MOTORCYCLE ENGINEERING—31

Two-stroke Power

The theory behind today's high outputs

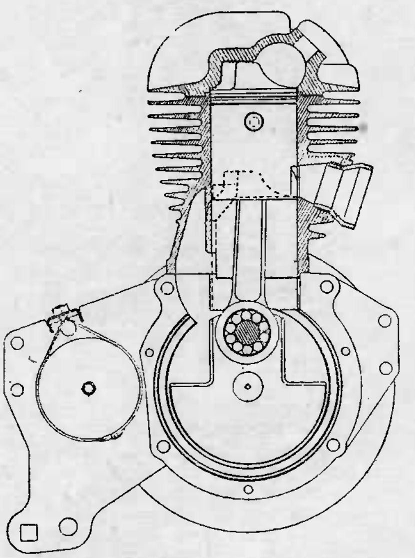
By PHIL IRVING

IT is common to think of a two-stroke as being a type of engine which fires twice as often as a four-stroke and is very much simpler mechanically. This conception is quite correct as far as it goes, but is a drastic over-simplification of the fundamental differences between the types, which are affected much more strongly by two less obvious factors.

One is that the processes of expelling burnt gas from, and admitting fresh mixture to, the working cylinder occur simultaneously, or nearly so, instead of on two separate strokes as in the four-stroke. The admission (commonly referred to as "transfer") ports are open for nearly as long as the exhaust ports, and this immediately introduces the problem of getting all the spent gas out without losing a lot of fresh charge while the scavenging process is taking place.

The second big difference is that the cylinder is not filled directly from the atmosphere, but the mixture must first be drawn and compressed into some other enclosed space. This is usually the crankcase, but may just as well be an additional charging cylinder or some variety of air-pump, such as a Roots or eccentric-vane blower.

Whatever method is used, energy is lost in work expended on pumping and not recovered, or in additional frictional loss;



A classic three-port design—the GTP Velocette, with "squish" combustion chamber.

and in the normal arrangement, using a plain piston and crankcase compression, the overall volumetric efficiency is considerably less than in an equivalent four-stroke.

The net result is that it is not possible to obtain the same mean effective pressure on each firing stroke as it is on a four-stroke. Consequently it is also impossible to obtain twice the power at equal speeds—or anything remotely approaching that—unless by some departure from simple crankcase compression.

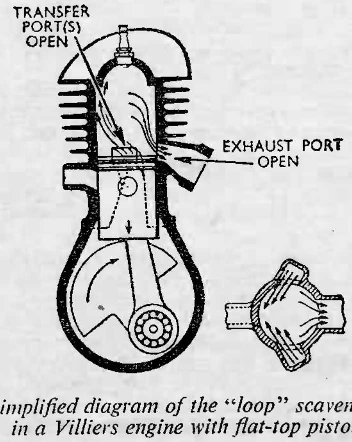
Various devices have been used to increase the pumping ability of the crankcase—by a double-diameter piston, as on the Dunelt, or by an additional charging piston, as on some D.K.W.s, or by an external air-pump large enough to act as a supercharger. Whilst these methods may increase the power output they must be paid for either in undesirable limitations on design or in increased mechanical complication. And they usually entail an increase in fuel consumption above a figure which is already not very good, judged by four-stroke standards.

"Blowers" Barred

Besides these practical objections, F.I.M. racing regulations have debarred the use of any such aids to power-production for several years, just as superchargers are not permitted on four-strokes. All these considerations have had the effect of stopping further development along the complicated lines which were being followed in the 1930s and focusing attention upon variants of the original "three-port" type which, whatever its shortcomings, possesses the crowning merit of extreme simplicity.

The three ports in the rudimentary (i.e., deflector piston) type consist of the inlet port controlling the entry of mixture into the crankcase, the transfer port controlling the admission of mixture into the cylinder, and the exhaust port. Of these, the inlet port takes no real part in the combustion cycle, and we can for the moment put it mentally to one side.

The exhaust port is opened by the top edge of the piston at around 70° before bottom dead centre and the transfer, which is placed directly opposite to the exhaust, is opened 10 or 15° later—this interval, termed the "blow-down" period, being necessary to allow the cylinder pressure to drop from 60 or 70 lb./sq. in. to a figure much nearer to the transfer pressure, which cannot be more than 5 or 6 lb./sq. in. above atmospheric because of the unavoidably large volume of the crankcase.



Simplified diagram of the "loop" scavenging in a Villiers engine with flat-top piston.

Immediately after the transfer opens, a stream of fresh mixture pours into the cylinder at the same time as exhaust gas is still going out. To prevent the new charge from travelling across the piston and straight out of the exhaust port, it is necessary to form the piston crown so that it deflects the transfer gas upwards, which not only discourages it from escaping out of the back door, but causes it to displace the burnt gas lurking in the upper end of the cylinder and thereby promotes good scavenging.

Gas Separation

In diagrams illustrating this principle, incoming and outgoing gases are often indicated by separate arrows, but, unfortunately, things are not so neat in practice. Much of the new charge gets mixed up with the old and some is inevitably lost, while the mixture eventually left in the cylinder is contaminated to a greater or less extent by spent products of combustion.

Another source of loss lies in the fact that, in a normal engine, the port timing is symmetrical and there is a period of crank-movement, equal to the "blow-down" period, during which compression is taking place with the transfer shut and the exhaust still open, obviously leading to some more charge being lost. True compression, in fact, does not commence until the exhaust port is actually shut.

The deflector-head piston also has other disadvantages which react unfavourably on performance or life. It is heated on one side by the exhaust stream and cooled on the other by the transfer stream; this, in conjunction with its asymmetrical shape, is conducive to distortion. It splits a symmetrical combustion chamber into two portions. And, if the plug is placed adjacent to the top of the deflector, burning becomes a distinct possibility.

An endeavour to overcome these shortcomings was made in the GTP Velocette by forming the combustion-chamber wall to conform closely to the transfer side of the deflector, so concentrating the gas in one space and setting up a squish effect which was beneficial to good combustion; even so, collapsed piston crowns were not unknown.

Today, the sole remaining stronghold of the deflector piston is the American outboard marine-engine field, where the engines have the benefit of water cooling. Although very high powers are obtained (70 b.h.p. from one six-cylinder model of 1,100 c.c., for example) they are achieved only with port timings which give a fuel economy so poor that it would not be tolerated in the motorcycle world.

The "Split-single"

A method of eliminating the deflector head which enjoyed considerable success and is still in limited use is the "split-single" layout, in which a pair of pistons occupy parallel cylinders closed by a common head. The transfer ports are formed in one cylinder, the exhaust ports in the other and these can be made of ample area since they can occupy most of the circumference of each bore.

The mixture has to travel up one bore and down the other before it can escape through the exhaust ports, which reduces the possibility of charge loss. Though this distance may seem great in view of the very short period of time available, in fact it is not farther than the bulk of the mixture has to travel with either a deflector or flat-top single piston.

However, there are undesirable features inherent in the scheme. The total area exposed to combustion heat is 40% greater than in an equivalent single, which reduces the thermal efficiency. Also the exhaust barrel runs much hotter than the transfer barrel, which is liable to promote distortion, although the effect can be offset by placing the hotter barrel towards the front of the block and so equalizing the temperatures.

There are two ways of coupling a "split-single's" pistons. They may be caused to move in unison (as in the German T.W.N.) by means of a forked con.-rod; or they can be arranged to move slightly out-of-phase by using a pair of rods on one crankpin, or a master rod with a second rod pin-jointed to it (as in the Austrian Puch).

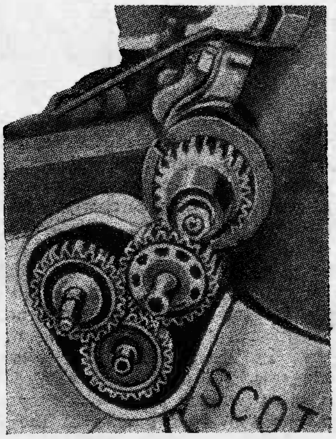
Differential Timing

In the first layout, the port timing is symmetrical, just as if there were only one piston. In the second the timing is not symmetrical and it is even possible to arrange the transfer ports to close *after* the exhaust ports, while still providing an adequate "blow-down" period, though this would be of no value unless some form of supercharging or augmented crankcase pumping was also employed.

One adverse effect of moving the pistons out-of-phase is that their top dead centres do not coincide and for a short period one is still going up while the other has commenced to go down. The volume of the space between the head and pistons therefore remains substantially constant for a few degrees just when it should be rapidly expanding to take the utmost advantage of the peak pressures, so there are limits to how much phase-difference can be usefully employed. The system shows at its best when water-cooled and supercharged, as in the pre-war D.K.W. racers, though the resulting engine is heavy, bulky and lacking in the simplicity which makes the two-stroke so attractive.

The advent of the "loop-scavenged" engine, developed first under the Schnürle patents in Germany, completely altered the picture by eliminating the deflector piston and also by providing much more efficient scavenging. The earliest flat-top piston engines had two diametrically opposed exhaust ports and two pairs of transfer ports, each pair being fed through a single Y-shaped passage. The arms of the passages and the positions of the four transfer ports were so contrived that the gas-streams impinged upon each other and were directed upwards towards the top of the cylinder, so that, despite the close proximity of the exhaust ports, there was little charge loss because the outgoing and incoming streams were travelling opposite directions.

It was found that equally good, or even better, results could be obtained with only one exhaust port (or a pair of ports divided by a narrow bar which, from the aspect of port timing, comes to the same thing), with a transfer port on each side of it. The entering gas-streams then travel across the piston, up the far side of the barrel, and curl over and down to complete the scavenging process. Some mixing does occur, of course; but the loop-scavenge principle enables two-stroke engines to produce power comparable with that obtained from the best four-stroke practice, with excellent reliability, even if the specific fuel consumption is, perhaps, 15 or 20% greater than that of four-strokes.

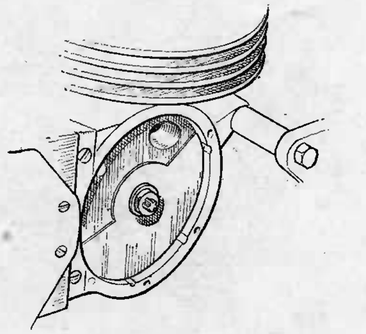


Utilizing the lower edge of the piston to control an inlet port and making the crankcase act as a pump to supply mixture to the transfer ports is ideal from the standpoint of simplicity, but is not ideal in other respects.

Due to the inevitably large volume available for mixture in the underside of the piston and in the crankcase itself, the theoretical crankcase compression ratio is only about $1\frac{1}{2}$: 1 at low and medium speeds. The pumping efficiency is therefore low and is reduced still further by the short period for which the inlet port can be permitted to open, especially on a touring model, in which excessive blow-back through the inlet port would occur with wide-open throttle at low speeds if the port timing were unduly prolonged.

As the speed rises, the ram effect brought about by the higher gas-velocity in the inlet pipe suppresses the blow-back; but as the speed rises still further, the amount of charge which can be induced through the now inadequate inlet port limits the power output to an extent which cannot be affected by the size or timing of the cylinder ports. It then becomes necessary to increase the effective area of the inlet port by making it as wide as possible and increasing its length, the latter action reducing still further both the pumping efficiency and the tendency to blow-back at low speeds, but increasing the power at high speeds.

Still further potential increase can be gained by lengthening the inlet pipe, thereby increasing the ram effect but also taking advantage of the pressure-wave set up when the fast-moving air-column is suddenly stopped by the closure of the port. This wave oscillates backwards and forwards in the inlet tract, and at those speeds at which it is in resonance with the engine can assist markedly in improving the crankcase filling, though at other speeds its effect may be non-existent or even adverse.



Rotary valves for T.T. twins, ancient and modern: (left) gear drive to the valve of the 1912 *Senior Scott and (above) the* 1959 250 *c.c.* MZ, *with one crankcase cover removed to show the inlet port and rotating disc valve.*

In other words, it is not really possible to make a piston-controlled inlet porting system which is effective at *all* speeds. It must be proportioned according to the kind of characteristics the engine should possess.

There are two alternatives. One is to utilize automatic valves of the reed or diaphragm type, consisting of very light spring-steel blades seating against a flat face. These were used in some pre-war D.K.W.s and still are on the American outboards.

They practically eliminate blow-back at any speed and give good breathing, though this is not by any means unrestricted. The reeds require a little pressure-difference before they will open and it is not possible to provide a straight-through passage, as it is with a plain port, but the type in which the reed lies in a position almost parallel to the gas-flow is very effective and offers great possibilities.

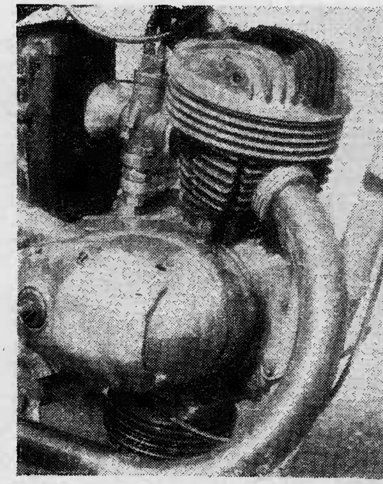
The other alternative is to employ a rotary valve, the usual method being to incorporate it in one of the mainshafts. With suitable porting, it can be arranged to give, say, 200° of opening instead of the 120° which is about the maximum that can be used with piston control. This scheme is employed in the British Anzani twin, in which two ports are drilled in the centre main bearing, each feeding one crankcase from a single carburetter. Unless the bearing is extremely large, the effective port area is, however, not very great even though the timing is favourable, because for most of the time the port is not fully open.

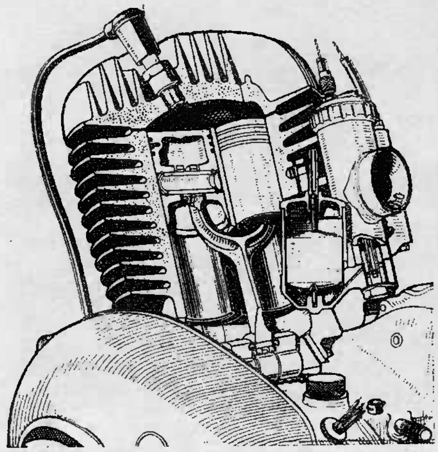
This objection is overcome by the disc-valve which is used in the MZ and, no doubt, is part of the reason why the 125 c.c. model can turn out power equivalent to 170 b.h.p. per litre.

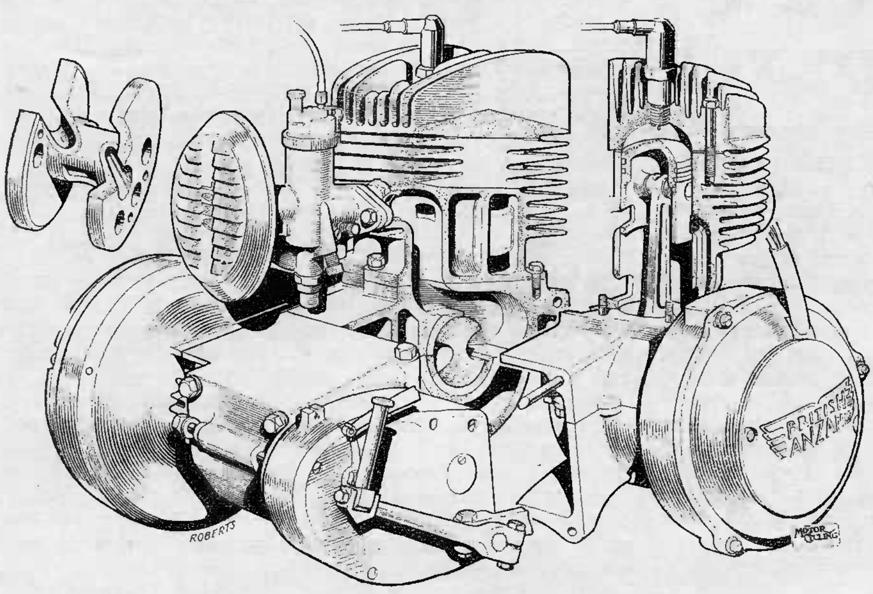
The valve itself is of sheet steel, .020 in. thick, and rotates in a space only .040 in. wide. It is not mounted firmly on the main-shaft, but is driven by splines so that it can centralize itself in the gap or move to one side or the other, so acting like a reed-valve during the periods when it is closed.

Part of the periphery is cut away to open the port, which then has a clean, unobstructed entry into the crankcase and, moreover, is fully open for about 140° of its total opening period of 200°. Apart from its vulnerability to foreign matter, it is

(Right) This 1947 125 c.c. D.K.W. racer had an additional charging piston mounted below the crankcase. (Below) The T.W.N. "split-single," in which the two pistons move in unison.







A combination of piston-controlled transfer porting and rotary valve (inset) is employed in the 322 c.c. British Anzani twin.

difficult to see how this valve could be bettered for high-speed work.

Conditions inside the crankcase can be improved by careful disposition of all the components which it contains. For example, if the crank-webs are cut away in the region of the pin to provide mechanical balance, a quantity of mixture will be contained in the spaces which, at b.d.c., are as far as could be from the transfer ports. It is clearly much better to make the cranks in the form of discs, closely fitting the case, and also to use a narrow con-rod, with the big-end recessed if necessary into the discs to reduce the space between them.

Balancing can be effected by drilling the discs and closing the holes with light plugs on the pin side, or by using heavy plugs on the non-pin side, the real object being not so much the increase in compression ratio, as to keep as much gas as possible close to the transfer passages. These should be large in cross-sectional area, smoothly contoured and possess the smoothest possible entry; the last point is sometimes overlooked and the piston is allowed to obstruct the entry very badly just at the moment when the gas-velocity should be at its highest.

It was at one time held that high power could not be obtained at high speed because of the short port opening time available. But actually the reverse is the case—it is precisely because the times *are* so short that full advantage can be taken of pressure-waves in the exhaust system and what is known as the "Kadenacy effect" to get the high outputs previously thought to be impossible.

Kadenacy found, by ingenious experiments with a special engine, that if the exhaust ports were large and opened with sufficient rapidity the imprisoned gas would rush out at such high velocity that it continued rushing out until the port was closed again, by which time the pressure in the cylinder had become sub-atmospheric. What follows? If another valve, which may be a port or may be a poppet-valve, is opened at the right moment, enough fresh mixture may be drawn in to enable an engine to keep running without the aid of crankcase compression. But if crankcase compression is present, this effect obviously assists the entry of mixture from the transfer ports, though at the same time it has a tendency to suck a portion of this mixture out through the exhaust, as there may be a depression of 5 or 6 lb./sq. in. present in this port.

Exhaust Waves

By using a short, open pipe this negative pressure wave can be reflected back as a positive wave which promptly rams some of the lost charge back into the cylinder, with a marked increase in power at the appropriate speeds. It has since been discovered that, so far from needing an open pipe, it is better to use an expansion chamber with a restricted outlet, when the desired wave-effects will be intensified. A curious fact is that the outlet area may be less than that which would normally be provided on a touring machine developing about one-quarter of the power: that on the 250 c.c. twin Adler racer, for instance, is only about $\frac{5}{8}$ in. diameter.

Representative port timings for an engine designed on these lines are: exhaust opens (and closes) 80° from b.d.c.; inlet opens (and closes) 68° from b.d.c. The top edges of the exhaust ports should be square to the axis in order to achieve a strong Kadenacy effect in the blown-down period of 12° thus provided.

The trouble with these engines is the old one of lack of flexibility. Maximum power may be in the region of 9,000-10,000 r.p.m., but there is little useful power available at a mere 2,000 r.p.m. or less, when the resonant conditions upon which the high power depends cease to exist. Nevertheless, a lot may still be learnt by a modified application of this principle to sports engines.

NEXT WEEK: IGNITION