MOTORCYCLE ENGINEERING—18

Which Type of Engine?

Two-stroke or Four-stroke? What capacity? How Many Cylinders?

by PHIL IRVING

THE selection of the most suitable design of engine for any particular motorcycle is governed largely by the conditions in which it is to be used, the nature of the work to be done, and the permissible ceiling cost of manufacture.

In some instances, the third item may be of paramount importance. Shortcomings in the way of low power output or high fuel consumption may have to be accepted in engines designed for the very cheapest class of vehicle.

At the other end of the scale, for special racing or record-breaking power units the question of cost can almost be disregarded, provided that the success of the end-product eventually justifies the money laid out on its design and development. Engines for limited numbers of production road-racing, scrambling or trials models fall into an intermediate category. A few pounds may justifiably be added to the cost if the improvement in performance so gained makes the difference between a potential winner and one which is virtually beaten before it starts.

Regulations imposed either by the law of the land or by competition rules also have to be considered. In some countries, models powered by engines below a certain capacity are granted tax relief or may be ridden without a licence, and the lion's share of the market in these areas will naturally fall to the maker who produces the most outstanding model of this restricted size.

50 to 1,200 c.c.

In recognized international competitions, a series of capacity limits ranging from 50 to 1,200 c.c. has been adhered to for many years. There are no limitations whatever on the general design, except that supercharging is prohibited and so is the use of additional charging pistons on two-strokes, both being devices which, in effect, defeat the purpose of the capacity limit. For record-breaking, however, these restrictions do not apply and you can do what you like in the way of forced induction or the use of special fuels provided the swept volume of the actual working cylinders is within the capacity limit.

Only in the U.S.A. is any distinction made between engines of differing designs. There, side-valve models up to 750 c.c. are permitted in certain types of races to compete against 500 c.c. overhead-valve models, and there is also a limit on the compression ratio permitted.

The number of variable factors in the basic design—the actual capacity, the number of cylinders, the type of valve-gear, whether two-stroke or four-stroke and so on—is so great that it is no easy matter to decide which combination is the best for any particular application. Several preliminary layouts may have to be prepared and investigated for cost and ease of manufacture before a final choice is made.

Frequently the size, type and accuracy of the machine-tool equipment available places some restrictions on either the general or the detail design. Changing public opinion must also be considered, especially in introducing a new model which is expected to continue in production for several years.

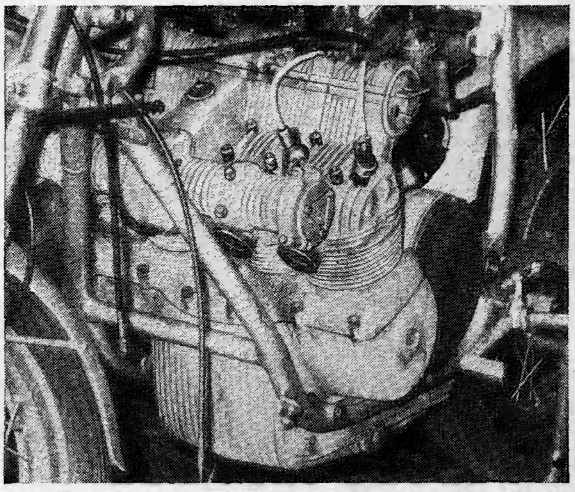
An example of changing status is the two-stroke engine, which not so very many years ago was acceptable only in small, inexpensive machines and was really no more than tolerated (except by true believers in the type) for its cheapness and simplicity of construction. Today, the position is quite different. Thanks to the development of the "loop-scavenge" principle, which eliminated the deflector-type piston, and better knowledge of port design, two-stroke performance figures are comparable with those of four-strokes of equivalent capacity, and a certain amount of mechanical complexity is acceptable if it yields a gain in performance or economy. The odd theory that once a departure is made from the essential simplicity of the two-stroke, you might as well make it a four-stroke, has gone by the board.

However, the two-stroke principle is seen to its best advantage only with cylinders of small capacity, partly because the ratio of port area to volume becomes less favourable as the dimensions are increased, and partly because cylinder distortion due to the unequal temperatures existing in the region of the ports becomes more serious with increase in cylinder diameter. For these reasons 200 c.c. per cylinder is near the desirable upper limit of capacity. Unless, therefore, one is prepared to go to the length of using three or even four cylinders, with their attendant difficulties of maintaining effective sealing between the various crankcase compartments, the four-stroke cycle is almost an automatic choice for air-cooled engines of over 400 c.c.

This leads us to a consideration of what size the engine should be. For racing, of course, this depends only on the category in which one wishes to compete, a promising line being to start off with a "125," designed in such a way that it can be duplicated to form a "250" later on.

For touring, a designer with wide terms of reference may well have in mind the adage that there is no substitute for litres. In other words, for certain jobs, such as fast touring on motorways or carrying heavy loads, a big engine, working well within its limits for most of the time, is preferable to a small one, screaming its heart out in order to develop the same amount of power.

While it is common practice to compare engines on the basis of peak power output, a much better yardstick is provided by ascertaining the specific output, or power



A classic example of an engine designed and built regardless of cost for the specific purpose of winning races—the Italian M.V. "four."

developed per litre per thousand r.p.m. For example, the ordinary run-of-the-mill o.h.v. engine, with valve timing and compression ratio designed to give a good all-round performance for normal road work, has a specific output of between 8 and 9.5 b.h.p./litre/1,000 r.p.m. This figure is reasonably consistent for all engines, irrespective of capacity, *which conform to these requirements* (see table). A little engine can only be made to turn out as much power as a big one by making it turn over faster, or else by increasing its specific output.

This can, of course, be accomplished by the well-known expedients of raising the compression ratio, lengthening the valve timing, increasing the diameter and length of the carburetter choke and induction system, and fitting a resonant unobstructed exhaust system. But a price will be paid in loss of flexibility, erratic slow running and a tendency to raise the speed at which useful power is developed towards the upper end of the power curve—how heavy the price will depend upon the extent to which the aids to power-production have been exploited.

B.H.P. Target

These are serious disadvantages for normal road use and therefore it is not a good plan to aim at more than 10 b.h.p./litre/1,000 r.p.m. for this work. But for racing, where sheer power is the major requirement, they cease to matter much and it is possible to raise the specific power output to 15, though this is about the maximum which has so far been obtained from any four-stroke using atmospheric induction. If a quick check on the performance figures quoted for some engine indicates a specific output appreciably higher than this figure, either the claims are exaggerated or the test results have been obtained with nitro-methane in the fuel (this compound provides a kind of chemical supercharging by the liberation of oxygen, thus enabling more fuel to be burnt per stroke).

Pursuing this matter of specific power a little further, the average side-valve engine can only achieve 8 to 8.5 b.h.p./litre/1,000 r.p.m., a figure which can be bettered by a conventional two-stroke with flat-top piston and designed for use on the road, complete with silencer.

A racing two-stroke with mechanical inlet valves of the rotary or reed type may record nearly double that figure if skilful use is made of the pressure-waves in a resonant exhaust system. However, the speed range over which this very high output is attained will be even narrower than in the case of the four-stroke with high specific output; the bottom falls out of the power-curve at around 8,000 r.p.m., making a six-speed gearbox essential for road-racing and rendering the engine useless for ordinary work.

The crux of the matter, where racing is concerned, is that everything, except reliability, must be subordinated to the need for obtaining power, though the shape of the power-curve must suit the kind of racing for which the engine is intended. Further, the reliability must be of the order which will withstand very high stresses for short periods under good conditions—rather than less intense duty for an indefinite time, possibly under the very adverse conditions, including neglect and poor maintenance, which fall to the lot of many touring engines.

TABLE OF CALCULATED PERFORMANCES

Make and model	Capacity c.c.	Claimed output, b.h.p./r.p.m.	Specific output, b.h.p./litre/1,000 r.p.m.	Rear wheel size, in.	Top gear ratio	Theoretical speed at 4,000 r.p.m.	Theoretical speed at peak r.p.m.
						Based on claimed output	
Four-stroke Tourers							
Ariel "Square Four"	1,000	42/5,800	7.3	4.00×18	4.4	72	103
B.M.W. R69	600	35/6,800	8.6	3.50×18	4.9	62	106
B.S.A. B33	500	23/5,500	8.4	3.50×19	5.0	63	87
Gilera "Extra"	175	9.1/6,000	8.7	2.75×19	7.1	42	63
Panther 120 (solo)	650	27/4,500	9.2	3.50×19	4.6	68	77
Royal Enfield "Meteor Minor" ..	500	30/6,250	9.6	3.50×17	4.7	62	97
Triumph "Tiger Cub"	200	10/6,000	8.3	3.25×17	6.8	43	64
Triumph 3TA	350	18.5/6,500	8.1	3.25×17	5.3	54	87
Velocette "Valiant"	200	12/7,000	8.6	3.25×18	7.3	41	72
Velocette MSS	500	23/5,000	9.5	3.25×19	4.9	63	79
Vincent "Rapide"	1,000	45/5,500	8.2	3.50×19	3.5	90	124
Four-stroke Sportsters							
B.S.A. "Super Rocket"	650	44/5,600	12.0	3.50×19	4.5	70	98
Harley-Davidson XLH	900	47/5,000	10.5	3.50×18	4.2	73	91
NSU "Supermax"	250	17/7,000	9.7	3.25×19	6.8	45	80
Royal Enfield "Crusader Sports"	250	17/6,250	10.8	3.25×17	6.1	47	74
Royal Enfield "Constellation" ..	700	51/6,250	11.6	3.50×19	4.4	72	113
Triumph T100A	500	32/6,500	9.9	3.50×17	4.8	60	100
Triumph "Bonneville 120" ..	650	46/6,500	10.9	3.50×19	4.6	70	113
Vincent "Black Shadow" ..	1,000	55/5,500	10.0	3.50×19	3.5	90	124
Two-stroke Roadsters							
Ambassador "Super S"	250	15/5,500	11.0	3.25×17	5.8	50	69
Ariel "Leader"	250	16/6,400	10.0	3.25×16	5.9	47	75
B.S.A. D1 "Bantam"	125	4/5,000	6.4	2.75×19	7.0	43	53
D.M.W. Mk. 9	200	8.4/4,000	10.5	3.25×18	6.2	48	48
Dot "Sportsman's Roadster" ..	350	22/5,000	12.6	3.25×18	Optional	—	—
Excelsior F10 "Consort" ..	100	2.8/4,000	7.0	2.25×19	7.4	38	38
Greeves 24DB (single)	250	11.5/4,750	9.7	3.25×18	5.7	52	61
Guzzi "Zigolo Mk. 2"	100	4.6/5,200	8.8	2.75×17	7.9	35	45
Messerschmitt KR200	200	9.7/5,000	9.7	4.00×8	4.2	43	54
Rumi "Junior"	125	9/7,300	9.8	4.00×8	5.4	44	81
Scott "Flying Squirrel"	600	30/5,000	10.0	3.25×19	4.1	75	94

For example, the speedway J.A.P., with its scanty finning, cast-iron cylinder head and drip-feed, total-loss lubrication system—but very rugged, simple and easy to work on—is an ideal example of a design built and developed for, and invincible in, a specialized sphere of operation. In this case, the demands to be met were a moderately high output allied to an ability to " hang on " at low speed and pull away from a momentary check without the help of a gearbox.

At the other end of the scale could be placed the 500 c.c. Guzzi V-8, in which complexity has been carried about as far as it can be in a two-wheeler, and to a degree which would render it useless for the knock-about work in which the J.A.P. seems to revel. In between there are engines like the double-o.h.c. Norton which, though not quite as fast as a highly developed multi-cylinder, is robust, simple to tune and relatively easy to maintain, and therefore probably a better proposition for the rider who has to do his own work, or at least does not have a flock of factory mechanics to do it for him.

There is another matter worth remembering, too. It is easier and less expensive in the long run to make a very fast, or potentially very fast, engine in the first place, and subsequently modify it or de-tune it for use on the road, than it is to start with a touring engine and then try to make it into a racer—as more than one factory has found out the hard way.

Sticking strictly to the script in embodying all the design principles essential to a top-flight racer may, however, result in a product which even when de-tuned is too expensive for the bread-and-butter market—as witness the present-day absence of the once-popular overhead camshaft in this field. A designer may, therefore, have to make some concessions in order to conform to the sales policy of his company.

This course of action has been discernible in the development of some models, especially for competing in events of the Clubman type. It is not by any means a bad thing, because the fruits of experience gained in racing can be almost directly incorporated into other models in the range which are substantially similar in design, whereas it may be difficult or even impossible to do so if the racing and production models are markedly different.

Whereas a racing engine is driven at or near its maximum all the time, it is more usual, on the open road at least, to drive a touring engine at its best cruising speed. " Cruising speed " is one of those terms which everyone seems to understand, but nobody can define accurately; one possible description is the speed at which the vehicle appears to travel most happily. It will work up to that speed almost by itself, yet a conscious effort has to be made to push it along at any higher velocity. Some models do not exhibit this characteristic very strongly, but others do—in fact they almost "go to sleep" at some point in their speed range, buzzing along quite happily with the throttle rolled well back after the cruising speed has been reached.

It will be found that, provided the top-gear ratio is correct, the engine r.p.m. corresponding to this "best" speed is very close to 4,000 r.p.m. for all contemporary o.h.v. engines designed to produce around 50 b.h.p. per litre with good flexibility, irrespective of their cylinder capacity. The super-sports type of motor with higher compression ratio may cruise better at 4,500 r.p.m., whilst with side-valvers and two-strokes the speed may be more like 3,500.

Important Factor

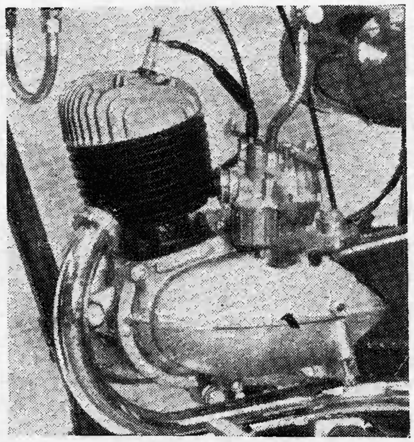
"Cruising speed" is not necessarily—in fact it is unlikely to be—the most economical speed, but it gives the best return measured in miles per gallon per hour's running; and, after all, to many people time is of greater value than money, a factor which is sometimes overlooked when comparing the running costs of rival models.

The existence of a well-defined cruising speed is probably bound up with the fact that the peak of the torque curve also occurs at 4,000 r.p.m. in engines of average power output, and therefore at this speed both the combustion efficiency and the mechanical efficiency are of a high order.

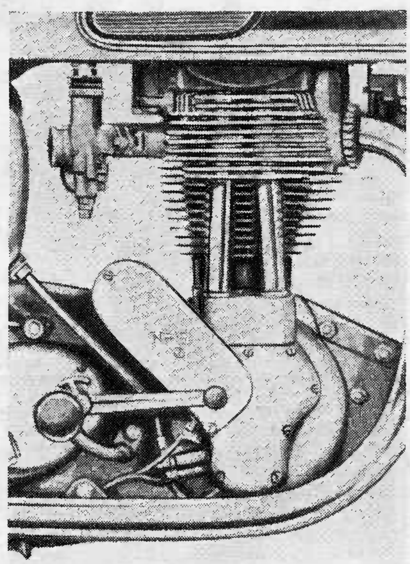
To summarize: the easiest way to provide the tourist with more power and a high cruising speed without fuss is to use an engine of large capacity and of moderate specific power output rather than a smaller engine made into a semi-racer.

A 1,000 c.c. engine developing 45 b.h.p. at 5,300 r.p.m. will propel a solo model at over 100 m.p.h. on a top gear of 3.5 to 1 and will cruise at 80 m.p.h., at which speed the engine is turning over at only 3,800. This ability to lope along in an effortless manner is the main charm of the big engine, especially when it is in twin-cylinder form.

But the big—and consequently heavy—machine has been steadily going down in public favour for some years until today it is no longer built in Britain and is in production by only one maker in the U.S.A., a country which has produced more models of between 1,000 and 1,300 c.c. than any other.



An engine designed to give uttermost economy in production, consumption and maintenance. It is the 98 c.c. Villiers unit used in Britain's cheapest motor-cycle—the Excelsior "Consort."



A type once supreme in British motorcycle favour—the 500 c.c. o.h.v. single. The example seen above is that of the ES2 Norton.

It would appear that the 650 c.c. engine, turning out around 35 b.h.p., is fast enough for the majority of hard riders, especially for areas where high speeds cannot be sustained for very long periods. As it is possible to design such an engine in the form of a parallel-twin without incurring too much trouble from the inherent lack of balance of this type, it is understandable that it should have achieved considerable popularity in recent years.

How many "Pots"?

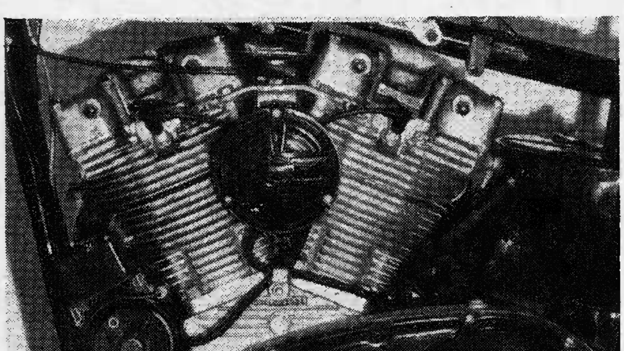
This brings us to the thorny question—how many cylinders? From the mechanical point of view, the fewer the better. From the aspect of smoothness, the opposite is the case, but there seems little to be gained in this direction by using more than one "pot" in sizes below 150 c.c. for touring purposes. This is especially true of two-strokes, because it is more difficult to obtain good idling with a twin-cylinder two-stroke than it is with a single.

The single begins to lose its attractiveness in two-strokes, for reasons already mentioned, in capacities above 200 c.c. The same thing occurs in four-stroke form above 350 c.c., when its lack of balance and irregular torque commence to outweigh the merits of simplicity. Nevertheless, there is still plenty of scope for this type even up to 500 c.c., but above that at least two cylinders are required to furnish the degree of refinement which one expects nowadays.

Whether the four-cylinder engine will ever come back to favour except for racing is doubtful. However the cylinders are arranged, either with a conventional transmission or with shaft drive, one is up against very tricky cooling problems—unless one resorts to a complicated construction with geared crankshafts, or the engine is mounted transversely, as in Italian racing practice.

In the transverse four, cooling is about as good as it is possible to be, but is gained at the cost of a complicated, expensive and potentially noisy geared primary drive, into which it would not be very easy to incorporate a flywheel large enough for touring purposes. A possible alternative would be to take a leaf from the scooter designer's book and use fan cooling with fine-pitched, small-diameter cylinder fins enclosed in close-fitting cowls, though a fan of the necessary diameter would not be an easy component to fit into the space available.

Another possibility would be to adopt water-cooling. This method has been used sporadically for many years and is found today on the LE Velocette and Scott, but it has never really been held in much esteem and its overall cost and weight are both greater than that of conventional direct air-cooling, which works perfectly well with either a parallel-twin or a V-twin.



(Left) The only Vee-twin of its capacity built today, but once a type frequently used by designers of machines intended for heavy work—the 900 c.c. Harley-Davidson, from the U.S.A.

NEXT WEEK: THE RELATIVE MERITS OF S.V., O.H.V. AND O.H.C.