Single-cylinder Balancing Theory

It is well-known that it is not possible to balance completely a single-cylinder engine (or a twin in which the pistons go up and down together), but it is possible to arrive at an acceptable compromize. The weight of the rotating parts, i.e. the big-end and crankpin, can be balanced completely by counterweighting the flywheels opposite to the pin but if a weight equal to that of the *total* reciprocating parts, i.e. piston, rings, gudgeon and the top half of the rod were also added, the inertia forces at t.d.c. and b.d.c. would be cancelled out, but at the 90° positions, there would be nothing opposing the centrifugal forces generated by the counterweight, and the balance would be just as bad as before, but the direction of vibration would be at right-angles to the cylinder axis instead of along it. Consequently, it is necessary to effect a compromize by adding only a certain percentage of the reciprocating weight, this figure being termed the "balance factor".

Whilst counterweighting can be performed either by adding weight opposite the pin, it can also be done by removing it from the pin side, or a combination of both. It is immaterial at what radius the adding or subtracting is done, provided you get the correct final result.

As vibration is a matter of frequency which in turn is decided by the crankshaft r.p.m. it might be wondered why an alteration in balance-factor has any significant effect in changing the speed at which vibration becomes excessive. Severe vibration in any machine is almost invariably caused by a resonant effect when the frequency and direction of the exciting force are such that some component of the machine is also set into vibration. This may be the entire frame, one of the frame tubes, the rear end of the mudguard, or very frequently the handle bars, and often an improvement can be effected just by altering the natural frequency of the vibrating part: the legendary T.T. rider, Walter Handley, for instance, cured violent vibration of the very expensive light-alloy bars first used on the K.T.T. Velocette by filling them up with lead!

When the balance factor is altered, the magnitude of the unbalanced force is changed to some extent but also the direction in which it acts is altered; at zero factor, it would be in line with the cylinder axis and at 100 per cent it would be at right-angles to it, but at factors in between those two unusable extremes, it would be at some intermediate angle which would be independent of speed. Thus altering the line of action of the unbalanced forces by a change in balance-factor may cease to excite a previously offending resonant vibration, or might equally well bring in another.

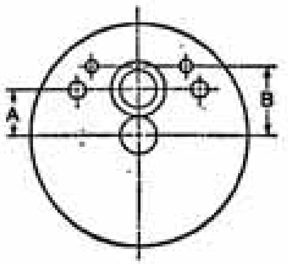
There are in fact so many considerations involved that it is impossible to quote one figure as being the ideal, since it varies with every type of engine, and even for the same engine in different or differently-equipped frames. The only source of reliable information is the parent factory who have certainly done a lot of experimentation. The M.O.V. Velocette factor is as high as 85 per cent, while some engines have been under 50 per cent, but failing any reliable information 66 per cent is a good starting-off point.

As an instance of rebalancing to suit different frames, the Speedway Vincent engine with the standard 66 per cent factor caused severe vibration in a very light dirt-track frame until the factor was reduced to 61 per cent, a matter of 1·3 oz at pin radius.

Strangely enough, some makers use a smaller factor for racing than for touring, while others do the reverse; the idea in all cases, however, is to get an engine which runs most smoothly in the speed-range at which it is intended to operate for the majority of its life. It does not matter much if the engine feels "rough" at 4,000 r.p.m. if it is to be raced and feels smooth at 6,000, whereas such an engine would be very undesirable for fast touring, where much of the running is done at the lower r.p.m. Altering the balance factor will usually succeed in moving the rough period, if any, well away from the most-used speed.

Practical Methods

If a piston weighing say an extra 1½ oz. is being fitted to an engine which ran smoothly with the original piston, the extra weighting required could be taken to be 66 per cent of 1½ oz, i.e. 1 oz, even if, as is probable, the exact balance factor is not known. As long as the factor



7.7. When drilling balance-holes, only the positions measured in the direction of A or B need to be taken into account. B can be greater or less than A. In the example quoted on page 87, B has been taken as 1⅓A purely for convenience.

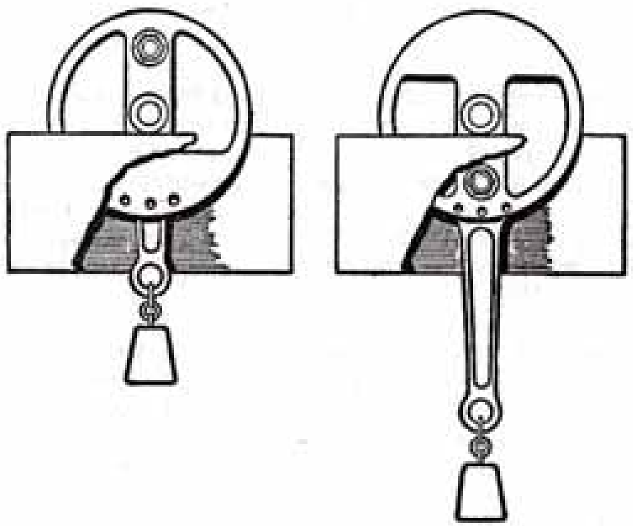
lies within the usual limits, this weight would be within ¼ oz either way of the correct amount and would be quite close enough, at least for a trial shot.

The easiest way to rebalance is by drilling holes, but these must be equal in each wheel and be either in line with the crankpin or symmetrically disposed on both sides of it. The following table shows the weight removed per inch of depth for common hole sizes in steel and cast iron.

Hole diameter (in.)	½	7/16	⅜	5/16	¼
Area (sq. in.)	0·196	0·150	0·110	0·077	0·05
Ounces (for steel)	0·88	0·68	0·50	0·35	0·23
Ounces (for cast iron)	0·80	0·62	0·45	0·32	0·21

The effect of the weight removal depends of course on the position of the holes and is proportional to their distance from the mainshaft, measured in the way shown in Fig. 7.7. The distances on each side of the pin are immaterial, provided they are equal in each wheel. In the example quoted, where 1 oz is to be removed, the table shows that a total of 2 in. of ⅜-in. hole would be required in steel wheels at the dimension A: this could be made up from two holes, ½ in. deep in each wheel. But if this was not suitable, ¾ oz at dimension $B(=1\frac{1}{3}A)$ could be removed by drilling ⅜-in. holes, only 0·33 in. deep; alternatively ¼-in. holes in the same position would need to be $\frac{100}{23} \times \frac{3}{4} \times \frac{1}{4} =$ 0·73 in. deep; and so on for any suitable combination of hole size and position. If subsequently the engine vibrates, experiments can be made quickly by removing one or more rings to lighten the piston temporarily, or fitting a thicker gudgeon to give the effect of a heavier one; the results of these checks will show whether the factor is too small or too great.

If you are starting from scratch with new parts and want to balance these to some particular factor, an accurate pair of scales, or a spring balance and some simple equipment is necessary. First, weigh the big-end, with the rod supported at both ends absolutely horizontally and in a frictionless manner. Also weigh the roller cage and rollers; the sum of all these figures comprises the rotating weight and must be balanced 100 per cent. Next, weigh the small-end, again with the rod horizontal and add this to the weight of the complete piston assembly to determine the reciprocating weight. Multiply this figure by the desired factor, say 66 per cent, add the result to the rotating weight and the total is the equivalent weight to be balanced at the crankpin radius. Now turn up a ring of any available material which fits the crankpin and weighs exactly the same as the equivalent figure just determined, and assemble the wheels with this ring in position in place of the connecting-rod. Balancing can then be done by resting the mainshafts on a pair of horizontal knife edges, such as are often found in machine shops for balancing grinding wheels. If the shafts are not of equal diameters, a sleeve must be fitted to the smaller one, and in fact, unless the shafts are already hardened more accurate results will be obtained if two hardened sleeves



7.8. A jig for checking balance can be made from two lengths of angle iron bolted to the bench and protruding sufficiently to allow the assembly to revolve freely.

If, with a weight to give the desired balance, attached to the small-end, the crankpin comes to rest in the uppermost position, the counterweights must be drilled as shown on the left. If the crankpin stops at the bottom the wheels must be drilled adjacent to the pin.

are fitted, though it is essential that they are truly concentric. The wheels will probably show a tendency to roll until the pin is either directly above or below the mainshafts, but always come to rest with the pin somewhat off-centre. In that event, the wheels are not symmetrical and this fault must first be rectified by drilling holes of equal value in each wheel at right-angles to the pin and on the "heavy" side. An indication of the hole size required can be obtained by first fixing nuts or similar objects on the "light" side with sticky-tape or Plasticene.

This scheme can then be used to perform the final balancing, which is proceeded with until the wheels roll freely along the knife edges and show no tendency to settle in any particular position, even when the assembly is reversed on the knife edges. As correct balance is approached, jarring the fixture slightly will assist in showing up any small error remaining. As an alternative, the shafts can be supported in free-running ball-bearings, but supporting them between lathe-centres as you do when lining them up is not satisfactory because there would be far too much friction to get anything like accuracy. A better and certainly a quicker method is to get the assembly balanced on one of the modern electronic machines with which many crankshaft grinding firms are equipped but they will need to be told what balance factor you require,

unless the wheels are supplied to them correctly aligned and with the appropriate dummy ring in place. However, this process will not necessarily make the engine any smoother; it will merely ensure that you do get exactly what you asked for.

On the other hand, work may be going on in a locality where accurate knife edges or electronic balancers are unheard of. In this event some jury-rig can be devised which though it might horrify a purist, will nevertheless work quite well if it is sufficiently rigid. For instance, two lengths of angle iron can be bolted to the bench-top overhanging the latter by about a foot. The only vital qualification is that the top edges must be flat, smooth and absolutely horizontal and level with each other when the wheels are resting on them. A good spirit level is the best aid to checking this point, but failing that a dead-round bar such as a piece of silver steel will prove the point, since it will obviously tend to run towards whichever is the lower end.

Balancing a Complete Assembly

If it is desired to check or alter the balance without disturbing a completed assembly, it can be done with simple equipment in the following manner, provided that the big-end has a roller-bearing and not a plain one in which there would be too much static friction.

Arrange the wheels on a flat surface with the connecting-rod (minus piston) lying horizontally and with the small-end supported by an accurate spring balance or on a short bar resting on the edges of the pan of a pair of scales. A few oddments can first be placed in the weighing pan to counterbalance this bar and avoid subsequent confusion. Let us suppose the weight of the small-end so determined is 6 oz and that the weight of the complete piston assembly is found to be 15 oz: the total reciprocating weight is therefore $15 + 6 = 21$ oz and at a factor of 66 per cent, the amount to be balanced is therefore 14 oz.

The wheels minus piston are then placed on knife edges as previously described and most probably will come to rest with the pin vertically upwards. Any tendency to lie to one side, indicating lack of symmetry, must first be corrected.

When symmetrical balance has finally been obtained, attach to the small-end a weight equal to the amount to be balanced *minus* that of the small-end; using the figures quoted above, this would be $14 - 6 = 8$ oz. The manner of making up this weight or of attaching it to the small-end is purely a matter of choice—it can be, for instance, a bag full of oddments, or a bolt with the requisite weight of washers. If the balance-factor does actually correspond to the figure desired, the wheels will roll freely along the straight-edges and show no tendency to settle in any one position; if not, the pin will go to the top or bottom according to whether the counterweight is too heavy or too light (Fig. 7.8).

Correction is usually made by drilling the wheels in the appropriate positions but can equally well be done by tapping and plugging existing holes. If experimenting to find the best balance is part of the tuning programme, it is a good idea to drill and tap a few holes of, say, $\frac{3}{8}$-in. or $\frac{1}{2}$-in. diameter, into which plugs of the required weight can subsequently be fitted or removed. In some engines it is possible to drill a hole somewhere in each crankcase wall and tap it $\frac{1}{4}$ in. B.S.P. which is the thread commonly employed for drain plugs, and drill several holes in the flywheels at the same radius, tapping these out $\frac{1}{8}$ in. B.S.P. Plugs of various lengths in steel or bronze can then be inserted or removed from the flywheels through the crankcase holes in a couple of minutes without disturbing the engine and experiments to find the most satisfactory balance can be very rapidly conducted. This is a very good scheme to employ when adapting engines for use in small racing cars, because the different method of mounting as compared to a motorcycle very often leads to trouble in obtaining smooth running.

Two-strokes and Multi's

Two-strokes are sometimes fitted with non-circular wheels and instead of drilling, it may be easier to file or grind off excess metal where required. Holes are in any case undesirable in two-stroke flywheels and are often filled up with plugs which are of light metal on the pin side, or heavy metal such as lead on the side away from the pin. The special features of two-stroke and multi-cylinder balancing are discussed more fully in Chapters 15 and 16.

Fuller discussions can also be found in the author's books "Motorcycle Engineering" and "Automobile Engine Tuning".

Torque Vibration

Finally, lack of smoothness may not be caused by incorrect balance, but by the torque reactions which tend to rock the engine backwards and forwards when power is on. The position of the stay sometimes fitted to steady the engine exerts quite an effect and it is worth experimenting with the position or tension of this component or even leaving it off altogether, except in the case of Manx Nortons in which the stay connecting the cylinder head to the steering column is a vital part of the Featherbed frame construction.

CHAPTER EIGHT

WORK ON THE CRANKCASE

The primary duty of the crankcase is to provide a rigid mounting for the main bearings and a foundation for the cylinder sufficiently solid to maintain that component square to the mainshaft axis at all times, irrespective of temperature changes or cyclic load variations. The rigidity of the bearings is settled by the original design; thus in the search for speed little can be done other than to see that the outer races are a good fit in the case when the latter is hot. If they are not, the races will show signs of "creep" indicated by a polished appearance of the outer surface. If there is any doubt about the matter, each side of the case, complete with bearings, can be immersed in boiling water, after which the bearing rings should not be free enough to turn by hand.

Several methods are available for curing loose races, of which the easiest—tinning the surface—is not to be recommended, as it is almost impossible to get an even coating, and in any case it inevitably gives away after a while. Chromium or nickel-plating the races is satisfactory, provided that the finished outer surface is absolutely circular and true to the bore; if only about 0·001 in. thickness of deposit is required to restore the fit it will not need to be finished to size if the job is done by a competent plating shop, but deposits of greater thickness will need to be finally sized by grinding owing to the tendency of these metals to build up more thickly at the edges than at the centre. Copper-plating on the other hand does not show this tendency and can easily be cleaned up to size with a file whilst the race is rotated in a lathe chuck. Owing to its softness, copper plating does not always last very long but is such a convenient method that it is often utilized.

"Loctite" can be used very effectively provided the cold clearance is not more than 1 thou. This liquid is rather expensive but need only be used sparingly, and is made in several grades for different applications. For bearings which need not be disturbed later, the correct variety is grade B. A similar material is known as Sta-Lok, of which grade 500 is suitable for this application.

If the wear is very great, a permanent cure can be effected by boring the housing out and fitting a bronze sleeve about $\frac{1}{16}$ in. thick and 0·002 in. per inch of diameter larger than the housing. Having heated up the crankcase to 200° C (400° F)—which can be done with the aid of a domestic oven—the sleeve can be dropped into place, and after peening the aluminium over the edge as shown in Fig 8.1, the sleeve is then finish-bored to 0·001 in. per inch smaller than the race. This job must be done extremely accurately; the crankcase must be set up in the