MOTORCYCLE ENGINEERING—16

Torque Reactions

Their Bearing Upon General Engine Design

by PHIL IRVING

WHEN assessing the merits and demerits of the basic engine types briefly described in last week's article, reference was made to the effects of torque reaction, especially with regard to power units in which the flywheels lie at right-angles to the centre-plane of the machine. As torque reactions in any direction have a great influence on the "feel" of the whole machine when the engine is revolving, and vary in their intensity and direction according to the overall design, they must be taken into account at the design stage. To avoid unnecessary repetition or explanations as the subject of engine design is explored more fully, this article will deal with the matter in relation to engine types in general.

When Isaac Newton propounded the law that to every action there is an equal and opposite reaction, he stated one of the major truths upon which all engineering is based. It applies to torques or twisting moments as well as to direct forces. The simplest instance, in our own particular sphere, is the tendency of the engine (in a model with all-chain drive) to rotate *backwards* in its mountings, with a torque equal to that developed at the crankshaft and transmitted to the primary chain.

This reaction torque has to be resisted by the engine mounting-bolts. It will be seen that if the crankcase were held merely by one transverse bolt fore and aft in a weak rectangular frame with little corner rigidity, the whole thing would distort at every firing stroke and spring back again during idle strokes. If the natural frequency of vibration of the assembly ever coincided with the rate of firing, the induced vibrations might build up to very uncomfortable proportions.

While nobody would be silly enough to build a frame as badly as this, the same *kind* of effect must exist, however well the design is executed. Hence it is advisable to space the engine-bolts widely apart, preferably using two at the front and two at the rear to spread the loads over as large an area as possible and also to give stiffness against "lozenging."

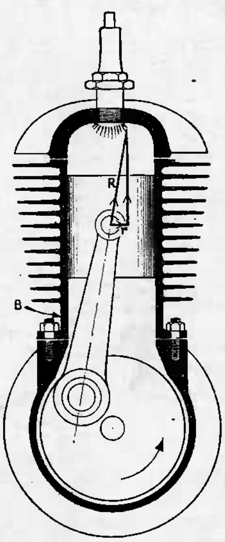
Head-steadies

Some makers, however, prefer to employ stays attached to the cylinder head and running to some suitable anchorage on the frame. These can sometimes be a mixed blessing; they may hold the engine firmly enough, but at the cost of transmitting vibrations of small amplitude but intense effect to areas where the rider is uncomfortably aware of their existence.

The effect of a head-steady on the internal stresses in the engine depends to a degree upon the circumstances. In an engine with the crankcase held quite rigidly in torsion, the rearward thrust of the piston against the cylinder tends to push this component backwards in relation to the crankcase—and, in fact, on occasion has accomplished this feat by fracturing the wall just above the base-flange. If one now imagines the engine to be fitted with a head-steady and the crankcase anchorage considerably reduced in stiffness, the effect will be to *reverse* the direction in which the barrel tends to rotate on the crankcase. In other words, *without* a head-steady the front cylinder bolts have a tensile stress to carry in addition to that due directly to explosion pressure, while *with* a steady and a flexible crankcase mounting the additional tensile stress is applied to the rear bolts.

Of course the nature of the power torque reaction varies according to the number of cylinders and the working cycle of the engine. As a rough approximation, the mean torque of a sports engine of contemporary design is 56 lb.-ft. per litre of swept volume.

"Mean torque" is the twisting moment which the engine would exert if it had an infinite number of cylinders and the power were delivered in a smooth stream. It is numerically equal, on the Imperial system, to the power output at 5,250 r.p.m., so if the latter figure is 28 b.h.p. the torque is 28 lb.-ft. Obviously at any other speed the torque can be found by multiplying the power by 5,250 and dividing by the speed in question.



During acceleration, reaction of the flywheels to con-rod thrust (R) *has a rearward component* (r) *acting against the cylinder. Without a head-steady, a weak cylinder may fracture at* B.

In practice, the torque is not steady but fluctuates above and below the mean figure by an amount which varies mainly with the number of explosions per revolution. Thus the single-cylinder four-stroke, firing once every two revolutions, has a very irregular torque, with the maximum reaching anything between four and 10 times the mean, while in the smoothest practicable types—the four-cylinder four-stroke and twin-cylinder two-stroke, with power impulses occurring twice per revolution—the peaks are only about twice the mean value.

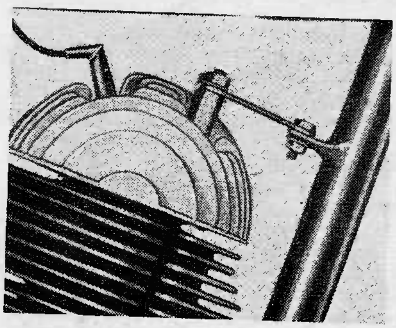
It is difficult to be dogmatic about the ratios of maximum to mean, because the exact figure also depends upon the flywheel weight, the compression ratio, the effectiveness of the engine-shaft shock absorber (if any) and some other minor factors; all of which would give even an electronic computer a headache, or maybe valve-bounce, in endeavouring to assess their combined results with any degree of accuracy. In any case, the rough running associated with irregular torque is seriously apparent only at low engine speeds in top gear, higher speeds or a change to a lower ratio making it less noticeable—unless, as has been noted, the frequency of fluctuation happens to correspond with that of some other part of the machine which may then vibrate in resonance, even though it is a long way from the source of excitation.

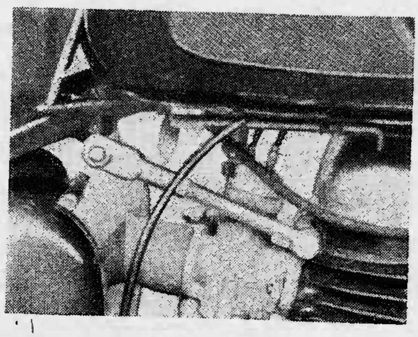
Torque reactions still exist even when the transmission is in neutral, because by their very nature the flywheels resist being accelerated violently and a rearward thrust of the piston against the cylinder is created at each firing stroke. The shudder which is evident in some models if the throttle is opened quickly is due to this effect rather than to the imperfect balance inherent in any single (or four-stroke parallel-twin) engine. In fact, vibrations due to the latter cause are dependent solely on the speed of rotation, whereas any vibrations which vary with throttle opening while the speed remains reasonably constant are due primarily to torque reactions and secondarily to the resonant frequency of some portion of the frame.

Inertia torque reactions when the flywheels are located parallel to the centre-plane do not disturb the machine as a whole, because they act in the plane of support. If, however, the flywheels are at right-angles to this plane, as in horizontally opposed twins and in-line fours with fore-and-aft crankshafts, the reaction tends to push the model to one side against the direction of rotation of the flywheels, but only when the latter are being rapidly accelerated.

This effect is quite noticeable in neutral when the throttle of a large transverse twin is "blipped," but becomes less so when travelling in gear because the rate at which the wheels can be accelerated rotationally is then automatically limited by the rate at which the whole machine can be accelerated linearly. The higher the gear and the lower the power-to-weight ratio, the less evident does this adverse feature become.

The only way to eliminate the effect entirely is to employ two crankshafts and flywheels of equal weight, geared together so that they revolve in opposite directions, as in the Brough Superior "Golden Dream" and the parallel-twin racing Velocette. The inertia torque reaction from one shaft is then balanced by that arising from its mate; though that was not the only reason underlying the adoption of the principle, which also confers a very much better balance of the whole unit.





Head steadies on the James "Flying Cadet" (left) and the Royal Enfield "Crusader."

When the throttle is closed with the engine running at high speed, there is a tendency, if only a single transverse flywheel assembly is used, for the model to bank over in the same direction as this wheel rotates. The effect, though present, is not very noticeable when the road wheels are on the ground, but if they are in the air it could be great enough to have a pronounced influence on landing. This is so because, when not supported on its tyres, the machine is free to rotate about the crankshaft axis, and it has less polar moment of inertia (or flywheel effect of its own) in relation to this line than it has in relation to the line of contact with the ground.

Therefore, if the rider of a flat twin crosses a humped bridge very fast, and in a panic snaps the throttle shut when the engine screams up as the wheels aviate, the machine is bound to bank over to some extent in unison with the flywheel. If there is a curve immediately following the touch-down, it may well be that the bank acquired during flight is the wrong way to that required to take the bend, and considerable riding skill may be necessary to avoid unpleasant consequences. The smaller the flywheel in relation to the total mass of the machine, the less the effect will be, but the only way to eliminate it entirely is by adopting the contra-rotating principle, with flywheels of equal weight.

Since the input torque to the gearbox is always less than the output torque in any of the indirect ratios, the difference appears as a tendency to rotate the whole gearbox backwards about the mainshaft (which may be a contributory factor to down-tube breakage in some frames).

There is also a tendency to rotate the box about a vertical axis due to the primary and secondary chains being at different distances from the centre-line of the frame; but as the primary chain, with the lesser pull, is usually farther out than the final chain, which has the greater pull, this effect is not very great in a conventional layout with both chains on one side. It would be of serious proportions, however, in a cross-over box mounted separately from the engine. In the Scott, which has its primary drive located on the centre-line and therefore about 3½ in. away from the rear chain, an additional outboard bearing is mounted on the frame to maintain the box positively in alignment.

When the gearbox and crankcase are either constructed as a true unit, using common castings, or as two assemblies rigidly bolted together, all the primary transmission forces become internal to the unit, and it no longer becomes advisable to keep both chains on one side to avoid this undesirable twisting action. In fact there seems little justification for retaining this system, as the cross-over drive confers advantages in the way of simplifying oil-retention in the primary-drive casing.

Another advantage of unit-construction is that the engine bolts are spaced on a very broad base, thus reducing torque-reaction loads in the mountings and generally providing a construction with more potential rigidity. However, this is no justification for employing a frame so lacking in stiffness that under lateral deforming forces the power unit is doing most of the work of holding the thing straight—unless the castings and bolt-bosses are strong enough, or have been specifically designed for this purpose.

Crankcases which are subjected to heavy stressing should always have the bolt-bosses blended well into the casting walls with generous fillets, and extending if possible to the full width available. Cracks are very likely to develop adjacent to the holes if the bosses are narrower than the main walls and thus place the neighbouring metal in a peculiar state of stress which combines shear, bending and tensile loads—a dreadful combination which should be avoided at all costs.

To quote one actual example of failure from this cause, an early version of a popular speedway engine had bolt-bosses only 2½ in. wide attached to a crankcase about 3½ in. wide, and it was not unknown for a piece of aluminium, complete with the two rear bosses and part of the crankcase, to be pulled right out. A cure was effected by bringing the bosses to full crankcase width.

Another concerns the original Vincent-H.R.D. singles which did have full-width bosses, spaced, however, fairly closely together for interchangeability with Rudge engines. After a week's T.T. practice, cracks developed round the lower rear bosses, necessitating some frantic rebuilding and extension of the engine-plates to the extreme bottom corner to utilize another bolt, which previously had only helped to hold the halves together. Spreading the load in this manner entirely eliminated cracking even on the "Rapide" engine which, though a V-twin of twice the power, used similar rear engine plates and bolts.

A power unit with fore-and-aft crankshaft, but with integral bevel gearing and chain drive to the rear wheel, is exactly the same as any other engine so far as its power torque reactions affect the frame; but when shaft drive is used the unit tends to rotate in the opposite way to the shaft, while the bevel casing tends to rotate in the same direction as the shaft. This imposes a twisting effect on any portion of the frame lying between the unit and the bevel-box.

Hence it it advisable either to mount the rear forks on the unit or to brace them thereto as directly as possible (the Velocette "Valiant" is an example of the second arrangement). Any deflection can then occur only in the forks themselves and ample provision can be made for resisting the torque within the forks; unless this is done, the wheel will twist out of the centre plane, either under power or when the gears are used on the over-run to provide engine braking. The tail will then veer to one side or the other to quite a marked extent, partly because the rear tyre contact-point is out of alignment with the front, and partly because the wheel is inclined and consequently endeavours to run in a circle.

On top of all these internal torque effects and reactions, there is the overall tendency for the front wheel to lift under power whatever the form of drive may be. This is most evident during a violent standing start. The lifting of the front wheel is accentuated by the fact that the line of thrust is at ground level whereas the centre of gravity of the whole machine is about 30 in. above this line; but, even at steady-speed conditions, with full power applied this effect does result in a considerable transfer of weight from the front to the rear wheel and has a bearing on the fact that at very high speeds the rear tyre gets hotter than the front.

NEXT WEEK'S ISSUE is our Christmas Number so Phil Irving relaxes, in reminiscent mood which we think will amuse his readers. Back to serious matters in our issue for December 31, he discusses the question of engine/gearbox layout.