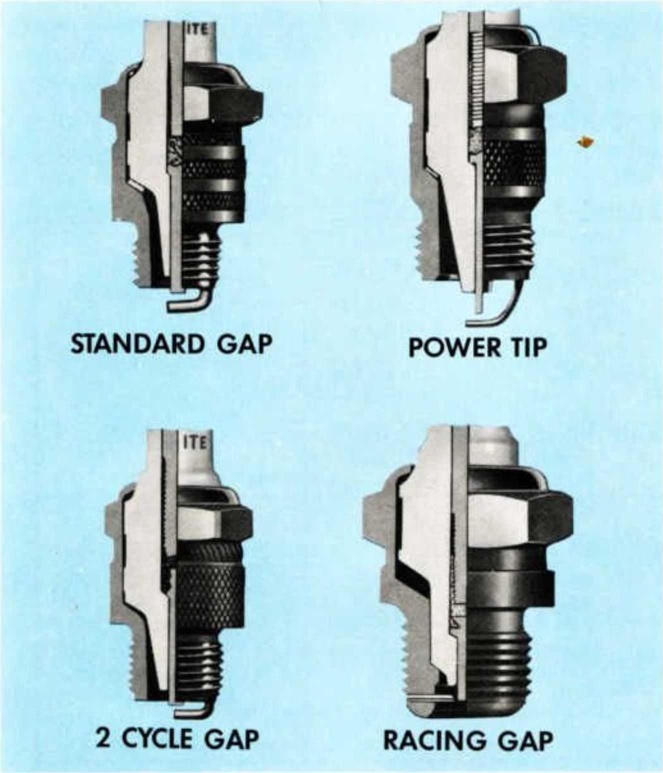


FIGURE 124. SPARK PLUG TYPES

(ground electrode cut off at the center of the center electrode) is to be used with Go-Carts, outboard engines and any other two-stroke cycle engine. The other three designs (standard gap, power tip, and racing gap) are to be used in the four-stroke cycle engines for which they are specified.

Heat Range Selection

The rule for selecting heat range is as follows: "the hotter the internal engine temperatures, the colder the heat range". (See Figure 125.) It would be impossible to discuss all of the factors that influence heat range selection but we'll list some of the more important ones:

- Increased engine compression ratios cause higher combustion chamber temperatures. This increase in temperature requires a colder spark plug.
- Increased engine displacement from boring, stroking, or head or block milling raises compression; thus, a colder spark plug may be necessary.
- Various types of fuel and fuel mixtures tend to create different temperatures in the engine. Lean air-fuel mixtures cause increased temperatures requiring a cooler plug. Fuelers are a different story . . . when running alcohol, one heat range warmer plug should be used, than when using gasoline. Nitromethane on the other hand, produces much greater temperatures and it may be necessary to go two or three ranges colder than normally used.

FIGURE 125. HEAT RANGE

- Supercharging increases combustion pressures and temperatures. The blown engine requires a colder spark plug.
- Super speedways permit extended periods of high speeds resulting in increased combustion chamber temperatures. On short tracks, only short periods of high speeds are attainable, keeping combustion chamber temperatures at a minimum. Generally one range hotter plugs than used on a long track will give better results for short track racing.
- After selecting a suitable spark plug for the engine, a test should be made to determine if the proper heat range has been selected. Generally one to three laps will be sufficient. Near completion of the last lap the engine should be "shut-off" during full power, and the clutch disengaged. Pull and check the plugs immediately before any further engine operation and compare the firing tips. (Refer to Figure 126.)

As an engine safety precaution, *whenever doubtful in selecting a proper heat range for trial runs, always select a colder range to avoid pre-ignition.* Remember . . . pre-ignition causes internal engine temperatures to rise rapidly . . . resulting in detonation . . . *AND DETONATION BLOWS PISTONS.*

Care must be taken when selecting spark plugs to avoid trying to compensate for some other engine problem with spark plugs. Make sure that the ignition timing, engine tuning, and air-fuel mixture are all correct. Then select a spark plug. Autolite has a racing heat range chart to aid in this selection.

Figure 126 illustrates the Autolite spark plug numbering system. Note that each number and/or letter has a specific meaning in identifying the correct spark plug.

IDENTIFYING SPARK PLUGS

SPARK PLUG DIAMETER

FIRST LETTER	DIAMETER	EXAMPLE
A	14MM	A5
B	18MM	BT8
H	12MM	HE1
P	10MM	P6
T	7/8"-18	TT8
F	1/2" Pipe	F11

SPARK PLUG REACH AND TYPE

SECOND LETTER	REACH	EXAMPLE
None (Standard)	1/4"	P6
None (Standard)	3/8"	A5
E	1/2"	AE6
G	3/4"	AG5
L	7/16"	AL7

OTHER LETTERS	PLUG TYPE	EXAMPLE
F	Tapered Seat	BF82
R	Resistor	AER6
T	Transport	AT4
U	Power Mowers	AU7PM
Z	Internal Series Gap	BZ8

LETTERS AFTER NUMBERS	PLUG TYPE	EXAMPLE
M	Moisture Proof Pack	A3X-M
N	Special Design	A7N
P	Power Mower	AU7PM
S	Shielded	A8S
X	Marine Outboard	A3X

Numbers: First number indicates heat range. Second number indicates design or design change "1" or "0".

Example: BTF31 is a BTF3 plug with a design change. Does not affect heat range.
A21X is a A2X plug with a design change. Does not affect heat range.
AR80 is a AR8 plug with a design change. Does not affect heat range.
Second number "2" means a power tip plug. A52, BF42, etc.

SPARK PLUG HEAT RANGE

HOT PLUGS	EXAMPLE
11, 10, 9	A11, AR10, A9
MEDIUM PLUGS	
8, 7, 6	AT8, A7, AT6
COLD PLUGS	
5, 4, 3, 2	A5, A42, A32, A21X

IMPORTANCE OF CORRECT THREAD REACH SELECTION

INSTALLATION OF IMPROPER REACH SPARK PLUGS CAN RESULT IN SEVERE ENGINE DAMAGE AND POOR PERFORMANCE, ALWAYS CHECK SPECIFICATIONS, AND ENGINE TO DETERMINE THE CORRECT THREAD TO BE USED.

RACING PLUGS

THE LETTERS PRECEDING THE NUMBERS ON RACING PLUGS HAVE THE SAME MEANING AS STANDARD AUTOMOTIVE PLUGS, HOWEVER THE NUMBERS HAVE DIFFERENT MEANINGS.

THE FIRST TWO NUMBERS ARE HEAT RANGE (EXAMPLE 903.) IN AUTOMOTIVE PLUGS THE COLDEST PLUG IS DESIGNATED BY A NUMBER 1. IN ORDER TO DESIGNATE LESS THAN NUMBER 1 – THE RACING PLUGS ARE NUMBERED .90–.70 – ETC. THE DECIMAL IS DROPPED, SO THE NUMBER BECOMES 90–70 – ETC. THE THIRD NUMBER (903) IS USED TO DESIGNATE THE TYPE OF PLUG. THE NUMBER "3" INDICATES RACING GAP OR SIDE ELECTRODE. THE NUMBER "1" INDICATES STANDARD GAP OR BOTTOM ELECTRODE. EXAMPLE 903 OR 901.

FIGURE 126. SPARK PLUG IDENTIFICATION CHART

READING AUTOLITE HIGH-PERFORMANCE SPARK PLUGS

Reading spark plugs is an "art". However, with some practice, a magnifying lens, and the chart supplied in Figure 127, anyone can do a reasonable job of selecting the proper heat range spark plug and pinpointing engine troubles. There are several guidelines to be considered when attempting to analyze engine or spark plug condition. The first and most important is to "read" the plug at maximum power output. In order to do this, care must be taken to cut off the ignition under full power and de-clutch the engine at the same time so that the plug readings will not be erased. Other factors, which influence plug condition, are: knowledge of which plug came from which cylinder, which carburetor or venturi supplied each cylinder, engine speed, temperature, oil pressure, types of fuel, etc. Finally, if each spark plug, in a given engine, is not the same general condition or color, the engine is not producing full horsepower.

Figure 127 will help you interpret some of the important conditions which "reading" spark plugs will reveal. Experience will undoubtedly help the technician to find many more. It must also be remembered that the conditions found in racing plugs are not necessarily the same as those found in passenger car plugs. The racing plug is usually "read" after two or three laps

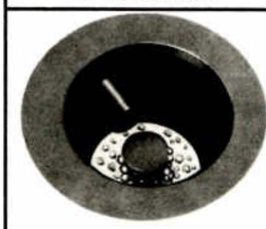
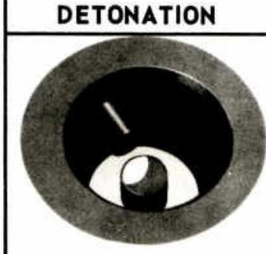
PLUG CONDITION	WHAT TO LOOK FOR	INDICATIONS
 NORMAL	INSULATOR NOSE WHITE OR LIGHT TAN SHARP CORNERS ON CENTER ELECTRODE NO CERAMIC BOIL AROUND ELECTRODE ELECTRODE NOT DISCOLORED OR ERODED	PROPER HEAT RANGE PROPER OIL CONTROL PROPER AIR/FUEL RATIO GOOD IGNITION
 FUEL FOULED	INSULATOR NOSE DARK GRAY OR BLACK SHELL SURFACES BLACK DRY FLUFFY OVER-ALL DEPOSIT	OVER-RICH MIXTURE MISFIRING PLUG WRONG HEAT RANGE DEFECTIVE SECONDARY WIRES WEAK IGNITION
 OIL FOULED	INSULATOR NOSE SHINY BLACK AND WET OILY DEPOSITS	PISTON RINGS NOT SEALING WORN VALVE GUIDES AND STEM SEALS PLUGGED CRANKCASE VENTILATOR BLOW-BY
 OVERHEATED	INSULATOR NOSE BLISTERED CHALKY WHITE WITH BROWN SPOTS NOSE HAS SATIN-LIKE SHEEN SIDE ELECTRODE BLUED EXCESSIVE CERAMIC BOIL	WRONG HEAT RANGE LEAN MIXTURE INADEQUATE ENGINE COOLING PRE-IGNITION DETONATION
 DETONATION	TINY SPECKS ON INSULATOR NOSE EXCESSIVE CERAMIC BOIL EXPOSED SHELL SPECKLED TINY ALUMINUM BEADS ON NOSE	**TROUBLE** RICHEN MIXTURE OR RETARD SPARK TO PREVENT FURTHER ENGINE DAMAGE.
 IGNITION MARK	BURNISHED, HIGHLY POLISHED AREA WHERE SPARK HAS JUMPED NEW MOON SHAPE ON CENTER ELECTRODE	STRONG IGNITION OUTPUT – NORMAL USUALLY FOUND WITH TRANSISTOR IGNITION

FIGURE 127. RACING PLUG DIAGNOSIS CHART

at the track. Regular production vehicle plugs are usually removed at 10,000 miles or more. Even though the same conditions might exist, the condition of passenger car plugs would be extreme. The purpose of reading race plugs is to prevent this extreme condition and prevent any possible engine damage. The technician who reads the condition of racing plugs must learn to recognize problems as they start to develop and not after they have caused engine damage or poor performance. Again, we say "spark plug reading is an art", but this art can be mastered with lots of experience and a little patience.

OTHER ELECTRICAL EQUIPMENT

The balance of the electrical system remains about the same for high performance and stock vehicles. Sometimes it is necessary to substitute components such as batteries and charging systems in order to overcome space problems created by using a larger engine than the one for which the chassis was designed or by adding headers or other high-performance components. Batteries and charging systems must be picked according to the function that they must perform. At the present time Autolite-Ford does not offer a special battery or charging system for high-performance. Because of higher current requirements caused by higher torque demands on the starters for high compression engines, a larger capacity battery is recommended. Most original equipment charging systems are adequate for these high output batteries. Individual competition events or combination street and track use dictate the need for any other electrical equipment, such as lights, tachometers, etc.

Exhaust System

INTRODUCTION

When modifying an engine for high-performance or racing it is important to consider the exhaust system. It doesn't do much good to use intake components which improve the breathing characteristics of an engine and then neglect the exhaust side. Most modifications to the exhaust system are external; however, as we discussed in the cylinder head section, getting the burned portion of the gas out of the cylinder by using larger exhaust valves, high lift cams, and enlarged exhaust ports, we are accomplishing the first steps to improving exhaust efficiency.

We repeat, the job of the exhaust system is to get rid of the heat and gases stoked-up in the "burner". Just how efficiently it performs this task can be measured in terms of horses gained or lost. The best engineered exhaust system will have a delicate balance of factors; factors which include cam timing, valve area, port dimensions, exhaust system component dimensions, amount of carburetion, and engine particulars such as, stroke and rod angularity. Rod angularity, you'll recall, affects piston speed. Sharp corners and small passages also restrict the flow of exhaust gases. This subtracts from the power output of the engine. Dual exhaust and "tuned" exhaust manifolds (headers) reduce back pressure and provide free breathing for improved performance.

DELICATE BALANCE OF PRESSURE WAVES

The effects of harmony between the induction system and the exhaust system are most important. We've heard reports of as much as a 40 percent gain in horsepower . . . when the exhaust system is correctly matched to a properly tuned engine.

Most of us are familiar with sound waves and ripples in the water which we can watch after tossing in a stone. Would you believe that similar waves are present in both the induction and exhaust systems? Take our word for it . . . there are. These waves are called pressure waves and their rate of travel makes an 8-second E.T. sound like a turtle walking in molasses by comparison; the actual speed of these pressure waves is difficult to calculate because the speed varies with temperature, and temperatures are always changing . . . but, it's somewhere in the neighborhood of 1700 feet per second—that's faster than the speed of sound!

At this point in our discussion, you may be saying to yourself—"so what . . . what's really happening?" Well, let's take a closer look. Near the end of the power stroke, the exhaust valve opens and the high pressure (remember the P/V charts in Figure 4?) in the cylinder forces the burned gases out past the exhaust valve. A pressure wave is created and it travels all the way to the end of the tail pipe. When it reaches the end of the tailpipe, the wave reverses direction and travels back toward the valve. When it reaches the valve, it reverses once again and assists the remaining gases out of the combustion chamber by means of a partial vacuum or suction that exists behind the wave. The gases that leave the cylinder react to the pressure waves from that cylinder only . . . if they join in a common manifold, the gases and pressure waves from other cylinders will interact and may cancel the scavenging effects that were gained by use of individual exhaust tubes.

EXHAUST HEADERS

The term "header" can cover any number of exhaust manifold designs. Each of these headers is designed to reduce exhaust back pressure. This back pressure is a result of high pressures at the exhaust valve in the cylinder head working against sharp corners and restricted passages in the manifold, exhaust pipes, muffler and tail pipe. The exhaust gas cannot escape as fast as it enters these components and a "back pressure" is formed. Figure128 shows some typical header designs. Note that they incorporate larger passages and every effort is made to eliminate sharp curves and unequal length pipes.

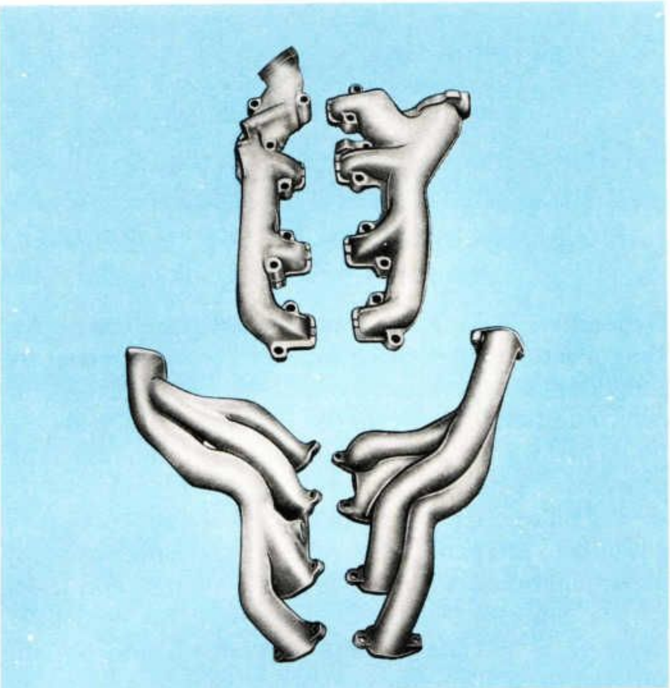


FIGURE 128. EXHAUST HEADERS

Factory engineered and built headers are available for most high-performance engines, however, some enthusiasts prefer to fabricate them.

Here's where two schools of thought enter the high-performance picture. One school is firmly convinced that individual stacks for each exhaust port are superior while the other believes that the pipes (of equal length in both instances) should terminate into a common collector. (See Figure 129.)

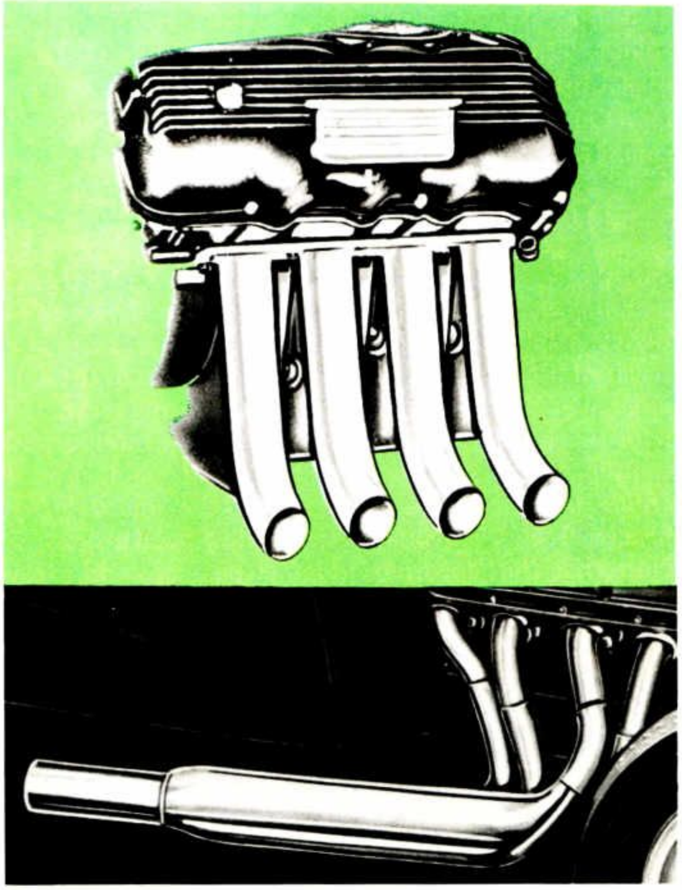


FIGURE 129. INDIVIDUAL STACKS VS. COMMON COLLECTOR

Generally speaking, most header designers agree that the collector configuration will add horsepower over the individual stacks. First, by applying the collector concept, additional power on the low end of the scale can be picked up for engine's coupled to automatic transmissions. Secondly, a few hundred r.p.m.s can be tacked on to the high end of the horsepower curve. It is possible to alter the entire range of the power curve by experimentation with the length, diameter, and shape of the collector. The important thing to remember, however, is that the collector unit must be individually tailored to each specific engine and vehicle application. The shape and volume of the collector will determine the amount of time the pressure waves spend on their way to and from the exhaust valve. The total time must, of course, be coordinated with the intake system and valve timing.

INTAKE AND EXHAUST SYSTEM LENGTHS

Since the speed of the pressure waves on the intake side are considerably slower (1100 ft./sec.), a relationship is established between the length of the two systems. As a rule-of-thumb, a longer intake system will call for shorter exhaust system components. Again, coordination between these two systems must be considered so that the pressure waves don't get in each other's way . . . especially at the valve end during the valve overlap period.

FABRICATED HEADERS

Headers must be designed to aid and improve the flow of exhaust gas and reduce back pressure. This means large diameter, straight as possible, and smooth surfaces. The headers are of equal length and are tuned to exhaust impulses. By taking advantage of these impulses, the release of exhaust gases is helped at extremely high r.p.m.s.

The fabricated steel tube headers shown in Figure 130 are known as the "four-into-one" configuration. Tubes are of equal length and are measured from the mounting flange to the end of the tube. The four tubes come together and resemble a four-leaf clover when viewed from that end (See insert in Figure 130.) A cone-

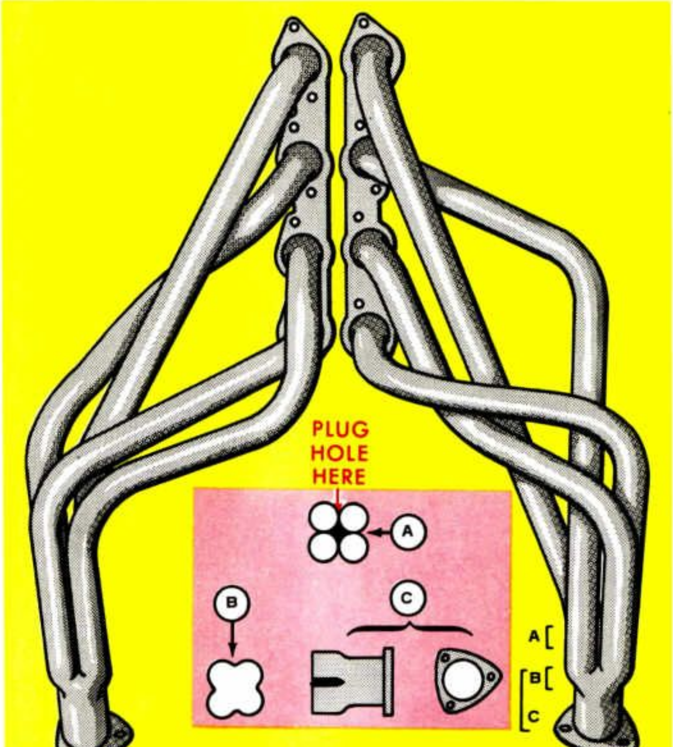


FIGURE 130. FABRICATED HEADERS

shaped piece of metal is then welded over the four tubes and gradually reduces the O.D. of the pipe to fit into a collector tube of a given length. The collector tube is then connected to the exhaust pipe and finally through the muffler into the tail pipe. Recommended flange thickness is from $\frac{1}{4}''$ to $\frac{3}{8}''$. If flange material is too thin, it may warp and leak, causing the tuning effect to be lost.

TUNED EXHAUST

The ultimate goal in competition headers is to extract the spent gases in the most efficient manner. Production headers, on the other hand, must direct these gases through a legal muffler system while maintaining an acceptable noise level. Tubing headers, being of thinner construction, do not soak up the exhaust pulsation noises as well as cast iron headers. The advantages of increased horsepower through use of fabricated tubing-type headers, however, has proven to be well worth the effort expended.

Acoustical Tuning

In header tuning, the performance-minded are concerned both with acoustical and inertia tuning. As we've mentioned previously, the pressure wave travels through the exhaust system at about 1700 ft./sec. When this pressure wave leaves the open end of the tube, a suction wave is created back up inside the tube. When the length of this tube is correct, for that particular engine, the suction wave reaches the port near the end of the exhaust stroke and actually helps to suck the remaining gases from the combustion chamber. The proper length of tubing then, assures that the wave timing will be correct. The diameter of the pipe is not so critical as long as it's somewhere near the exhaust port size.

Inertia Tuning

Inertia tuning is where the weight of the gases in motion is effective. This type of tuning is more often concerned with engines being prepared for street use because of the r.p.m. range involved. The principle of inertia tuning is based on the fact that gases have weight . . . this means they also have inertia. When the exhaust gases are expelled from the cylinder at high velocity, the mass will continue to move after the exhaust valve has closed. This action results in a series of pulses and a resulting suction area between each pulse. The suction effect, in turn, is used to scavenge the cylinder of burned gases.

MUFFLERS AND TAIL PIPES

Low restriction straight-through mufflers and larger diameter tail pipes will help to complete the low back pressure picture. The straight-through muffler design is just as its name implies. Baffles are not used at all, but rather an inner core and an outer shell with an insulating or sound absorption material between the two. This insulating material is either of steel modules or spun glass. Reportedly, the steel packs will have a longer lifespan because of their ability to remove the moisture content from the muffler. The core or center pipe diameter is as large as the inlet pipe (otherwise it would not remain a straight-through design) and sound waves pass through a number of holes punched in the core on the way to the absorbing material. A good muffler and exhaust header combination will reduce exhaust flow restrictions; but, for competition, maximum performance will be obtained when the muffler is disconnected from the collector. These mufflers are generally available through various speed equipment manufacturers and dealers.

Tail pipes are a different story. In most instances it will be necessary to fabricate tail pipes to fit your particular vehicle. Do not, under any circumstances, use flexible tubing anywhere in the exhaust system as the efficiency of the flow will be reduced. Properly selected or fabricated exhaust headers, when used with larger extension pipes and adequate mufflers, can lead to a gain of 15 to 20 horsepower over the standard system.

Keep in mind that, even though these straight-through mufflers and enlarged tail pipes will aid in increasing horsepower, for the most part they will be too noisy for legal street use.

This, then, is part of the story of the exhaust system and its contribution to the total performance picture. We stress that it's only a part of the story because continuing research and development turns up new concepts every day. The latest to crop up is in the area of collector design . . . whereby, even though the tubing header pipes themselves are of equal length, their terminating points within the collector vary in length. This is necessary because of unequal distances between the front and rear exhaust ports . . . and the experimentation goes on . . . and on. Now, there is one final area, which follows, that cannot be overlooked.

EMISSION CONTROLS

Another factor to be considered in modifying vehicles for high-performance is the use of various devices on stock vehicles to meet the Federal regulations on the control of exhaust emissions. These regulations are quite strict now and will become more rigid in the near future. Field research and engineering have proven that emission control devices are more of a nuisance to the high-performance enthusiast than a horsepower factor. Most of these devices are designed to be effective at low speed or idle only. Of course, carburetor jet changes could affect the mixture to the extent that incomplete combustion could result and the total emission level raised above the acceptable level even at higher speed. In such cases these changes would be illegal.

The extent of the affect of these regulations on high-performance will have to be evaluated as time passes. It is enough to say here that any modification that raises the emission level of contaminants above certain levels is contrary to Federal regulations.

APPENDIX I

Engine Assembly Procedures

All good competition engines perform best if assembled with extreme care and according to specification. Care must be taken to assemble the engine with a minimum of contamination such as dirt, paint chips, or other abrasive materials. At this point, you have all your component parts cleaned and prepared according to suggestions we've offered earlier; now, the remaining task is to assemble and properly fit these pieces together. The operations outlined on the following pages are intended as guidelines and helpful installation tips. Take your time . . . the major emphasis is on *QUALITY* of work rather than quantity!

PROCEDURE

If the cylinder block is to be replaced, transfer the cylinder head dowels and cylinder block drain plugs to the new cylinder block and start the assembly procedures with Step 5.

1. If the orginal block is used, remove any glaze which may exist in the cylinder bores by following instructions previously detailed under "Preparations for Improved Performance – Cylinder Block Assembly".
2. Invert the block on a work stand so that the pan rails are facing upward.
3. Position the new camshaft bearings at the bearing bores, and press in place. (See Figure A-1.)

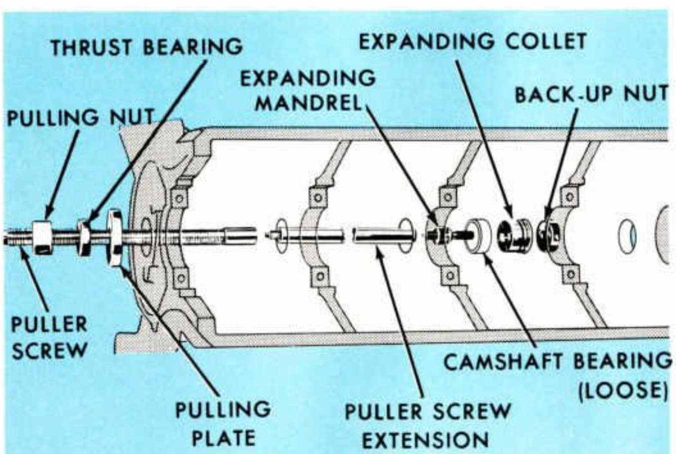


FIGURE A-1. INSTALLING CAM BEARINGS

Align the oil holes in the bearings and cylinder block as the bearings are installed. Be sure the camshaft front bearing is installed the specified distance below the front face of the cylinder block. (See Figure A-2.)

4. Thoroughly clean the camshaft rear bearing bore plug recess. Coat the flange of the new plug with an oil-resistant sealer and install the plug with the cup side facing out. Drive the plug in until it seats slightly below the camfer in the bore. (See Figure A-3.)

FIGURE A-2. MEASURING FRONT CAM BEARING DEPTH

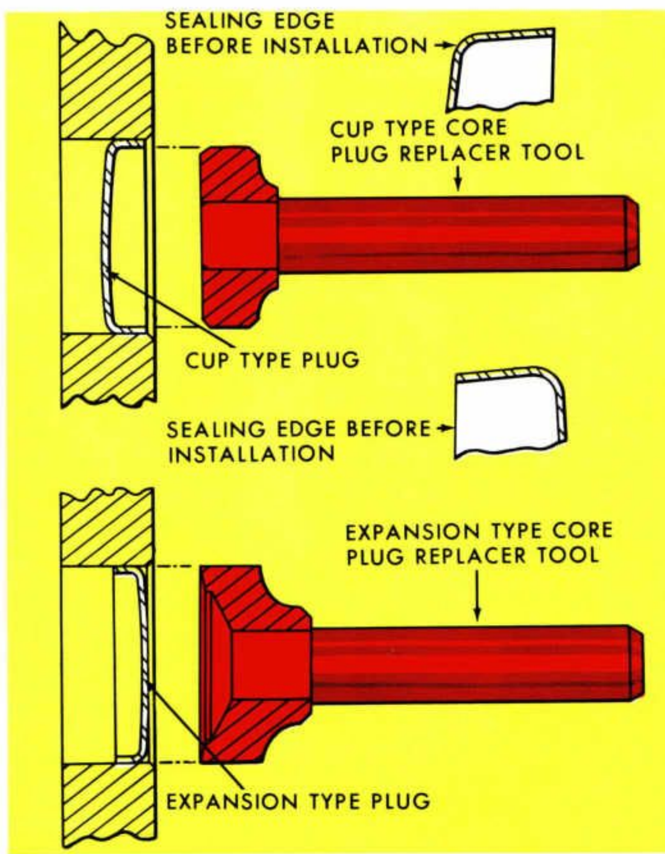


FIGURE A-3. TYPICAL CORE PLUGS AND INSTALLATION TOOLS

5. Oil the camshaft journals and apply Lubriplate to all lobes; then carefully slide the camshaft through the bearings. Install the camshaft thrust plate and check the camshaft end play. (See Figure A-4.)
6. Clean the rear journal oil seal groove and the

mating surfaces of the block and the rear main bearing cap. Pre-form the new seal by hand to the radius of the cap.

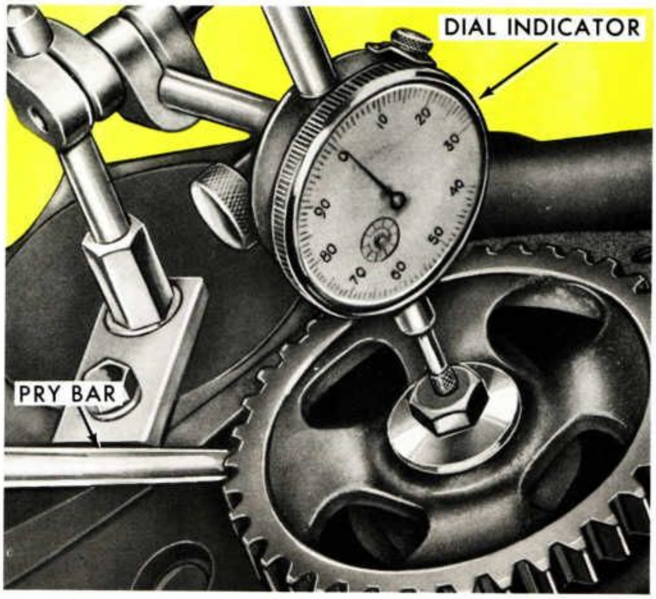


FIGURE A-4. CHECKING CAMSHAFT END PLAY

7. Insert the seal in the oil seal groove, seating the center of the seal first and allowing the seal to extend equally on both ends. Press the seal down firmly with your thumb at the center of the seal, then press both ends into the groove, working from the ends to the center.
8. Position the seal forming tool and complete the seal installation. After installation, cut the ends of the seal flush. (See Figure A-5.)
9. If the crankshaft main bearing journals have been refinished to a definite undersize, install the correct undersize bearings. Be sure the bearing inserts and the bearing bores are clean. Foreign material under the inserts will distort the bearing and cause failure. Place each upper main bearing insert in the block bore with its tang in the slot provided.
10. Install each lower main bearing insert into the bearing cap with its tang inserted in the slot.
11. Carefully lower the crankshaft into place. Be careful not to damage the bearing surfaces.
12. Check the clearance of each main bearing with plastigage. (See Figure A-6.)
13. After the bearings have been fitted, apply a light coat of engine oil to the journals and bearings.
14. Install a new journal oil seal in the bearing cap, using Steps 6, 7 and 8 as a guide. (See Figure A-7.)

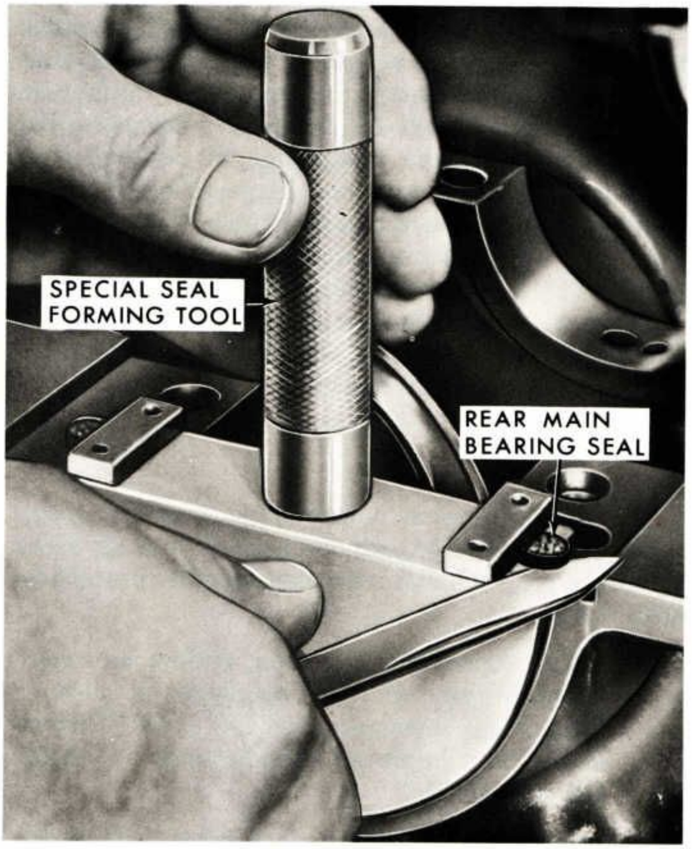


FIGURE A-5. REAR OIL SEAL-TO-BLOCK INSTALLATION

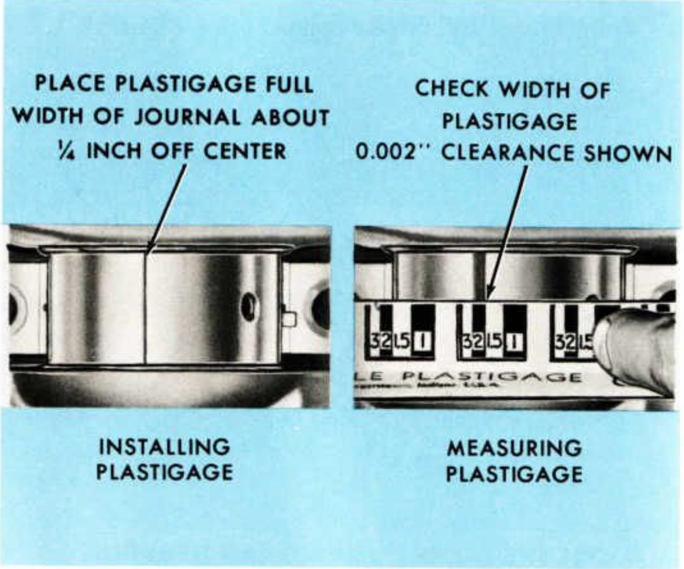


FIGURE A-6. MEASURING MAIN BEARING CLEARANCE

Apply a thin coating of oil-resistant sealer to the rear main bearing cap at the rear of the top mating surface. Do not apply sealer to the area forward of the oil slinger groove. Install the rear main bearing cap and all other caps except the thrust bearing cap (Number 3 bearing). Be sure the main bearing caps are installed in their original positions. Torque the bearing cap bolts to specifications.

FIGURE A-7. SEAL-TO-REAR MAIN BEARING CAP INSTALLATION

15. Install the thrust bearing cap and check the crankshaft end play. Rigidly mount the dial indicator so that it contacts the rear flange surface of the crankshaft. (See Figure A-8.)

16. Turn the engine on a work stand so that the front end is up.

17. Prepare the piston and rod assembly for installation into the block.

FIGURE A-8. CHECKING CRANKSHAFT END PLAY

- Check the ring end-gap clearance. (See Figure A-9.)

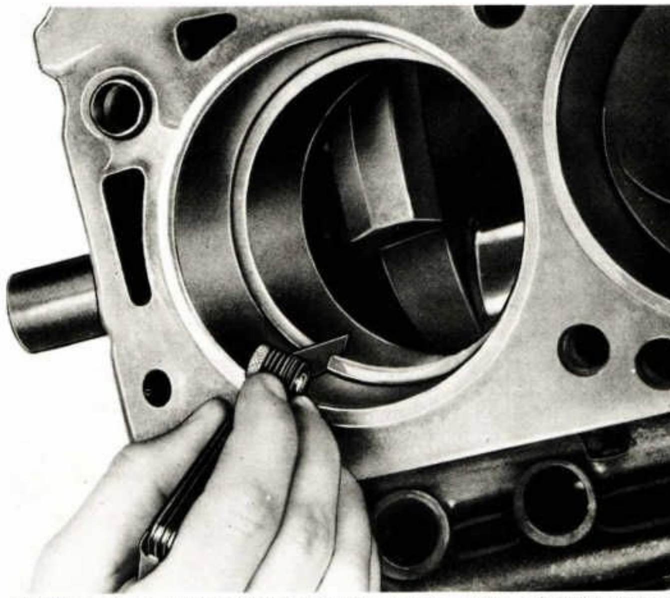


FIGURE A-9. MEASURING RING END GAP CLEARANCE

- Check the piston-to-cylinder wall clearance. (See Figure A-10.)

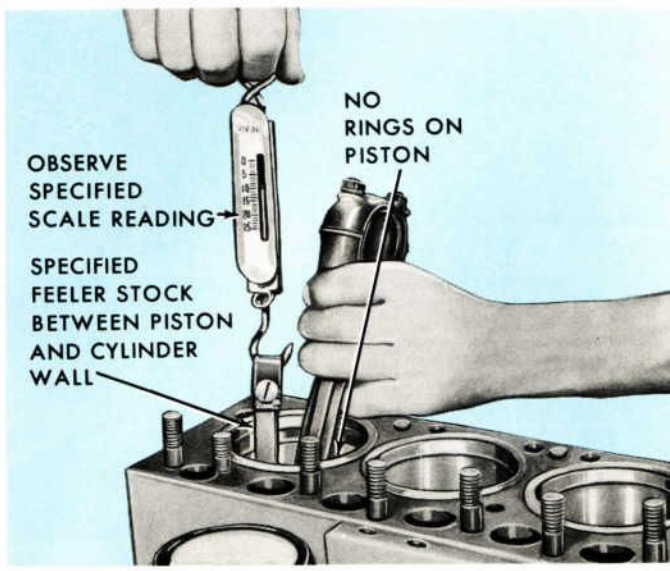


FIGURE A-10. MEASURING PISTON-TO-CYLINDER WALL CLEARANCE

NOTE:

An alternate method for checking the piston clearance is as follows:

1. *Measure the cylinder diameter at right angles to the crankshaft.*
2. *Measure the piston diameter across the thrust faces.*
3. *The difference between these two measurements is the piston clearance.*

- Check the piston ring-to-groove side clearance. (See Figure A-11.)

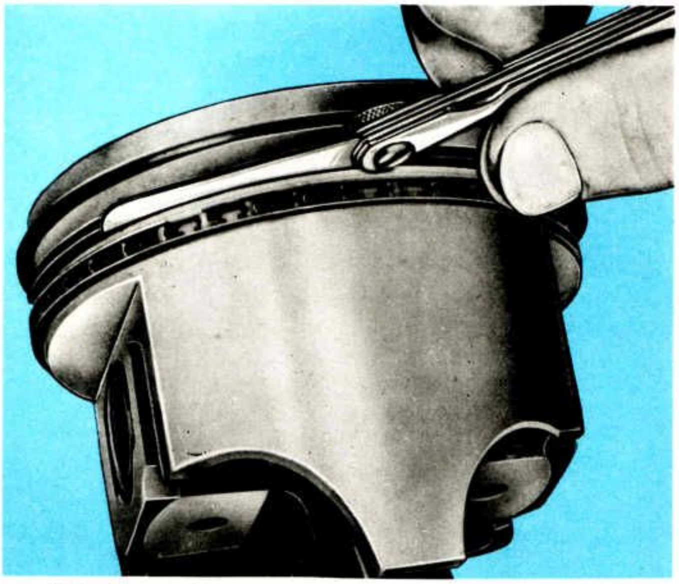


FIGURE A-11. MEASURING PISTON RING SIDE CLEARANCE

- Install the piston pin to the rod and piston; observe the specified tolerances. (See Figure A-12.)

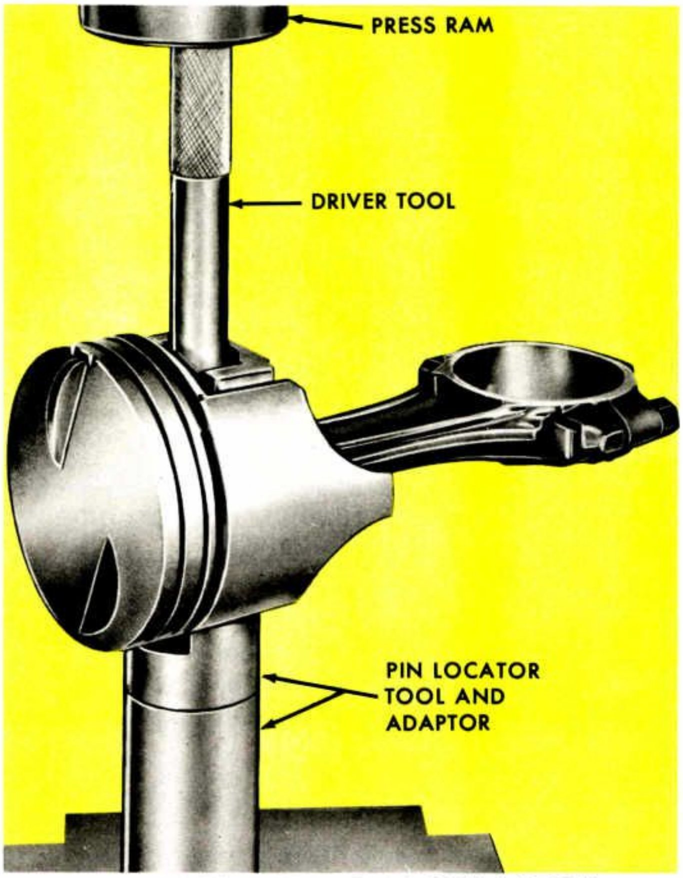


FIGURE A-12. PISTON PIN INSTALLATION

- Install the piston rings onto the piston; stagger the end gaps so they are not aligned. (See Figure A-13.)
- Install the bearing inserts in the connecting rod and cap with their tangs fitted into the slots provided; be sure the bearing backs and bores are clean, as dirt under the inserts will distort the bearings.

FIGURE A-13. INSTALLING PISTON RINGS

18. Install the piston and connecting rod assembly into the block.
    - Thoroughly lubricate the pistons with engine oil.
    - Rotate the crankshaft until the throw you are working on is at the bottom of its stroke.
    - Slide protective sleeves over the connecting rod bolts; oil the bearing inserts.
    - Install a piston ring compressor on the piston and push the piston in with a hammer handle; observe any marks that indicate front of engine. (See Figure A-14.)
    - Check the clearance of each bearing with plastigage. (Refer to Figure A-6.)
    - Torque all connecting rod bolts to specification; be sure the rod bolt heads are properly seated in the rod.

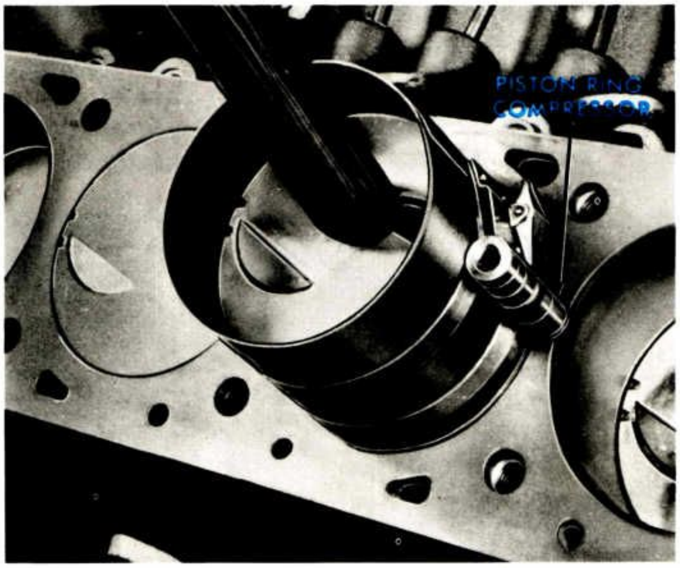


FIGURE A-14. INSTALLING PISTON AND CONNECTING ROD ASSEMBLY

- After all piston and connecting rod assemblies have been installed, check the side clearance between the connecting rods on each crankshaft journal. (See Figure A-15.)

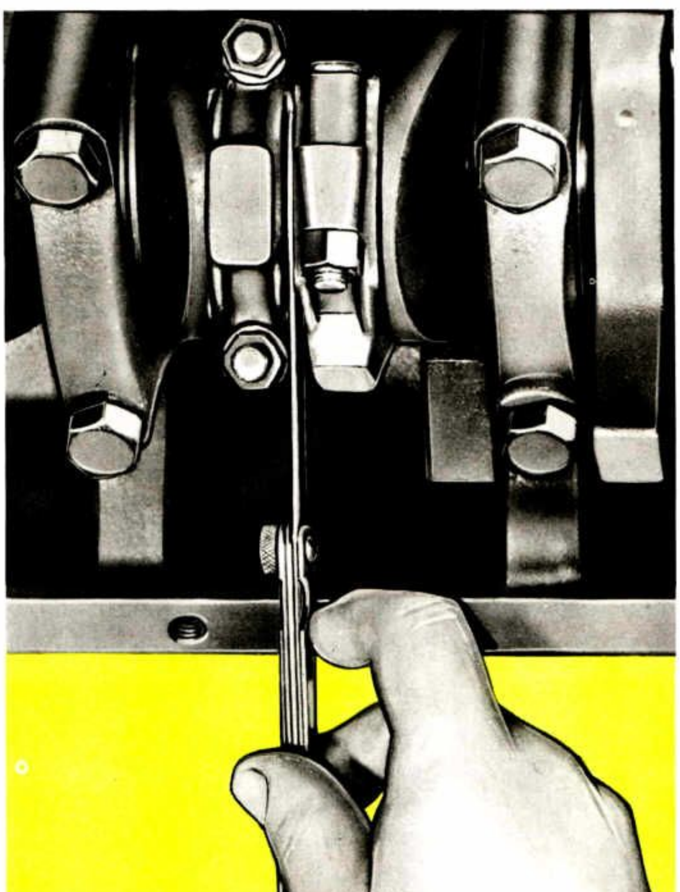


FIGURE A-15. CHECKING ROD SIDE CLEARANCE

NOTE:

Adhere to specifications . . . Clearances are increased by machining or hand-sanding the inner facing surfaces of the rod.

19. Position the sprockets and timing chain on the camshaft and crankshaft. (See Figure A-16-View A.) Be sure the timing marks on the sprockets are correctly aligned. (See Figure A-16-View B.)

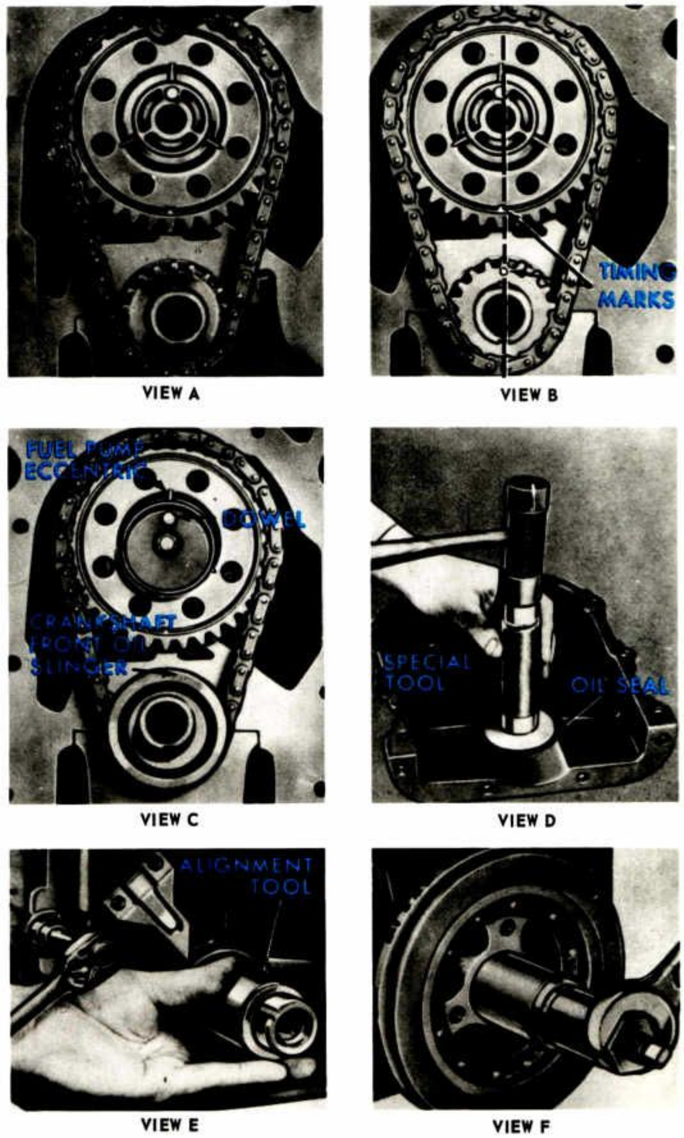


FIGURE A-16. INSTALLATION TIPS FOR TIMING CHAIN, SPROCKETS, FRONT COVER AND VIBRATION DAMPER

NOTE:

Special high-performance camshaft timing instructions are detailed under "Preparations for Improved Performance—Cylinder Head Assembly."

20. Lubricate the timing chain and sprockets with engine oil.

21. Install the fuel pump eccentric, washer and camshaft sprocket cap screw. Torque the

sprocket cap screw to specification. (See Figure A-16—View C.)

22. Clean the cylinder front cover and the cylinder block gasket surfaces. Install a new front oil seal. (See Figure A-16—View D.)

23. Coat the block, the front cover gasket surfaces and the cover bolt threads with an oil-resistant sealer. Position a new gasket on the block.

24. Install an alignment pilot tool on the cylinder front cover. Position the cover and pilot over the end of the crankshaft and against the block. (See Figure A-16—View E.)

25. Install the cylinder front cover bolts finger-tight. While pushing in on the pilot, torque the cover bolts to specification. Remove the pilot. Install the fuel pump with new gaskets.

26. Install the Woodruff key and sleeve to the crankshaft. Line-up the crankshaft vibration damper keyway with the key in the crankshaft, then install the vibration damper. Install the damper cap screw and washer, and torque the screw to specification. (See Figure A-16—View F.)

27. Invert the engine on the work stand so that the pan rails are facing upward. Position the oil pump intermediate drive shaft into the distributor socket. With the shaft firmly seated in the distributor socket, the stop on the shaft should touch the roof of the crankcase. Remove the shaft and position the stop as necessary. (Typical for Ford engines.

28. With the stop properly positioned, insert the intermediate (hex-shaped) drive shaft into the oil pump, if your engine is so equipped.

29. Prime the oil pump by filling the inlet or outlet port with engine oil. Rotate the pump shaft to distribute oil within the pump body.

30. Position a new gasket on the pump housing and install the pump and shaft as an assembly. Do not attempt to force the pump into position if it will not seat easily. The drive shaft hex may be misaligned with the distributor shaft.

31. Clean the gasket surfaces of the block and oil pan. Coat the block and oil pan gasket surfaces with an oil-resistant sealer. Position the new gaskets on the block; position the new seals on the cylinder front cover and rear main bearing cap. Make sure the tabs on the seals are over the oil pan gaskets. Install the retaining screws and tighten them from the center outward to the specified torque.

32. Turn the engine so that the top is facing upward. Clean the cylinder head and block gasket surfaces. Install the head gasket over the cylinder head dowels.

33. Place the cylinder head on the engine. Coat the head bolt threads with a water-resistant sealer and then install the bolts.

34. Torque the bolts in recommended sequence to 75 ft.-lbs., then torque them to final specification. When the cylinder head bolts have been tightened by this procedure, it is not necessary to retorque the bolts after extended operation. However, the bolts may be retorqued, if desired. (See Figure A-17.)

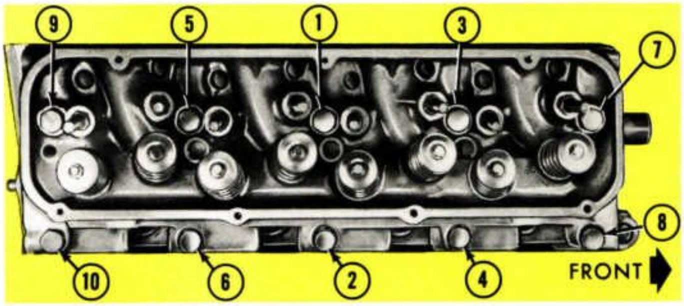


FIGURE A-17. TYPICAL HEAD BOLT TORQUE SEQUENCE

NOTE:

1. *When installing high-performance heads, check manufacturer's recommendation for necessity of scalloping the block . . . that is, removing metal from the edge of the cylinder bore to provide valve clearance.*

2. *After the head assembly is installed, a critical specified dimension to check is the valve-to-piston clearance. Detailed instructions are provided under "Preparations for Improved Performance—Cylinder Head Assembly."*

35. Coat the cylinder head mating surfaces of the exhaust manifold with a light film of graphite grease.

36. Position the exhaust manifolds on the cylinder heads and install the retaining bolts and flat washers. Torque the retaining bolts to specification, working from the center toward each end.

37. Install the spark plugs; torque to specification.

38. Use an hydraulic valve lifter leak-down tester to fill the lifters with test fluid. Coat the outside surface of each valve lifter with engine oil to provide initial lubrication. Place each lifter in the bore from which it was removed.

39. Install the push rods in their original positions. Apply Lubriplate to the valve stem tips. Install the rocker arms over the push rods. Perform the

valve clearance adjustment as follows:

- Make three chalk marks on the vibration damper (90 degrees apart) so that with the timing mark, the damper is divided into four equal parts. (See Figure A-18.)

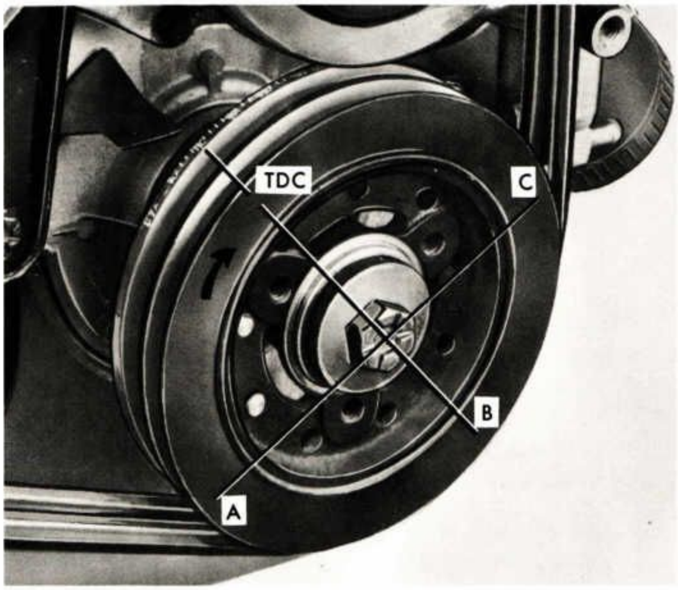


FIGURE A-18. VALVE CLEARANCE ADJUSTMENT POINTS

- With Number 1 piston on TDC at the end of the compression stroke, adjust the intake and exhaust valve clearance for Number 1 cylinder. Loosen the rocker arm stud nut until there is end clearance between the push rod and rocker arm, then tighten the nut to just remove all the push-rod-to-rocker-arm clearance. This may be determined by rotating and/or moving the push rod with the fingers as the stud nut is tightened. (See Figure A-19. View A.)
- When the push-rod-to-rocker-arm clearance has been eliminated, tighten the stud nut one-half additional turn to place the hydraulic lifter plunger in the desired operating range.
- Repeat this procedure for the remaining sets of valves, turning the crankshaft one-quarter turn at a time, in the direction of rotation, while adjusting the valves in the firing order sequence.

NOTE:

The above procedure pertains to hydraulic lifters only. When working with a solid lifter set-up, adjust to the specified dimension between the valve stem tip and the rocker arm; then, recheck after the engine has reached operating temperature.(See Figure A-19 –View B.)

40. Clean the mating surfaces of the intake manifold, cylinder heads and cylinder block.

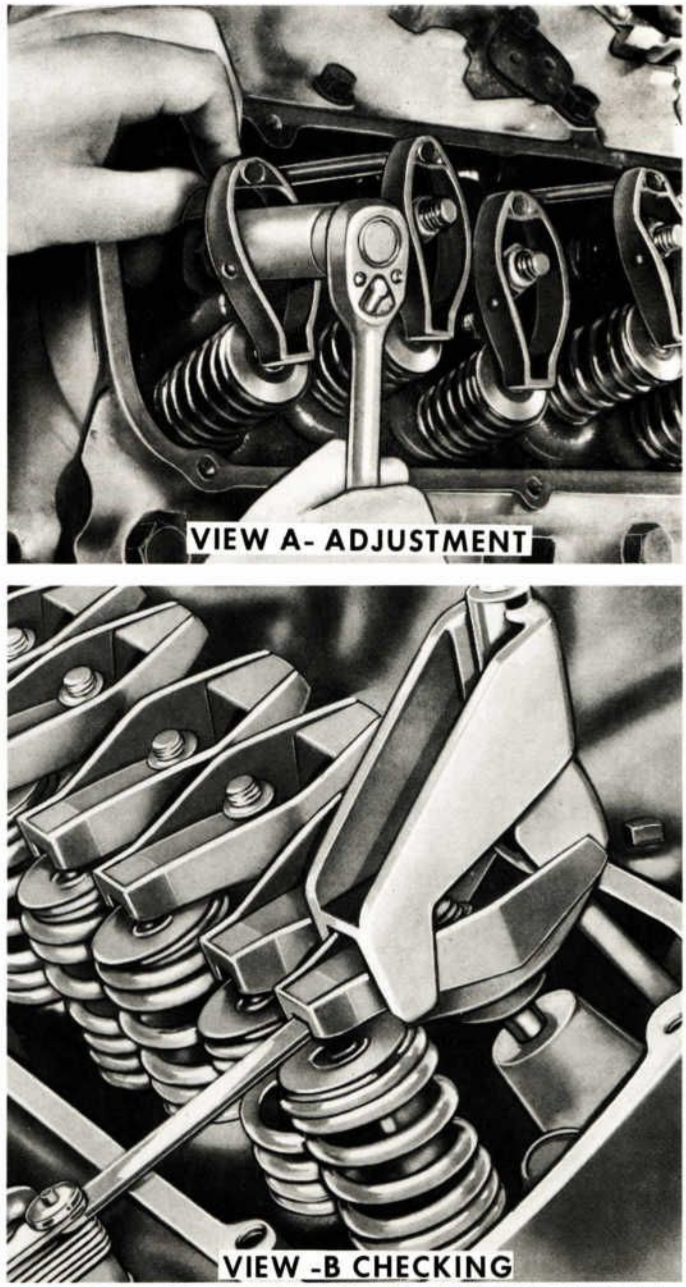


FIGURE A-19. ADJUSTING AND CHECKING VALVE CLEARANCE

NOTE:

If any stock has been removed from the cylinder heads; then a proportionate amount must also be removed from the intake manifold mating surfaces to ensure proper alignment. (See APPENDIX II Head Milling Chart I, for suggested amounts of stock to remove.)

41. Coat the intake manifold and cylinder block seal surfaces with a quick-setting adhesive. Apply a thin bead of non-hardening sealer at the four junction points of the head and block seal surfaces.

42. Position the new seals on the cylinder block and new gaskets on the cylinder heads with the gas-

kets interlocked with their seal tabs. Apply a non-hardening sealer at the four junction points of the seals and gaskets. Be sure the holes in the gaskets are aligned with the holes in the cylinder heads.

43. Carefully lower the intake manifold onto the cylinder block and cylinder heads. After the intake manifold is in place, run your finger around the seal area to make sure the seals are in place. If the seals are not in place, remove the intake manifold and position the seals.

44. Be sure the holes in the manifold gaskets and manifold are in alignment. Install the intake manifold retaining bolts and stud nuts, and torque them to specification in the proper sequence. (See Figure A-20.)

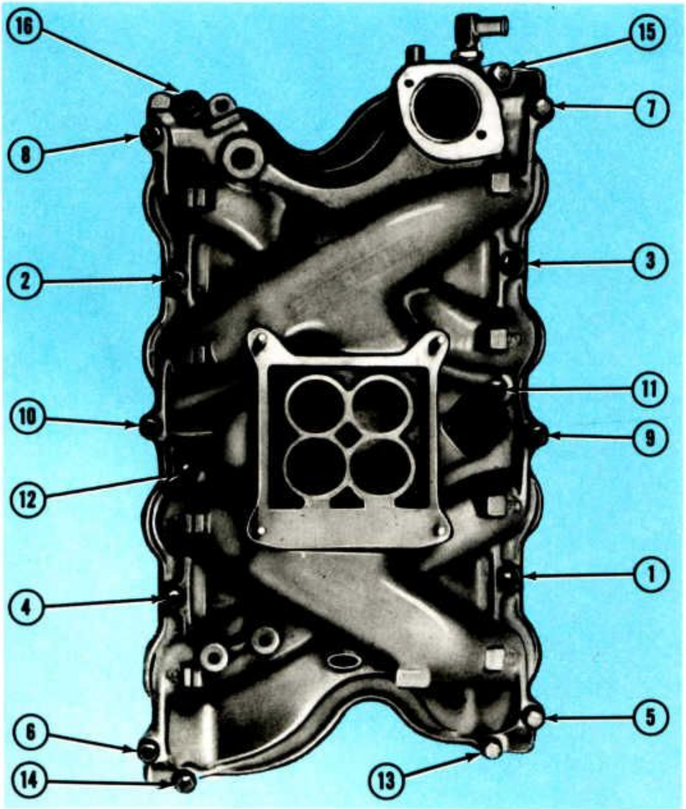


FIGURE A-20. TYPICAL INTAKE MANIFOLD TORQUE SEQUENCE

NOTE:

Retorque the bolts and stud nuts in sequence after the engine is installed and has been run at normal operating temperature.

45. Install the water pump by-pass hose. Slide the clamp into position and tighten the clamp.

46. Rotate the crankshaft until the Number 1 piston is on TDC on its compression stroke. Place the distributor into the block with the rotor at Number 1 firing position, with the ignition points open. Install the hold-down clamp.

47. Install the ignition coil.

48. Clean the valve rocker arm covers and cylinder head-to-cover gasket surfaces. Apply an oil-resistant sealer to one side of the new cover gaskets. Lay the cemented side of the gaskets in place in the covers.

49. Position the covers on the cylinder heads. Make sure that the gasket seats evenly all around the head surface. Install the retaining bolts. Torque the bolts to specification. Two minutes later, torque the cover bolts to same specification.

50. Install the crankcase ventilation system (P.C.V.) regulator valve and hose.

51. Install the distributor cap. Position the spark plug wires in the brackets on the valve rocker arm covers.
    - Connect the spark plug wires and coil wire.
    - Connect the distributor vacuum line.

52. Connect the carburetor fuel inlet line and pump inlet line.

53. Clean the oil filter gasket surface. Coat the gasket on the filter with engine oil. Place the filter in position and hand-tighten it until the gasket contacts the adapter face; then tighten it ½ turn more.

54. Install the rear cover plate on the cylinder block.

55. Coat the threads of the flywheel retaining bolts with an oil-resistant sealer. Position the flywheel and reinforcing plate on the crankshaft flange. Install and torque the bolts to specification.

The engine should now be ready for either bench testing or for installation into the vehicle for running tests. These engine running tests, such as ignition timing and air-fuel adjustments, are beyond the intended coverage of this basic manual. We do acknowledge that electronic (dynamometer or other instrumentation) testing and proper adjustments are necessary to ensure peak performance. Other manuals in this series will detail testing and adjusting procedures for specific high-performance engines.

APPENDIX II

Cylinder Head and Intake Manifold Milling Charts

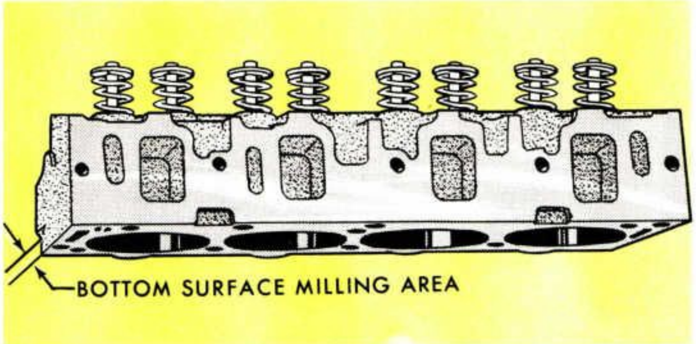
CHART I – AMOUNT OF STOCK TO REMOVE TO ASSURE CORRECT MATING OF PORTS.

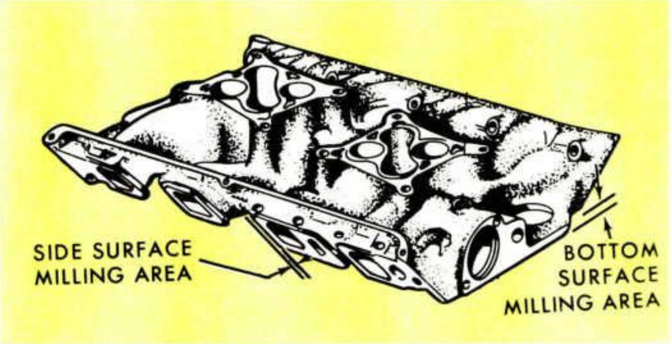
ENGINE (CU. IN. DISP.)	CYLINDER HEAD (INCHES)	INTAKE MANIFOLD	
		SIDES (INCHES)	BOTTOM (INCHES)
221 - 260 289 - 302 351	.010	.010	.014
	.020	.020	.028
	.030	.030	.042
	.040	.040	.057
352 - 390 406 - 427 428	.010	.012	.017
	.020	.025	.034
	.030	.037	.052
	.040	.049	.069
	.050	.062	.086

CHART II – AMOUNT OF STOCK TO MILL THAT WILL REDUCE COMBUSTION CHAMBER VOLUME BY ONE CUBIC CENTIMETER. (1 C.C.)

CYLINDER HEAD IDENTIFICATION	PRODUCTION YEARS	RECOMMENDED DEPTH OF MILL (INCHES)
289, Small Chamber	1963 – 64	.0065
289 - 302, Large Chamber	1965 – 68	.0060
289 - 351, (GT-40) Race	1965 – 68	.0055
352 - 390 HP	1960 – 61	.0070
390 GT	1965 – 68	.0050
406 HP	1962 – 63	.0060
427, Low, Medium, Hi-Riser	1963 – 68	.0050
427 Tunnel Port	1967	.0050
427 Tunnel Port	1968	.0045
427 SOHC	1966 – 68	.0030
428 CJ	1968	.0050

GT = Grand Turismo; HP = High Performance; CJ = Cobra Jet; SOHC = Single Overhead Cam





APPENDIX III

Engine and Cylinder Head Specifications for Ford Motor Company Production Engines

ENGINE SPECIFICATIONS

ENGINE (C.I.D.)	COMPRESSION RATIO	BORE AND STROKE (INCHES)	TAXABLE HORSEPOWER	BRAKE HORSEPOWER*	GROSS TORQUE FT.-LBS.*
170	9.1:1	3.50 x 2.94	29.4	105 @ 4400	158 @ 2400
200	8.1:1	3.68 x 3.126	32.5	120 @ 4400	190 @ 2400
240	9.2:1	4.00 x 3.18	38.4	150 @ 4000	234 @ 2200
				155 @ 4200**	239 @ 2200**
250	9.0:1	3.68 x 3.91	32.5	155 @ 4000	240 @ 1600
289-2V	9.3:1	4.00 x 2.87	51.2	200 @ 4400	282 @ 2400
289-4V-HP	11.6:1	4.00 x 2.87		271 @ 6000	312 @ 3400
302	9.5:1	4.00 x 3.00		210 @ 4400	295 @ 2400
351-2V	9.5:1	4.00 x 3.50		250 @ 4600	355 @ 2600
351-4V	10.7:1			290 @ 4800	385 @ 3200
390-2V	9.5:1	4.05 x 3.784	52.49	270 @ 4400	390 @ 2600
390-2V-PF	10.5:1			280 @ 4400	430 @ 2600
390-4-V-IP				320 @ 4800	427 @ 3200
427-HP	11.1:1	4.23 x 3.78	57.33	425 @ 6000	480 @ 3700
428-P	10.5:1	4.13 x 3.984	54.58	360 @ 5400	459 @ 3200
428-CJ	10.6:1			335 @ 5200	440 @ 3400
429-2V	10.5:1	4.36 x 3.590	60.82	320 @ 4400	460 @ 2200
429-4V	11.0:1			360 @ 4600	476 @ 2800
460	10.5:1	4.36 x 3.850	60.83	365 @ 4600	500 @ 2800

*At indicated r.p.m. **Police and Taxi P – Police CJ – Cobra Jet
HP – High Performance IP – Improved Performance PF – Premium Fuel 2V-2BBL.

CYLINDER HEAD SPECIFICATIONS

ENGINE	COMBUSTION CHAMBER VOLUME (C.C.)	VALVE GUIDE BORE DIA. (STANDARD INTAKE AND EXHAUST)	VALVE SEAT WIDTH		VALVE SEAT ANGLE	VALVE SEAT RUNOUT (MAXIMUM)	VALVE ARRANGEMENT (FRONT TO REAR)	ROCKER ARM STUD BORE DIA.-STD.	GASKET SURFACE FLATNESS *
			INTAKE	EXHAUST					
170-200	51.5-54.0	0.3115-0.3125	0.040-0.060	0.070-0.090	–	–	E-I-I-E-I-E E-I-E-I-I-E	–	0.003 inch in any 6 Inches 0.007 inch Overall
240	66.0-69.0	–	–	0.080-0.090			E-I-E-I-E-I E-I-E-I-E-I	0.3680-0.3695	
250	59.4-62.4	0.3115-0.3125	0.040-0.060	0.070-0.090	Intake and Exhaust 45°	0.0015		0.3685-0.3695	
289	52.0-55.0	0.3433-0.3443	0.060-0.080	0.060-0.080			Right I-E-I-E-I-E-I-E Left E-I-E-I-E-I-E-I		
289HP	47.7 (Min.)				Intake and Exhaust 44°				
302	56.7-59.7				Intake and Exhaust 45°			0.3680-0.3695	
351	58.9-61.9								
390-428P	68.1-71.1	0.3728-0.3735		0.070-0.090			Right and Left E-I-E-I-I-E-I-E	–	
427HP	73.0-76.0				Intake 30° Exhaust 45°	0.0020		–	
428CJ	72.7-75.7							–	
429	74.2-77.2	0.3433-0.3443		0.060-0.080	Intake and Exhaust 45°	0.0015	Right I-E-I-E-I-E-I-E Left E-I-E-I-E-I-E-I	–	
460									

* Head Gasket Surface Finish R.M.S. (Root Mean Square) . . . 90-150.

APPENDIX IV
Glossary

A

ALKY—Alcohol used as automotive fuel.

ALL-OUT—Full scale competition car; maximum car speed.

ALTERED—A competition class permitting extensive modifications to body and engine.

ANCHORS—Brakes.

APRON—Low, flat edge of racetrack used in case of emergency.

A.R.C.A.—Automobile Racing Club of America.

AT-SPEED—Operation of a car at its highest speed.

B

BAD CAR—Hot rodders' term for a very fast car.

BALLAST—Weight added to car to bring it up to legal poundage.

BANZAI—An all-out run, bringing car to peak of performance.

BIG ARM—Long piston stroke.

BIG BORE—Engine with larger than normal bore (cylinder diameters).

BIG END—End of the quarter-mile where car reaches top speed.

BINDERS—Brakes.

BITE—Traction on a racetrack.

BLINKEY—Timing light at the finish line.

BLOW—An engine failure.

BLOWN—Supercharged.

BLOWER—A supercharger.

BLOW-OFF—To pass a car decisively when racing.

BOMB—Car of exceptional performance.

BOOTS—Tires.

BORED—Cylinder diameter increased by boring out.

BORE OUT—To increase engine displacement and power by increasing cylinder diameter beyond stock specifications.

BOSS—The ultimate; top quality.

BOTTOM GEAR—Lowest driving gear.

BOX—Transmission.

BOTTOM OUT—Centrifugal force on car as it enters a high-bank turn on a high-speed run.

BROAD SLIDE—Driving sideways through turn on dirt track.

BUG CATCHER—Scoop or hood around the injector system on a supercharged engine.

BUMP STICK—Camshaft.

BYE—A single run to equalize the number of runs made by each contestant in a race.

C

C.C.—Abbr., for cubic centimeter; European measurement which is the basis for engine displacement. (1000 c.c. = 1 liter = 62 cubic inches — 16.38 c.c. = 1 cubic inch.)

C'D FRAME—Frame with side rails lowered and axle kickup areas raised.

CHANNEL—To modify a car body so it can be dropped down and around the frame.

CHEATERS—Slick tread rear tires used in competition events.

CHECK POINT—That point on the route of a road rally at which officials log-in car, driver and navigator, and impart information relative to the next leg of the rally.

CHICANE—A sports car race course with tight turns grouped close together.

CHOPPED—Cut down.

CHOPPING—Cutting in front of rival car.

CHRISTMAS TREE—Set of colored lights on short pole used to start races.

CHROMIES—Simulated magnesium racing wheels or chromed wheels used to dress-up a car.

CHUTE—Fast part of racetrack in front of main grandstand; also a parachute used to stop high-speed race car at end of drag strip.

CLEAN—Well-built car. (Also referred to as "sanitary").

CLOSED TRACK—Any track generally circular in shape.

CLUNKER—Sluggish, beat-up car.

CORNER—Curve on oval racetrack.

COUGHED ENGINE—Extreme engine failure.

CRANK—Crankshaft.

CREW CHIEF—Mechanic in charge of pit operations.

CROSS-UP—When one car slides sideways out of control.

CUBES—Cubic inches of displacement in engine.

CUT—To eliminate another car from race.

D

DECKED—Reworked rear deck and/or trunk area of custom car.

DICE—A driving competition. To compete.

DIG OUT—To accelerate rapidly from a standing start.

DOGGING—Driving extremely close behind another car in effort to force mistake.

DOWNSHIFT—To descend through gears from higher to lower.

DRAFTING—Stock car racing term for following closely on the heels of the car ahead, to lower wind resistance and to conserve fuel while maintaining speed.

DRAG—Two cars engaged in a quarter-mile acceleration race.

DRAGSTER—Specially-designed race car, usually with driver riding behind rear wheels for maximum traction; or, a driver who takes part in drag racing.

DRAG STRIP—Quarter-mile race course with deceleration area; also, any paved area used for straight-line acceleration contests; usually specified as 60 ft. wide and 4000 ft. long.

DRIFT—Maintaining a slight but controlled skid in curves, to keep speeds high in racing. See "hang out the rear".

DUAL QUAD—Carburetor setup using two carburetors each with four throats.

E

ELIMINATED—Beaten in a race.

ELIMINATOR—Drag car that wins by eliminating other cars in its class by running at higher speed.

—Abbr., for elapsed time used in drag racing, road races, rallies.

EXOTIC FUEL—Alcohols, nitromethane and other fuels besides gas.

EYEBALL—Look something over.

F

FASTBACK—Car with sloping back.

F.I.—Abbr., for fuel injection; a system where fuel is sprayed directly into engine cylinders rather than through a carburetor.

FISHTAIL—Side-to-side sway in the rear of a car when racing; also, to drive in such fashion.

FLAGMAN—Starts race at tracks not equipped with electronic starting system.

FLAME SUIT—Protective firesuit worn by open-cockpit drivers.

FLATHEAD—Early model engine with valves located in the block.

FLAT OUT—Driving at top speed.

FLAT SPOT—A point at which an accelerating engine momentarily fails to gain r.p.m. and speed.

FLYING START—In racing, a start made at speed after a pace lap.

FOUL—To leave the starting line before the green light signal.

FOUR-BANGER—Four-cylinder engine.

FOUR ON THE FLOOR—Manually-operated four-speed transmission.

FOUR-BBL. (4-BBL)—A four-venturi carburetor.

FOUR SPEED—Abbr., for four speed manual transmission; also "four-on-the-floor".

FUELER—Car that burns special racing fuels other than gasoline.

FULL BORE—Throttle wide open.

FUNNY CAR—An altered wheelbase competition car not officially approved by racing sanctioners.

FX CAR—Factory experimental class car.

G

GASOLINE ALLEY—Garage area of speedways.

GASSER—Racing car that burns gas.

GO BUTTON—Slang for accelerator pedal.

GOODIES—Hot rod accessories . . . engine modifications . . . rare or valuable auto parts.

GRAND AMERICAN—New late-model racing circuit starting in the South.

GRAND NATIONAL—Late-model stock car circuit.

GROOVE—That part of a racetrack where the cars handle best at peak speeds.

G.T.—Abbr. for gran turismo; a car usually sized for two people and luggage which is equally applicable to fast over-the-road touring or class racing.

GYMKHANA competitive meet to test driving powers consisting of timed contests in backing, parking and avoiding obstacles; a "road-e-o".

H

HAIR PIN—A turn that is greater than 90 degrees.

HAIRY—A car that is a potent performer; also, a difficult race course.

HANDLING—Car's chassis performance on the race course.

HANG OUT THE REAR—To take a corner or curve with the rear wheels in a controlled skid position.

HEADER—Racing type of exhaust manifold or exhaust tubes (headers).

HEEL-AND-TOE—A sports car downshifting technique wherein the right toe brakes while the right heel remains on the accelerator to maintain adequate engine speed for downshifting.

HEMI—Abbr. for competition engine with hemispherical combustion chamber design.

HIGH COG, LOW COG—Types of drag-racing axles.

HONKER—Drag term for potent performing car; a winning car.

HOT DOG—Leading driver on one of various circuits. Ex.: He's a Grand National Hot Dog; word also used to describe long, low-slung tubular racers.

HUFFER—Supercharger.

HYDRO—Automatic transmission.

I

IGNITER—Ignition distributor.

INDEX OF PERFORMANCE—An evaluation system in racing which mathematically considers engine size, car weight, efficiency and finishing position in relation to each other; thus, a car may win "on index" without being the overall race winner.

INFIELD—Area enclosed by oval track.

INJECTOR—Fuel injection system.

IN THE CHUTE—In the staging area, ready to race.

IRON—Slang for conventional cars (as opposed to sports and high-performance cars).

J

JUG—Carburetor.

JUICE—Nitromethane and other fuel additives.

JUMP—To leave the starting line ahead of the green light.

K

KNOCK-OFF—Quickly removable wheel lug.

L

LEADFOOT—Driver who keeps accelerator on or near floor.

LEANING ON HIM—When one driver gets inside another and lets him know he's there by crowding the turns.

LeMANS START—Drivers are across the track from their cars. At start, drivers run across the track, enter and start their angle-parked cars. Eliminates assigning of favored track positions.

LETS GO—Mechanical failure.

LIGHT THE TIRES—Accelerate so that tires smoke.

LITER (LITRE)—Metric measure of cubic cylinder displacement. (Equals 1,000 cubic centimeters or 62 cubic inches.)

LOCKER REAR END—Rear axle modified to eliminate differential gears.

LOSE THE FIRE—Stall engine.

LOOSE RACK—Wet drag strip.

LOSER'S LEAVE—Starting system with single amber light and random time lapse before "go" light flashes.

LOST IT—When a driver loses control of his car.

LUNCH—Destroy an engine.

M

MAGS—Magnesium wheels.

MAJOR SPEEDWAY—Track of one mile or more in length which stages races of major proportion in length and purse.

MATCH RACE—Two-out-of-three or three-out-of-five race between cars.

MILL—Slang for engine . . . to remove metal from the base of cylinder head or head surface of block to make combustion chamber smaller and thus increase compression ratio.

MOULDED—Body contours and panel joints worked into continuous smooth surface.

N

NASCAR—National Association for Stock Car Auto Racing; world's largest stock car race sanctioning body.

NITRO—Nitromethane, a special racing fuel.

O

OFF THE LINE—Start of race.

OFF THE PEG—Sports car term for pushing engine r.p.m. beyond the upper limit of the tachometer.

OVER-REV—To run an engine too fast.

OVER SQUARE—When the engine bore is greater than the stroke.

OVER THE BORE—Engine with cylinders larger than stock diameters.

OVERSTEER—The tendency of a car rear to swing out and thus help "steer" in going around corners.

P

PACE CAR—Car that leads pack through one or two laps just before race starts; pace car also paces race under caution flag.

PACER—Steady, consistent driver.

PARADE LAP—Ceremonial lap made by lined-up cars before pace lap and race.

PEAKING SPEED—The engine RPM at which peak performance is reached.

PEAK OUT—Rev engine to its limit.

PEEL—Also "peel rubber". To accelerate so that rear tires deposit rubber on the roadway.

PITS—Trackside area accommodating repair crew of each driver.

PIT CREW—Five-man team that works on a race car and services it during a race.

POLE POSITION—Coveted front inside spot given driver with best qualifying speed.

POP—Nitromethane fuel additive.

POP THE CLUTCH—Engage clutch suddenly.

PORT (PORTED)—To enlarge valve passages for improved engine breathing . . . the openings in the block, head or manifold through which the fuel mixture enters or exhaust leaves an engine.

POWER (WHEEL) HOP—Tendency of rear wheels to shudder or hop under full-bore acceleration. Known also as axle tramp, wheel hop.

PROGRESSIVE LINKAGE — Linkage for multi-venturi and multiple carburetion systems designed to permit greater flow of fuel mixture as engine RPM increases.

PUFFER—Supercharger.

PUSH CAR—Car that pushes drag racer to start it.

Q

QUAD—Four-venturi carburetor.

R

RAIL—A dragster.

RAIL JOB—Dragster with little or no body and exposed frame rails.

RAKE—Tilt of a car caused by front being lower than rear, or vice versa.

RAT—Bad running car.

RAUNCHY—Poorly painted or poorly constructed car.

ROLLBAR—Hollow steel tubing that forms a protective "cage" around the driver in case of accidents.

RESIN—Liquid or powder put on tires for better traction.

REVERSES—Wheels with rims turned around for a wider tread area.

S

SANDBAGGER—Driver who holds back in the staging area to select his opponents during elimination races; a poor sport.

SAUCE—Nitromethane and alcohol mixture fuel.

SCOOP—Opening in body to deliver cool air to engine, brakes or cockpit.

SCREAMER—A high r.p.m. engine—A fast car—A supercharged car.

SECTION—Customizing term for removing horizontal metal area from body and rejoining the two parts, for a lower silhouette.

SET-UP—To prepare a car for racing and to modify a car for racing; also carburetors and manifold system.

SHAVED — Ornamentation and hardware removed from car body. (Also see MILL)

SHOES—Race tires.

SKINS—Tires.

SLICK—Smooth, treadless racing or drag tire or wide cross section.

SLINGSHOT—Drag car with driver's compartment placed behind rear wheels; also a method used to pass another car—rear car moves out of path of leading car . . . a vacuum is then created, which pulls the front car back.

SOLIDS—Solid, mechanical valve lifters.

SOLO—Individual run down drag strip.

SOUP-UP—Change or modify an engine mechanically to increase speed potential.

SPEED SHIFT—Shift gears rapidly without releasing the accelerator.

SPIN OUT—Rotating end-around-end in a turn without overturning the car.

SPOKES—Bicycle-like wheels used on front of dragster.

STACKS—Slang term for tubular carburetor intake pipes and/or short individual exhaust pipes.

STANDING QUARTER—In drag racing, a quarter mile time race begun with vehicle at rest.

STAND ON IT—Run at full throttle.

STICK—Car with manual-shift transmission; or the car's camshaft.

STOCKER—Stock car owner or driver.

STREEP—Of or pertaining to street/strip especially dragsters and driver. Also, "in" happenings of performance enthusiasts. (1) The special essence found in a particular breed of automobile denoting: a) the look of speed, b) the feel of power, c) the thrill of performance, d) the excitement of winning; i.e. a super quick street/strip car.

STROKE—Distance the piston travels in the cylinder.

STROKER—Driver who keeps steady pace.

STROKER KIT—Crankshaft and connecting rod assembly engineered to increase engine displacement by lengthening the stroke of the piston.

STUFFER—Supercharger.

SUPER STOCK—Production car with special engine and chassis modifications.

T

TACH—Short for tachometer.

TECH—Technical safety inspection of a race car.

THROAT—Carburetor venturi.

TIME TRAP—Distance between two synchronized timing devices which record the time required by a car to travel between them. Also "trap" or "the traps". "Go through the traps" is to compete in time trials.

TIPPING THE GAS—Filling the tank.

TOP ELIMINATOR—Only car remaining in a class after elimination runs.

TOP ENDS—Car's highest power output; also, second half of a drag strip run.

TOP TIME—Terminal speed at the end of a quarter-mile.

TOUGH—Something nice.

TRAPS—Three-light system at the top end that stops the elapsed-time clock.

TROPHY RUN—Final run for a class or eliminator victory on drag strips.

TWILIGHT ZONE—Speeds in excess of 200 m.p.h.

U

UNDERSTEER—Condition wherein a car requires more steering angle in relation to speed in order to hold a given radius, as the rear wheels do not contribute to the steering effect.

UNGLUED—Slang for a broken part or assembly. Also "come unglued".

UNREAL—Exceptional, outstanding.

USAC—United States Auto Club—sanctioning body for championship car races as well as sprints and stocks.

V

VALVE FLOAT—The r.p.m. at which valve springs cannot shut the valves in time to maintain compression. (known also as "valve crash".)

VENTURI—Fuel passageway in the carburetor, narrowed to increase velocity of air-fuel mixture.

W

WAIL—To run fast.

WEDGE—Raise or lower various corners of race car to shift weight and improve handling; also, combustion chamber shape.

WHEELSTAND ("WHEELIE")—Where rapid acceleration lifts front end of car from pavement.

WIPED—Beaten.

Y

YELLOW BUMPER—Paint on rear of cars driven by first-year drivers on NASCAR track to warn veterans they are behind inexperienced competitors. Ex.: "There goes a yellow bumper".

Z

ZOOMIES—Unswept exhaust headers on dragsters designed to pre-heat tires.

APPENDIX V

List of Illustrations

INTRODUCTION

FUEL SYSTEMS AND INDUCTION

CYLINDER HEAD ASSEMBLY

CYLINDER BLOCK ASSEMBLY

LIST OF ILLUSTRATIONS (cont.)

ENGINE COOLING & LUBRICATION

IGNITION SYSTEM

EXHAUST SYSTEMS

APPENDIX I

ENGINE ASSEMBLY PROCEDURES

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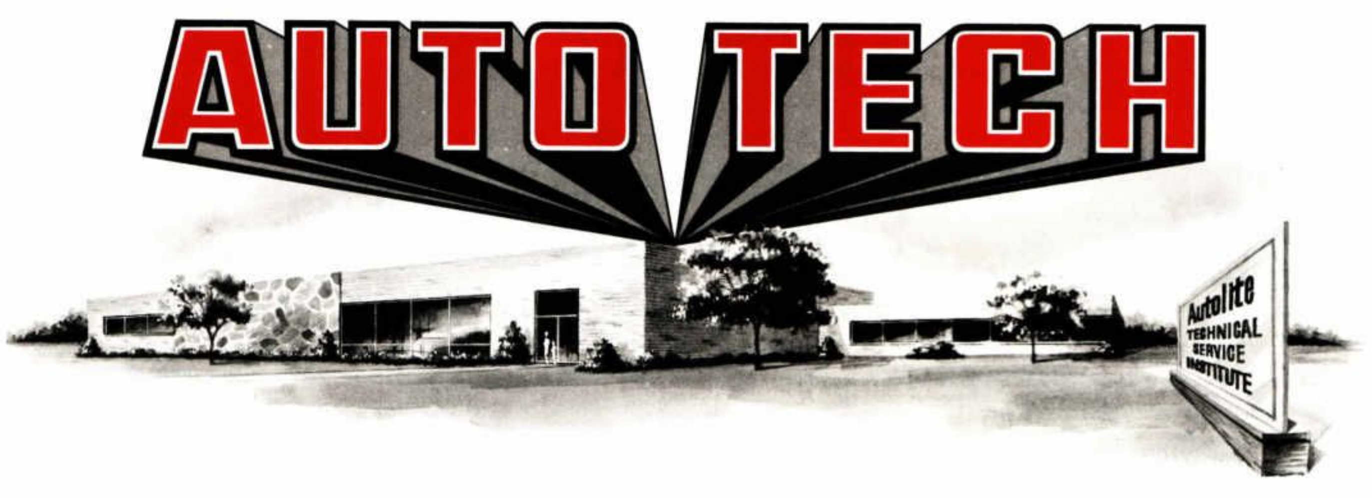

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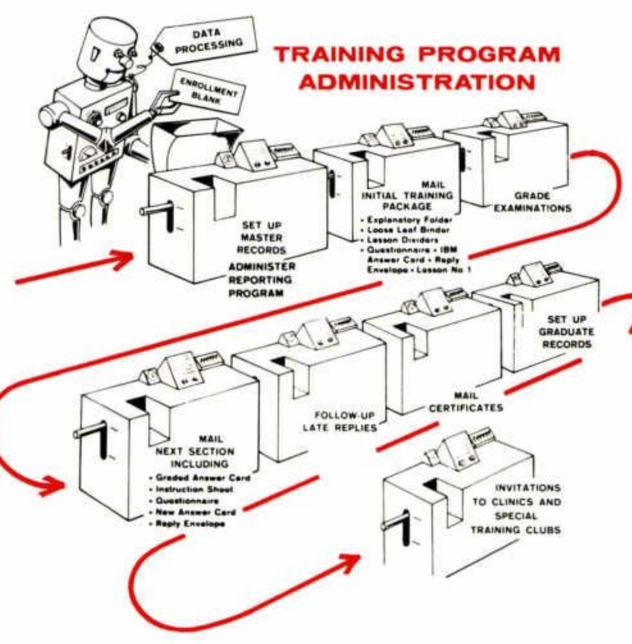

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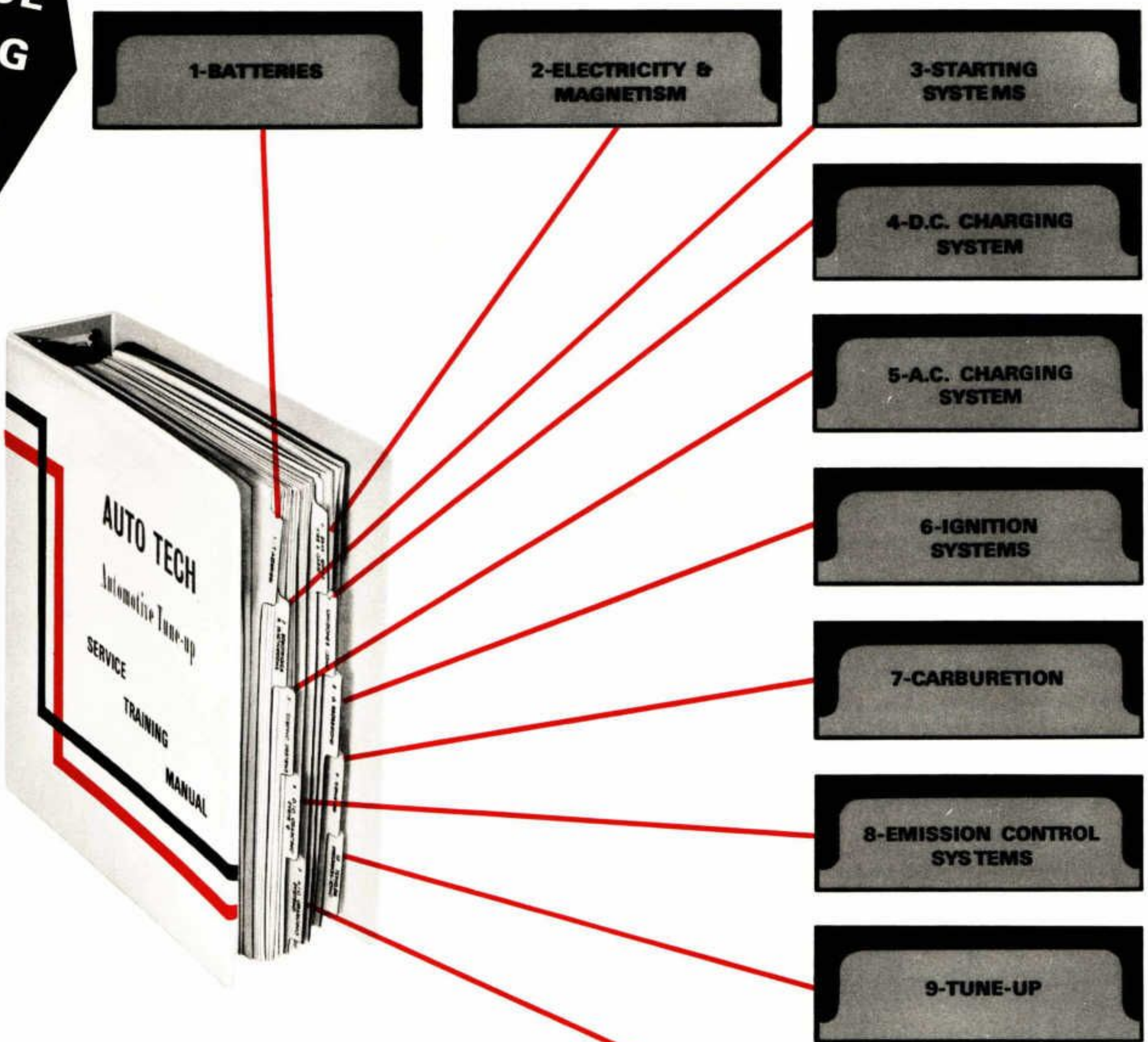

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