More Questions of Balance.

Tim Ramsay

Tim Ramsay continues his essay on engine balance and associated vibrations, with particular reference to twins of various configurations, and devices employed to reduce the effects of out-of-balance forces.

In my first article on engine balancing, I have considered only a single-cylinder engine, but armed with the knowledge previously gained, it is a simply matter to work out the implications for multi-cylinder engines of various configurations. First of all, the parallel twin, with 360 degree crankshaft, is clearly no more than two singles, running as it were, in phase, so that both the primary and secondary forces add up. The only advantage is that, for equal swept volumes the twin will have smaller and hence lighter pistons, and a shorter stroke, implying lower piston accelerations, and lower inertia forces.

Some manufacturers have attempted to improve the situation, by using a 180 degree crank (eg. Honda CB250, K4), but this necessarily produces an engine with uneven firing intervals, The advantage is that the primary forces act in opposite directions, and so cancel each other, but they do cause a rocking action on the crankshaft, because of their different lines of action. In this case, the secondary forces still add together, as in the 360 degree crankshaft.

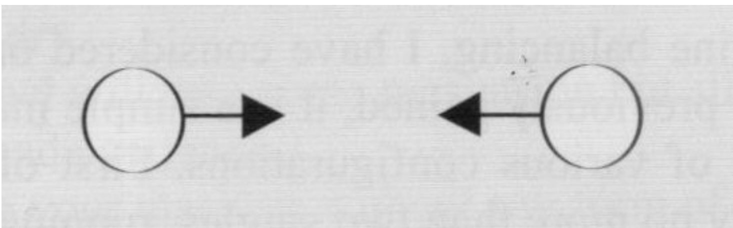
The horizontally opposed twin, as in the BMW and Douglas, is an interesting case to consider. In this engine, the pistons are always moving in opposite directions, and with equal velocities and accelerations at all times, so the inertia forces, both primary and secondary always cancel out. The only unbalanced force produced is that due to the inevitable offset between the cylinders, which means that a rocking couple is imparted to the crankshaft (and you get even firing intervals!). One disadvantage of this engine layout is the difficulty of mounting it in the frame of a solo motorcycle, although as we saw in the racing BMWs of the 1960’s, it is ideally suited for the sidecar outfit. (However, they are not smooth throughout the rev-range and, on a solo, the torque reaction from the in-line crankshaft can be disconcerting and has been alleged to throw a stationary bike off its stand when the engine is ‘blipped’ hard Ted).

At this point I would like to return briefly to the single-cylinder engine, and consider the effect of applying a balance factor of 100%. As we have seen previously, this would produce perfect balance of the primary forces in the vertical plane, but produce an equal unbalanced force in the horizontal direction at mid-stroke. But what if we had another cylinder, at 90 degrees to the first? The primary forces produced by the piston would exactly counteract the unwanted force in the horizontal direction, thus producing perfect primary balance! Thus we see that in the 90 degree V twin, we can produce perfect primary balance, but at the expense of uneven firing intervals. Unfortunately, however, the situation regarding the ‘secondaries’ is not quite so good, as they do combine to produce an increase in the resultant secondary forces. Any rocking couples on the crankshaft can be kept to a minimum, by using a common crankpin, or if necessary eliminated altogether by the use of ‘knife and fork' connecting rods, although this rarely done in practice! We see the best example of a 90 degree V twin in the present day Ducati, whilst other manufacturers content themselves with narrower angle V twins, which are easier to accommodate in a motorcycle frame, but display poorer standards of balance the further they depart from 90 degrees.

In a previous article on engine balancing, I showed how the effects of primary vertical out-of-balance forces could be reduced, but at the expense of introducing a horizontal component. I suggested that the primary forces could be balanced completely by the use of two contra-rotating shafts. One method that can be employed is shown diagrammatically in the figures below. The technique is to balance all of the rotating mass, but none of the reciprocating mass, and let the shafts do the job.

1. When the piston is a top dead centre, and the primary inertia forces act upwards, the balance shafts are in the position shown, and their inertia forces act downwards, to cancel the inertia forces.

2. When the piston has moved to the mid-stroke position, the balance shafts have rotated through 90 degrees, so that their out of balance forces cancel each other out.



3. When the piston reaches bottom dead centre, and the inertia forces are acting downwards, the balance shafts have rotated through another 90 degrees, so that their inertia forces act upwards.

This technique can produce an engine that has a feeling of smoothness, but it dies have two major disadvantages. Firstly, there is the added complication and cost of driving the two balance shafts, and secondly, it does nothing to reduce the piston inertia forces which have to be reacted by the crankshaft main bearings.

In an earlier article, I made reference to the secondary forces, which are due to the angularity of the connecting rod, and cause an oscillatory force at twice engine speed, with an amplitude that depends on the ratio of the con rod length to the stroke. The magnitude of this force can be calculated as S/2L times the primary force, where S is the stroke and L is the length of the connecting rod, and it acts upwards at the dead centre positions, and downwards at mid -stroke. This force could be balanced by a pair of contra-rotating shafts, similar in action to those described above, except they would have to rotate at twice engine speed. Thus at TDC their forces would act downwards, at mid-stroke upwards, and at BDC downwards, with their horizontal cancelling out.