Balancing of Radial Engines – Part I

By W.B. Richards

Several of our members have reported unacceptably rough running radial engines after overhauls by well-respected engine overhaul firms. Concerned lest the same happen to my Kinners as well as the Warner engines I am overhauling, I began a search for the formula and method for balancing of radial engines.

The Kinner publication, "Service Tools for B and R Series Kinner Engines," page 11, gives a picture and description of Tool No. 7371, "Fixture Assembly – Crankshaft Balancing," plus the following description of its use.

> This fixture is used for balancing or rebalancing the crankshaft. The fixture consists of two balance ways or arbors upon which the crankshaft is rested with the front main journal on one arbor and the rear main journal on the other. The crankshaft is then positioned between the two arbors. The arbors must be level and the height adjusted so that the axis of the crankshaft is level. On shafts having different size journals, lower the arbor for the front journal to make up for the difference in diameters. The fixture is equipped with a balance bucket to which is attached a ball bearing pulley wheel with a steel band which can be placed over the crankthrow (i.e. crank pin or master rod journal). Balancing is accomplished as follows: Add weight to the bucket so that the total weight to be hung from the crank throw is equal to the rotating weight plus .508 of the reciprocating weight.
>
> $$(1)\ \ W_c = W_{rot} + .508\, W_{recip}$$
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> The rotating weights are the end reaction of the large end of the master rod, master rod bearing, weight of the four knuckle pins (wrist pins) and the end reactions of the small end (knuckle pin end) of the link rods. The reciprocating weights are the end reaction of the small end of the master rod, the weight of the pistons, piston pins, piston pin buttons, piston rings and the end reaction of the large end (piston pin end) of the link rods. To obtain end reactions, the rod is supported by knife edges at the center of the bushings with one end on a scale and the other on a rigid support. The rods must be level and all bushings in place with the reactions are taken. With the balance weight thus determined, the steel band is placed over the crankthrow and the crankshaft balanced in for positions, i.e., with the crankthrow vertical pointing up and down and horizontal pointing to either side. Material is removed from or added to the crankshaft counterweights to obtain proper balance.

I should add that the calculated weight (W_c) to be hung from the crankthrow should include the weight of the bucket, pulley, steel band, as well as the weight placed in the bucket.

For my experiments, a simple balance stand was constructed, not unlike a prop balance stand, and a laboratory balance beam scale obtained that could weigh in excess of 2600 grams in 1/10 gram increments. For larger weights, scales such as used in paint stores provide sufficient accuracy. I now had the same formula for balancing the Kinner, but would the same formula hold for a seven-cylinder engine, or a nine, or three, or even a different 5 cylinder engine?

To tackle the Warner problem, two approaches were taken. First, a search for all available literature on balancing, and second, the actual weighing of all the rotating and reciprocating parts of several smooth running Warner Super Scarab engines. Four Warner 165 engines were carefully weighed with remarkable results. For example, nearly 50 pistons (including spares) were weighed and found to vary no more than 0.5% from the lightest to the heaviest regardless of whether standard, +.010, or +.020 diameter. Weights of other parts were equally close, showing that great care had been taken during original manufacture to keep parts weights equal. The biggest variation appeared between supposedly similar piston rigs. In contrast, a new set of Kinner pistons had been found to vary as much as 100 grams from lightest to heaviest before they were reworked to balance within 0.5 gram of each other. Results of these weighing experiments revealed that the apparent balance formula for Warner 165 engines should be:

$$(2)\ \ W_c = W_{rot} + \ .510\ W_{recip}$$

With help from friends, several excellent literature sources were turned up, including Den Hartog's "Mechanical Vibrations," third edition, pages 230-232; Taylor's "The Internal-Combustion Engine in Theory and Practice," Vol. II, pages 274-303 and pages 688-689; Lichty's "Internal Combustion Engines," pages 498-504. The most useful paper, however, was Coppens' "Improved Formula for Computer Counterweights of Single-Row and Double-Row Radial Engines," published in SAE Journal, Vol. 34, No. 3, March 19?4. All of these sources give the same basic formula for computing the counterweight (W_{cw}) of a radial engine as:

$$(3)\ \ W_{cw} = \frac{R_c}{R_{cw}} \times W_c$$

$$(4)\ \ W_c = W_{rot} + \frac{1}{2}\,W_{recip}$$

Where: W_{cw} = actual weight of counterweight
W_c = balance weight or bob weight hung from crank throw
R_{cw} = distance from centerline of crankshaft to c.g. of counterweight

R_c = distance from centerline of crankshaft to centerline of crank throw (or ½ the piston stroke)

Coppen's paper points out that the basic formula (4) is incomplete since the link rods are attached to the master rod at holes located a distance "r" from the centerline of the crankthrow that are not concentric wit the crankthrow. This construction introduces an error in the usual determination of reciprocating and rotating weights of about 0.3%.

Coppen's adjusted formula is:

$$(5)\quad W_c = W_{rot} + \frac{1}{2}\, W_{recip} + \frac{W_1\, r'}{2L}$$

Where: W_1 = weight of the rotating (knuckle pin) end of a link rod
r' = distance from centerline of crankthrow to center of knuckle pin hole
L = length of master rod from centerline of crankthrow to centerline of piston pin hole

Den Hartog points out that if the weight of the reciprocating end of the master rod is different from the reciprocating end weight of a link rod it is not possible to completely balance the engine for primary force. With the counterweight calculated by formula (5) above, Den Hartog states that there remains primary unbalance forces in the two main directions (across and along the axis of the master cylinder) of:

$$\frac{1}{2}\, R_c\omega^2 \left(M_{recipMR} - M_{recipLR}\right)$$

Where: ω = circular frequency = $2\pi f$ (f = revs/sec)
$M_{recipMR}$ = mass of reciprocating end of the master rod
$M_{recipLR}$= mass of the reciprocating end of a link rod

It appears that Kinner and Warner adjusted the basic balance formula (5) to compensate for these residual primary unbalance forces resulting Kinner taking .508 of the total reciprocating weight and Warner using .510. Other engine designs may use some other value but in the absence of factory data, a value of .508 to .509 would probably work best.

Twin rod radial engines require two counterweights, one for each row. If d is the distance between the planes of both cylinder rows and d' the distance between the planes of both counterweights, the value of each counterweight should be:

$$(6)\quad W_c = \frac{d}{d'}\left(W_{rot} + \frac{W_{recip}}{2} + \frac{W_1\, r'}{2L}\right)$$

Finally, some important factors to remember when overhauling an engine: If any of the original factory installed parts such as pistons, rings wrist pins, piston pins are replaced, be sure that new part weighs within .5% of the part being replaced. Kinner specifies replacement pistons should weight within .25 oz. (7 grams) of the weight of the piston being replaced. Original pistons, however, were weighed to within 4.5 grams of each other, which is less than 0.5% of the piston's nominal weight.

Once the desired balanceweight, W_c, has been calculated, however, any shop such as Babbitt Bearing Co. of San Jose or Nickson's Machine Shop of Santa Maria, having an appropriate balance machine, should be able to handle the balancing of the crankshaft.