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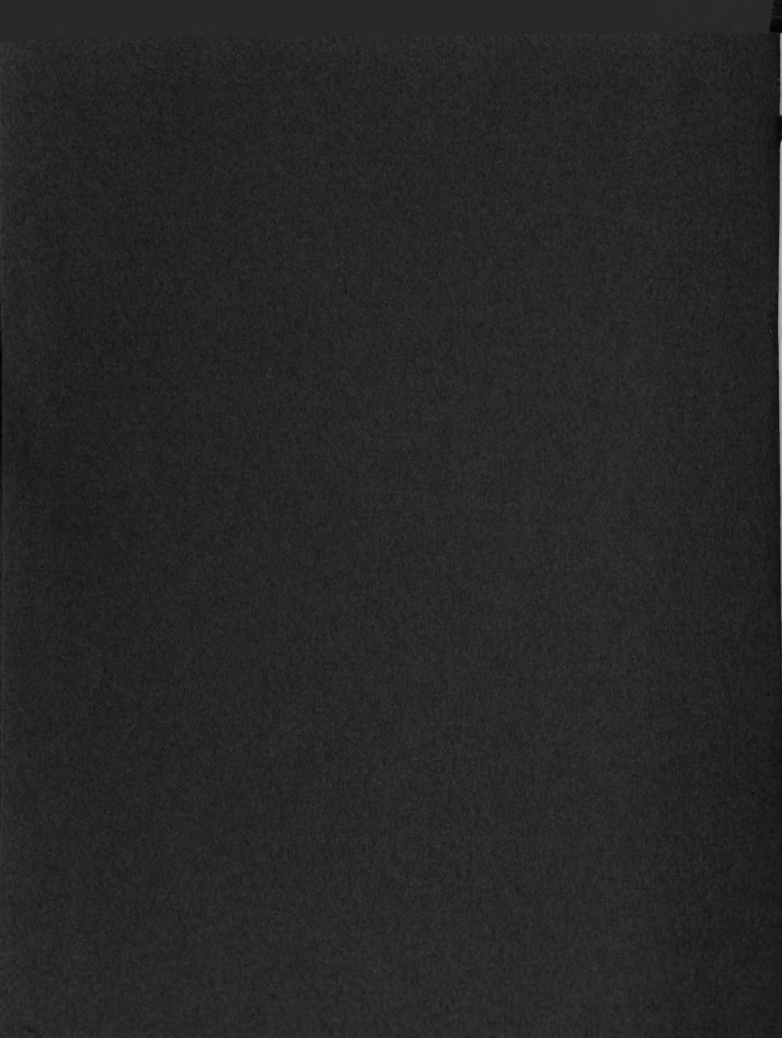
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OVERHEAD CAMSHAFT
MOTOR

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A Study of the Design of a Four Cylinder
Overhead Camshaft Motor

A Thesis Submitted to the Faculty of the
Michigan Agricultural College

By

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Candidate for the Degree

of

Bachelor of Science

THESIS

This subject was chosen because of the lack of overhead camshaft motors on the market and the chance for developement along this line. This design has fewer parts, less lost motion in valve operation, and can therefore be easily and cheaply built.

A motor of this type can be built which will embody strength, economy, durability, and accessability without eliminating those features which cost more to manufacture, but which are necessary to the long life and cheap maintenance of a motor.

It is the writer's idea to design such a motor and the data is to be found on the following pages.

General Description of the Motor.

The motor is four cylinder, four cycle type. It has a bore of three and one eighth and a stroke of four and one quarter inches. The motor is of the overhead valve type with a detachable head which carries the camshaft. The camshaft is removable with the head and is removable from the head by removing ten cap screws. It is rotated by means of a special silent chain which has a stream of oil running on it at all times. The valves are unusually large allowing an easy flow of gases in and out of the cylinders. The valve stems are large allowing a large radiation surface which prevents valve stickage. The valves are operated by cams on arms which are pivoted on one end and are adjustable on the other end to take up the play between the valve stem and the arm. The head and block are of semi-steel. The head is held to the block by fourteen cap screws. The crank shaft is large with large bearing surfaces and has three main bearings. The end bearings are three inches long and the center bearing is two inches long. The piston pins are extra large and are connected rigidly to the connecting rods and are floated in the piston. The pistons are cast iron and are longer than the average piston of this size. The pump and generator are run thru bevel cut spur gears. The oil pump is run from the crankshaft by means of spiral gears. The flywheel is geared to accomodate an electric starter.

Carburation.

The motor is designed to use a twin manifold. The intake part is cast on the inside to receive as much heat as possible. It is designed to take a one inch carburator. The manifold is made to take any standard carburator and is a matter of choice between manufacturers. The manifold is held to the block by four studs. The carburator sets up high where it is easily accessible.

Ignition, Starting and Generation.

This motor is designed to use a standard S.A.F. mounted dynamotor. This contains a starter, generator and ignition. The plugs are placed in the side of the block and are easily removable.

Cooling System.

The cooling system is of the pump type. The pump is located at the bottom of the block and takes the water from the bottom of the radiator and circulates it thru the motor. The pump is of the multi-vane type centrifugal pump. It revolves at engine speed. A fan is provided to draw air thru the radiator and revolves at two times engine speed. The water pockets are large and all parts receive ample cooling. The circulation will be very rapid. The water passes out at the side of the head to the radiator.

Compression and Clearance.

The S.A.E. Journal gives the following values of n as used in the calculation of compression pressures.

Initial pressure absolute $11\frac{1}{2}\#$ n is 1.21

Initial pressure absolute $13\#$ n is 1.29

Initial pressure absolute $14\#$ n is 1.34

The initial pressure will vary with the speed of the motor. The higher the speed, the lower the initial pressure. This is caused by the increased friction in the valve pockets and inlet pipe.

Favary gives a table of compression pressures for each of the above mentioned initial pressures for various compression ratios.

The ratio used on this motor is 5 to 1, counting the chamber as one part and the displacement volume as four parts. For $11\frac{1}{2}\#$ the final pressure is 80#; for $13\#$ it is 105#; for $14\#$ it is 121#. It is held that this motor will be reasonably high speed and $13\#$ is taken as being the probable initial pressure.

The stroke of the motor is $4\frac{1}{4}"$ and the compression space is $1\frac{1}{16}"$.

Cylinder Dimensions.

This motor is designed to drive a two thousand pound car. It is estimated that a motor of ten horsepower S.A.E. rating will be powerful enough for the work. The S.A.E. rating of a motor is equal to the product of the bore squared and the number of cylinders divided by a constant 2.5 which the Society has arrived at after much experiment. This holds true for 1000 piston f.p.m.

This motor develops 10.6 h.p. and as it is of overhead valve construction, twenty percent more power may be relied upon. This data is given in tests run by the Buick Motor Co,

The bore-stroke ratio is 1.36. This is smaller than the ratio recommended by Favary, but is thot to be sufficient to develop the required power and it is a known fact as given out in the above mentioned test, that the longer the stroke the less economical the motor is.

Thickness of walls equal $.045$ bore plus $.063$ plus $1/16"$ for irregularities in the casting. A $5/16"$ wall was used.

Thickness of water jacket walls equals $1/8"$ plus $1/32"$ for each $\frac{1}{2}"$ over $2"$. Use $1/4"$.

Thickness of jacket equals $.437$ plus $(\text{Bore}-3) \cdot .125$
A water jacket $\frac{1}{2}"$ thru was used with $\frac{1}{4}"$ between the pairs of cylinders. A large water pocket is placed in front to form a support for the head.

The head is bolted to the block and the walls are made thicker at these points. Large water spaces are left around the valve pockets. It was necessary to extend the block in the front so as to support the head which is long in front to take care of the camshaft bearings. A heavy copper gasket is placed between the block and head.

Valves.

The valves are located in the head because of the economy, accessibility, power, and size of motor necessary per horsepower. These advantages are set forth in a pamphlet published by the Buick Motor Co. The valves are $1 \frac{7}{16}$ " in diameter with a mean effective diameter of $1 \frac{1}{4}$ ". The stem is $\frac{3}{8}$ " in diameter. The valves are as large as possible in this size of motor. The large stem prevents sticking, conducts heat away readily, and forms a large wearing surface. The guides are $1 \frac{3}{4}$ " long and are pressed into the block thru a thin shell which allows good cooling. The guide is changeable and is long enough to prevent rapid wearing.

The valve springs are calculated by a method given by Clark. Assume the valve gear weight equal to 1 pound. The valve must open $\frac{9}{32}$ ". This is given by Favary as equal to $.125(\text{Mean Dia.} - 1.25")$ plus $.281"$. The motor speed is 2000 r.p.m. and the time of closing valve on the cam is 40 degrees. Lbs. Required equals the product of the weight and the angular velocity squared and the radius of the crank. This equals 69.2#. Use 70#. This is the force necessary to close the valve.

The diameter of the spring wire is equal to the cube root of product of the pounds required and the mean diameter of the spring divided by .39 of the permissible stress.

One inch was taken as the mean diameter of the coil, the weight required was taken as 70#, 70,000# is the required stress.

Wire No. 10, Washburn & Moen Gauge is .135" in diameter and will fill the requirements.

Deflection per coil the product of eight times the weight in pounds required and the mean diameter of the coil cubed divided by the allowable stress multiplied by the wire diameter to the fourth power.

Deflection per coil is .131".

Add 25% for the maximum stress that will come on the coil and take that ratio times the deflection. The maximum deflection that will result is .163".

The product of the number of free coils by the difference in the two deflections is equal to the lift of the valve.

.163-.131 equals .28. This gives the number of free coils as 9.

The spring rests on the head of the motor and is held in place by the spring caps and a pin thru the head or top of the stem.

Camshaft.

The camshaft is carried on the head of the motor and is driven by a silent chain off the crankshaft. The shaft is $\frac{3}{4}$ " in diameter at the bearings and at the cam bottoms. It is $\frac{11}{16}$ " between these points.

It is suspended on three bearings of sufficient length to prevent whipping. It is driven from the crankshaft by means of two gears and a silent chain. The ratio is 2 to 1 and the gears have 25 and 50 teeth. The distance between centers is 20". The amount of power required to turn the shaft is not readily obtainable but is estimated as being under $\frac{1}{2}$ h.p. A chain $\frac{3}{8}$ " pitch, $\frac{1}{2}$ " wide and 50.85" long will carry the necessary load. The gears are 5.97" and 2.99" in diameter and have a face $1 \frac{1}{32}$ " wide. The gears are equipped with wire clips to keep the chain lined up. The above data was taken from a hand book sent out by the Link Belt Co., manufacturers of silent chain. The shaft is hollow and each cam has a hole drilled in it so as to oil the arm and valve mechanism, as well as the cam bearing surface. The cam acts on an arm which is suspended from the valve stem to the arm holder. The cam acts at the center and therefore needs only one half the eccentricity usually required. This amounts to $\frac{9}{64}$ ". The arm holder is large and will allow a large amount to wear off before rebushing or other adjustment is necessary. An adjustment is provided on the valve end to allow for adjustment between the arm and stem. This should be not over ten thousandths. The vapor throw

out of the cam lubricates this point. The vapor is condensed and carried back to the base thru a drain pipe. The cam shaft can be removed by removing ten cap screws and the chaincase cover and chain. Wear in the chain may be taken up by placing pressed steel shims under the head. This will change the combustion chamber and compression but not enough to make any difference in the performance of the motor. The tendency of the camshaft is to drag while the tendency of the crank shaft is to pull and the driving side of the chain will always be taut. It is estimated that a 50" chain will not wear or stretch over $\frac{1}{4}$ ". In a gear 6" in diameter this means a difference in opening and closing of less than five degrees. Manufacturers vary in this respect from twenty to twenty five degrees and a matter of five degrees will make practically no difference. The gears are keyed to their respective shafts and suitable provision is made to remove them easily if necessary.

Cams.

The cams are opened and closed by means of Simple Harmonic Motion. The intake valve is opened in forty degrees on the cam, remains open fifteen degrees and closes in forty more.

The exhaust valve opens in thirty degrees on the cam, remains open for forty five degrees on a tangential face, and closes in thirty degrees.

The intake valve opens 10 degrees past upper dead center. It is wide open at 90 degrees past upper dead center and remains open for 30 degrees. It takes eighty degrees to close at 20 degrees past lower dead center, making a total of 190 degrees.

The exhaust valve opens at 30 degrees before lower dead center, takes 60 degrees to open fully, remains open for 90 degrees, and closes fully in 60 degrees at upper dead center, making a total of 210 degrees for the operation.

It is necessary to leave the exhaust valve open for a long period so as to completely scavenge the cylinder and leave it clean to receive the new charge. Some manufacturers fail to observe the fact that the exhaust gases do not flow out as readily as the intake gases and make no difference in the shape of the cams. These motors lack in power and acceleration.

Pistons.

The pistons are made of gray cast iron, have four rings, and are reenforced by rings of metal on the inside behind the ring grooves and at the bottom. The wall is $1/8$ " thick, carrying this dimension behind the ring grooves as well. The rib at the bottom is $1/16$ " thicker. The rings used are $3/16$ " wide. The head is $3/16$ " thick at the center and tapers at the sides to $1/4$ ". The boss diameter varies from $1\frac{1}{2}$ " at the wall to $1\frac{3}{8}$ " at the inner end. The boss is forty percent of the distance from wall to wall. The boss carries the piston pin bushings which are $7/8$ " inside diameter. The piston is made long to prevent slapping. It is $4\frac{1}{16}$ " long. The lower ring is a scraper to carry away the extra oil and

it also helps to prevent piston slap. The pin boss centers are off set because of placing the spark plug in the side of the block. This is done so as to make the side opposite the plug heavier. This extra weight helps to balance the force of the explosion which occurs earlier on the spark plug side. The amount of this offset will have to be determined by experiment. With a long piston this offset will not be very great.

Piston Pins.

The piston pins are $7/8$ " in diameter and 3" long. They are floated in bronze bushings in the piston and are held stationary in the connecting rods. The piston pin is slotted at the end so as to allow a place to turn the pin to line up the cap screw groove. The pin is drilled hollow to a dimension .65 the outside diameter. It is casehardened. Many manufacturers to-day are fastening the pin in the piston and floating it in the rod. By doing this they are cutting the bearing surface almost in half. It is done because it is cheaper to build and easier to change, but this type must be changed more than twice as often.

Connecting Rods.

The connecting rods are drop forged steel with large bearing surfaces. The lower end is made to fit the 2" crankpins, The upper end to fit the $7/8$ " pins. The rod is made 2.12" times the stroke. All corners are rounded and five degrees draft is allowed. Favary gives a chart of dimensions for I sections of connecting rods. From this chart the following data is obtained,

Total width at center $\frac{3}{4}$ "

Breadth	$19/32"$
Width of web at center	$1/2"$
Width of flange	$1/8"$
Thickness of web	$1/8"$
Length of rod	9"

The rod is two inches wide at the bottom and two and three quarters wide center to center of the bolts. The bolts have a round head with one side ground to fit the shoulder of the connecting rod. This is non-turnable. These bolts are fitted with lock washers and nuts, and with cotter keys. The bearing metal is $3/16"$ thick and is cast in the rod being held in place by the metal in depressions drilled in the rod and cap.

Balancing of Motor.

Three types of crankshaft may be used for a four cylinder motor. Two, three, or five main bearings may be used. Two bearings are usually not enough to keep the shaft from whipping and are easily loosened. Three bearings shafts are always in static as well as running balance. Five bearings are seldom used except for truck motors or other heavy duty motors. Three bearings were used in this case.

Crankshaft.

The diameter of the crankshaft as given by Favary is equal to the square root of a cylinder displacement divided by 16. The displacement is 32.5 cu.in. per cylinder. This gives a shaft $1\ 7/16"$ in diameter. A 2" shaft was used. The thickness of the arms is equal to the product of the square root of the diameter cubed divided by the

width of the crank arms and .6 or .8 according to which arm is being figured. The larger constant is used for the long arm. The width of the arms is equal to $1 \frac{1}{8}$ times the crank pin diameter. The thickness required is .65" and .87" for the short and long arms respectively. 1" and $1 \frac{5}{16}$ " were used. The crankshaft is 29" over all and the flange for the flywheel is forged integral. The front end carries the gears for the auxiliary drive and these gears are keyed on with Woodruff keys. It is threaded on the front end and drilled for pins to carry the crank hook which has the oil pump gear cut on it. The three main bearings are extra long and contain a greater area than is necessary. The front and rear bearings are three inches long and the center is two inches long. The total bearing area is $50 \frac{1}{2}$ sq.in. and only 30 sq.in. is required. The larger the bearing surface the longer the bearing will run without adjustment.

Flywheel.

By a comparison of displacements it was found that a motor of 130 cu.in. displacement would require a flywheel of approximately 50# weight. The mean radius was governed by the size of the housing and was taken as 5", Having the weight, mean radius, and assuming a thickness of two inches, the width was solved for. It is three inches. The cubical content is 192 cu.in. No allowance is made for the weight of the flange or the web. Experimental work is required to find the weight of the wheel exactly. The radius of the wheel must be given considerable attention. The type of clutch is a very important factor in the design of the wheel as it is necessary to design the wheel to fit the clutch.

A disc clutch could be easily used with this flywheel. It is necessary to use a flywheel large enough to prevent vibration and to carry the motor over to the next firing position. If the flywheel is too large the motor will pick up slowly and if it is too small there will be quite considerable vibration. The ideal flywheel is one that will allow fast acceleration and smooth vibrationless running. It can be easily seen that this may require a great deal of experimental work.

Crankcase.

The crankcase is made in two parts divided on the centerline of the main bearings. The upper half is made of aluminum and varies from $1/4"$ to $3/8"$ in thickness. The parts carrying the most strain are built thick and are well braced. This half has a pump bracket and a place to mount the dynamotor. The flywheel case is cast integral with this half. A wall extends across the case at the center bearing. The left side is clear except for a breather tube thru which the case is filled with oil. The motor is a three point suspension and the two rear points are carried on extensions of the flywheel housing. A plate is provided on the top of the flywheel case which may be swung to the side to allow a clear view of the flywheel for timing the motor. The studs which hold the block are carried in extra large bosses, and there are eight of them.

The lower half is pressed steel $1/8"$ thick and carries no strain, but acts as an oil retainer and a protection to the moving parts.

The gears are lubricated by revolving in a pool formed by welding a baffle plate directly behind them. As the pool fills with oil from the chain above, the oil runs over into the case. There are four troughs for the rods and an oil gage case is welded on. This half is bolted to the aluminum half by means of cap screws. The lower half of the flywheel housing is cast iron and is bolted to the aluminum and over the back end of the pressed steel half. This forms an absolutely rigid joint.

Auxiliary Drive.

The gears which drive the camshaft and pumpshaft are keyed to the crankshaft by means of Woodruff keys. The inside gear drives the camshaft thru a silent chain and gear. The outside gear propels the pump and generator shaft. The data for the silent chain is given in another part. The gears driving the pump and generator are of equal size, 56 teeth, 8 pitch, and 7" in diameter. One of these gears is steel, while the other is fiber with steel faces on either side but not running steel to steel. The fiber is the same width as the steel. The pump shaft is $5/8$ " in diameter and is fitted with joints between the case and pump and pump and dynamotor so as to allow easy removal of either. The impeller is pinned to the shaft and is enclosed in a case with a removable head.

Fan.

The fan is four bladed, $13\frac{1}{4}$ " in diameter. It is driven by means of a belt $\frac{3}{4}$ " wide. It is supported on the front end of the crankcase and a spring and adjusting screw

are provided to keep the slack out of the belt. The fan is mounted on ball bearings and the hub is hollow and carries oil for lubrication. The pulleys are two and four inches in diameter and this gives a ratio of two to one. The fan rotates at twice engine speed. This gives three thousand r.p.m. allowing for twenty-five percent slippage. The fan has a capacity of about 2700 cu.ft. of air per minute.

Lubrication System.

The lubrication is a combination splash and pressure system. The case is drained into a pipe and carried to the pump which is mounted on the front of the crankcase and is driven off the crankshaft. The pump is of the friction gear type. The oil inlet is above the line of mesh of the gears and the outlet is below at one end. The pump is always primed by means of a ball and spring placed in the line from the case to the pump. This closes when the force of the pump is stopped and the oil can not flow back to the base. Three leads carry the oil to the base, the chain, and the camshaft. Most of the oil is carried to base and distributed to the connecting rod sumps. The splash from these lubricates the cylinder walls and fills the main bearing pumps. Another lead carries the oil to the camshaft which is hollow and each cam is drilled to allow oil to get to the valve mechanism. The third lead carries the oil to the top of the chain case where it runs directly on the chain and fills up the sump at the bottom in which the gears rotate.

The pump is driven by means of a spiral gear which is pinned to the shaft and is easily removable and changeable. The case holds five quarts of oil and is drained by removing the plug at the bottom where the pump lead is fastened.

The size of the pump can be determined only by experiment only after the amount of oil per minute is determined.

In the foregoing pages, the writer has endeavored to give a good preliminary design of a light four cylinder motor. Such data as is necessary is given and calculations are made wherever possible. If this motor were to be manufactured it would undoubtedly be necessary to change it considerably before placing it on the market.

The writer believes these ideas and designs are fundamentally good. It is believed that as the over-head valve motor increases in popularity as it is doing, that manufacturers will be looking for a cheaper, easier means of operating valves and that the over-head camshaft will eventually come into popularity.

The writer owes much to the cheerful aid and
splendid assistance extended him in his work by
Professors Field and Hewlett.

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