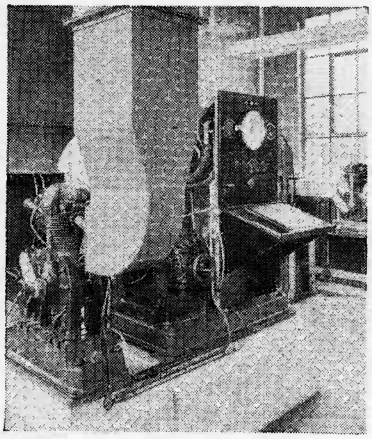

Power and Torque

The real significance of standard engine data

By *PHIL IRVING, M.I.Mech.E., M.S.A.E., M.I.P.E.*

WHEN James Watt started to sell his new-fangled steam engines about the middle of the XVIIIth century, he ran up against the problem of how to "rate" them, or describe the amount of work they were able to perform in a way that could be easily understood and appreciated. Since horses were the main source of power at the time and it was obvious to one and all that four horses could do four times as much work as one, it was a natural thing to choose "one horse-power" as the unit and rate a steam engine at 10 horse-power or whatever.

Since, however, all horses are not equal in size, physique or willingness to work (I drove an 11-horse team pulling a wheat-wagon for some time, so can speak with a little knowledge on that point), Watt promptly ran up against the problem that bedevils anyone who seeks to establish a standard which is: how does one define the standard itself?

Definitions

Watt settled this point by conducting an investigation from which he concluded that the average horse could do work at a rate equivalent to lifting 33,000 pounds one foot in one minute for reasonable periods of time without being flogged to death.

At least, that's how the story goes. The historical details may, perhaps, not be quite right; nevertheless, since that time all countries employing the English system of measurement have recognized that the unit of power for commercial purposes should be the "horse-power" and that this unit should be the equivalent of doing 33,000 ft./lb. work per minute. The force, distance, and time elements involved can be shuffled round in any way you like, as long as they work out to the unit equivalent. On the Continent, a similar unit was adopted using metric measurements; thus, 1 metric horse-power equals 75 kilogram-metres per second which, translated into our system, equals 542.4 ft.-lb. per second, or near enough to 1½% less than the English horse-power, which is $\frac{33,000}{60}$ or 550 ft.-lb. per second.

Continental Units

In France the metric horse-power is termed the C.V. or *cheval vapeur* (literally, "steam-horse") and in Germany is called the P.S., short for *Pferdestärke* ("horse-strength"). So, when you see powers quoted in these terms on a performance graph, they are as near as no matter the same as if quoted in h.p., but sticklers for accuracy can convert the Continental figures into English equivalents by multiplying by the factor 0.986.

But the matter does not stop at defining the term "horse-power." There are many shades of meaning given to it by tacking on words such as "brake," "taxable," "rated," "indicated," "gross" and "net" which cloud the issue considerably.

The combination most generally used is "brake horse-power." usually contracted to "b.h.p." This is the power which an engine can actually develop at the crankshaft and is measured by running it coupled up to some sort of power-absorbing device called a dynamometer, but more colloquially referred to as a brake.

The powers developed at various speeds are measured and plotted against r.p.m., to give the familiar power curve. The highest point of this curve is called the "peak," hence the term "peak power," but the speed at which this is attained may be hundreds of revs. lower than the maximum speed at which the engine *can* turn over—a speed which is sometimes called "peak revs."

Variable Factors

Brake horse-power is, then, something factual and definite and can be measured to within one or two per cent. of accuracy, depending on the quality of the equipment, but the figures obtained are true only under the conditions prevailing at the time of the test. The power of any engine decreases with a drop in atmospheric pressure, due either to the weather or a rise in altitude above sea-level, and varies in almost exact proportion to the barometer reading.

It also varies with air-intake temperature, dropping with increase of temperature and vice versa. This relationship, however, is not so clear cut and, moreover, it is difficult to decide what exactly the intake-temperature is, especially on a single-cylinder, where fuel blown back out of the carburetter can deposit itself on a thermometer bulb placed close to the inlet and the subsequent evaporation creates a temperature-reading lower than it should be. Alternatively, radiation from the cylinder or exhaust-system can give an over-high reading.

Nevertheless, it is usual to correct observed horse-power to allow for temperature and pressure, the result being termed "corrected" or "cor. b.h.p." "Normal" pressure and temperature (or NTP) are 29.92 in. of mercury and 15°C. respectively.

In technical descriptions or discussions, the term "indicated h.p." occasionally crops up. This is something which cannot be directly measured. The term derives from the early steam-engine days, when one way of assessing power was to take an indicator diagram of the pressures existing in the cylinder at all times throughout the cycle. From the area of this diagram and the speed of rotation, the indicated horse-power could be calculated.

The figure so obtained is the power actually developed in the cylinder, but makes no allowance for subsequent power-loss due to piston-friction, bearing-friction and the work required merely to pump the working gases into and out of the cylinder. Therefore the i.h.p. is always considerably more than the b.h.p., the relation between the two giving the mechanical efficiency of the engine.

I.h.p., therefore, means little to the buyer but is useful in development work because it shows the benefit or otherwise of some modification without having to make allowances for side-effects which are extraneous to the combustion cycle. It might well be, for instance, that some improvement to breathing would improve the i.h.p. without a corresponding increase in b.h.p., because of extra friction or deflection in the engine caused by the higher gas pressures. Without some method of obtaining the indicated horse-power (which nowadays is done electronically) there is no means of telling whether such a situation exists or not.

'Net' and 'Gross'

From the user's standpoint, all that matters is how much power he gets out of the crankshaft, but the development engineer is more concerned with the engine itself, disregarding the auxiliaries which, though not very power-consuming on a motorcycle engine, can swallow up quite a slice on a car engine. This situation led to the introduction of two terms, "net power" and "gross power"—"net" being the unit's actual output, "gross" being the amount obtained with no generator, fan or air-cleaner attached. The difference is considerable, averaging somewhere in the region of 10% for water-cooled engines, and

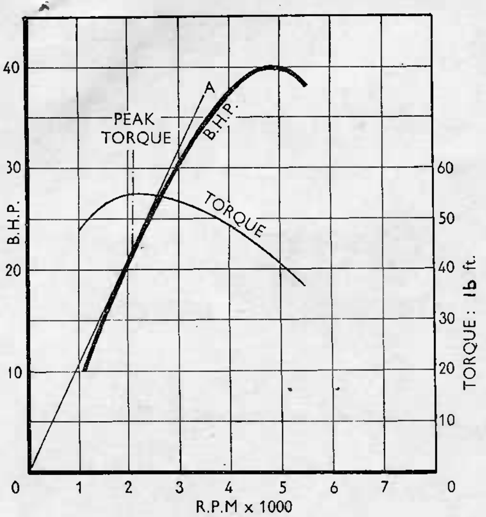

Fig. 1. Performance curves of a typical slow-revving engine; line A is the tangent for ascertaining peak torque.

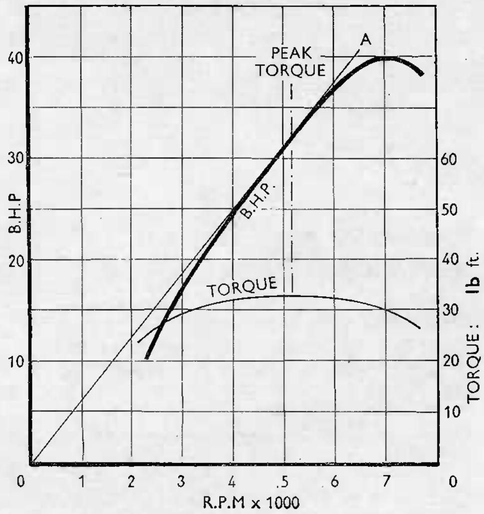

Fig. 2. Performance curves of a smaller, high speed engine developing the same power.

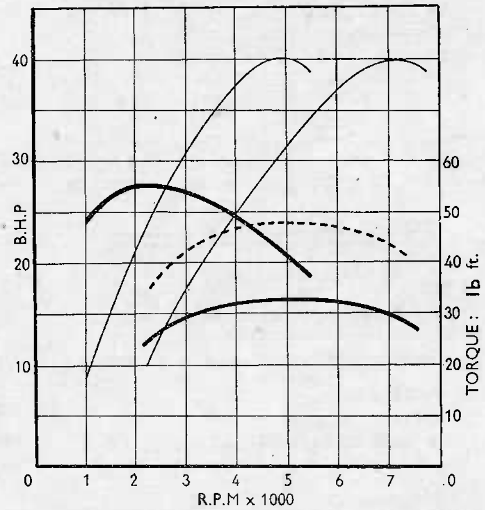

Fig. 3. Figs 1 and 2 with the small engine's "equivalent" torque curve (see text) in dotted line.

advertising copy-writers were not slow in taking advantage of the situation by quoting the higher figures, secure in the knowledge that few people were aware of what "gross" meant in this context.

Even more misleading were the results obtained by using a test procedure in which power was recorded with *every* extraneous item disconnected—generator, fan, fuel pump, silencer and all—and the mixture-strength and ignition-advance adjusted to their optimum settings at every recorded speed interval. Imagine what a godsend *that* was to the publicity boys at the height of the "horse-power race" in the United States a couple of years ago!

A similar sleight-of-hand has not been unknown in our own industry, where the performance graphs have sometimes been taken with open exhaust tuning instead of the silencer normally fitted, but happily this practice is dying out. In any case, it never pays in the long run; when an engine consistently fails to live up to its alleged performance, people eventually wake up to the discrepancy and are then inclined to view any future statements from the same source with considerable scepticism.

Taxation Horse-power

In the early days, when some scheme was required to rate engines for taxation purposes, the R.A.C. formula was adopted. This was based on the fallacious assumption that 1,000 ft. per minute was the highest usable piston speed and that lengthening the stroke merely resulted in having to run at lower r.p.m. Power would, therefore, be proportional to total piston area, regardless of stroke, and the formula adopted was

$$\text{Horse-power} = \frac{D^2N}{2.5}$$

where D is the bore in inches and N the number of cylinders.

Although it was painfully obvious that this was a totally unrealistic formula which led to the design of car and truck engines with about the same proportions as a tyre-pump, it was retained until 1945. After this the "capacity" system was introduced whereby 100 c.c. equalled 1 horse-power—for taxation purposes only, of course, and again with little relation to reality. Fortunately, even that system has now gone by the board and we might as well not talk about it any more, but move on to the more important matter of torque.

Torque

This term is simple enough. It means only the turning or twisting moment which the engine provides at the crankshaft and is measured in pounds-feet. An engine with say, 40 lb.-ft. torque could lift a weight of 40 lb. at a radius of 1 ft. or 240 lb. at 2-in. radius and so on.

Rotational speed does not come into it at all, although there is a simple connection between torque and power, the expression being.

$$\text{Power} = \frac{2\pi NT}{33{,}000}$$

where N = r.p.m. and T = torque.

From this expression it follows that at 5,250 r.p.m. the power figure is exactly equal to the torque figure, and if the power and torque curves are drawn on the same graph to the same scale the two should intersect at 5,250 r.p.m. Conversely, the torque curve can be derived from the power curve by reading off values of the latter at various speeds, dividing each value by the r.p.m. and multiplying by 5,250.

Surprising Results

This sometimes gives quite surprising results, slight dips or rises in the power curve appearing as relatively large valleys and mountains in the torque curve, and the peak of the torque curve occurring where you might not expect it. In fact, the speed at which this peak occurs can be found quite easily by drawing a line from the origin of the graph and tangential to the b.h.p. curve, which has been done in Figs. 1 and 2. These figures show representative performance curves, which might be expected from a large, slow-revving engine of 1 litre capacity with a peak power of 40 b.h.p., developed at 4,800 r.p.m., and from a smaller, high-speed engine of around 600 c.c. developing the same horse-power but at 7,000 r.p.m. Although the two b.h.p. curves are roughly comparable, the torque curves are quite different, the big motor reaching 55 lb.-ft. at 2,100 r.p.m., the small one only attaining 33 lb.-ft. but at more than double that speed.

In practice, this means that, if installed in the same frame, both engines would attain equal speeds, 100 m.p.h. being about the figure to be expected, but the smaller one would have to be geared much lower in order to be able to reach its peak power. As the tractive effort at the rear tyre is proportional to the engine torque multiplied by the gear ratio, the effect of lowering the ratio would be to increase the tractive force and so make up to some extent for the lower torque of the small-capacity engine. The effect of this is shown in Fig. 3. where a dotted curve has been added, equivalent to the true torque of the small engine, multiplied by the necessary drop in ratio which is proportional to the peak-power speeds, i.e., 4,800 and 7,000 r.p.m.

'Hanging On'

This "equivalent" curve is a purely hypothetical one, given for purposes of comparison. It intersects the true torque curve of the big engine at 4,200 r.p.m. Below that speed, the latter has an increasingly great excess of torque at the rear wheel, despite the lower ratio of the small engine, and consequently it will "hang on" up a hill or into a head-wind much better in top gear.

The shape of the torque curves therefore gives a much better indication of the characteristics of an engine than does the power curve. Sometimes a slight flattening of the latter curve will be found to cause a severe depression in the torque curve and if this occurs at a gear-change point the pick-up following the change will be poor. This is usually due to a resonance effect in the induction or exhaust system and quite a lot of experimenting on the dynamometer may be required before it is eliminated.