SYMBOL OF SW EXCELLENCE

PRECISION BALANCING OF RECIPROCATING ENGINES

INTRODUCTION

In order to achieve the highest horsepower output, greatest fuel economy, long component life, and smoothest operation, all rotating and reciprocating parts of an engine should be precision balanced. The parts that need to be weighed for this precision balancing include:

- Pistons
- Piston Rings
- Piston Pins
- Connecting Rods
- Connecting Rod Bearings and Inserts

Engine components that should be balanced (preferably mounted on the balanced crankshaft):

- Flywheel
- Front Pulley or Torsional Damper
- Clutch
- Clutch Disc

CRANKSHAFT CLASSIFICATION

Excluding special designs such as one, two, or three cylinders, or General Motors Corp. '71 Series engines, reciprocating engines fall into two general classifications. The first group is in-line engines, and these engines do not require bobweights. It is still necessary to match weight the pistons, rod, etc. The in-line engines have a balanced crankshaft design which is easy to identify in that the large counterweights on each end are in line, on the same side of the crankshaft. The second general classification of engines covers the V-type engines. These have an unbalanced crankshaft design where the large counterweights on each end are not in line, and are on opposite sides of the crankshaft. This type of design requires bobweights. Some engines in this group are designed with part of the counterweight on the flywheel and dampener. It is most important that you check to determine if the dampener and flywheel are counterweighted. If they are, they must be mounted when balancing the crankshaft.

COMPUTING THE BOBWEIGHT

On the standard V-8 engine, the bobweight total consists of 100% of the rotating weight and 50% of the reciprocating weight.

You have two rod and piston assemblies per throw on the standard V-8. The rotating weight would be the crank end of both rods and the bearing insert. The reciprocating weight would be the weight of one piston, one piston end of rod, one set of rings, pin and pin locks (if used). This gives you 50%, or half of the actual weight for the reciprocating part. Use of the following chart will give you percentages and also ensure that you do not forget to weigh any of the parts.

ROTATING WEIGHT (100%)

Weight of crank end rod ______
Weight of crank end rod ______
Weight of set of bearing inserts ______
Weight of set of bearing inserts ______
Weight of lock nuts (if separate) ______
Weight of lock nuts (if separate) ______
Weight of oil (estimate) ______

RECIPROCATING WEIGHT (50%)

Weight of piston ______
Weight of piston pin ______
Weight of piston pin lock (if used) ______
Weight of one set of piston rings ______
Weight of piston end of connecting rod ______

BOBWEIGHT TOTAL ______

PISTON MATCH WEIGHING

By using a precision scale, the lightest piston is determined. (See Figure 1.) Weigh all eight pistons, one at a time, find the lightest and record this weight. Place the lightest piston on the scale and zero the scale. Match the remaining pistons to within 1/2 gram. (See Figure 2.)

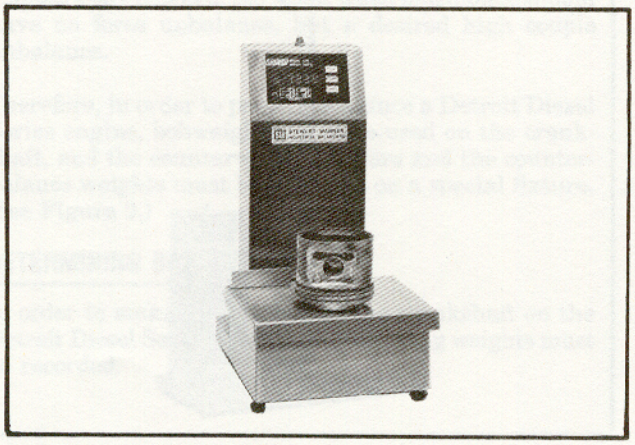

FIGURE 1: Weighing Pistons

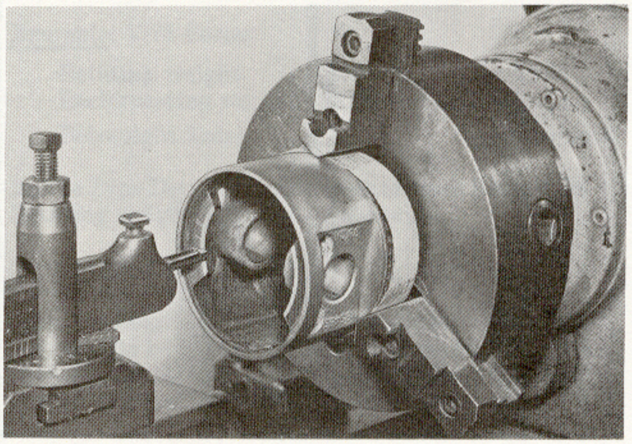

FIGURE 2: Removing Weight from Pistons

(Continued)

If, after attempting to reduce the weight of the heavier piston, it is found that enough weight cannot be removed to equalize the set, either the heaviest or the lightest should be replaced so that a matched set can be attained. It is possible to add weight to the lightest piston by pressing an aluminum slug into the piston pin that goes with the light piston. However, this should only be done with the consent of the owner. If it is done, the customer should be notified that this particular piston pin must always be placed with that piston, otherwise, the engine would be unbalanced.

WEIGHT REMOVAL FROM PISTONS

Weight removal* from pistons is usually accomplished in a lathe, or in some cases a vertical mill. In order to prevent scoring of the ring grooves and lands, a piece of light gauge strip steel should be wrapped around the piston. (See Figure 2.) The width of this strip of steel should be such that it protects the piston from the chuck jaws. In those cases where the piston is balanced with the pin in place, the steel wrap should be long enough to extend over the pin hole so it will prevent the pin from coming out when the piston is rotated in the lathe. (Usually, the pin is removed from the piston when match weighing; however, in some cases it is necessary to match weigh the two as a unit.) When piston and pin are match weighed as a unit, caution must be taken to keep the pin and piston together, and the owner should be notified, indicating that the various pins and pistons are not interchangeable. Weight removal is accomplished on the inside of the piston skirt. Weight should be removed from the pistons in the same place the piston manufacturer removed weight; usually on the inside surface of the piston skirt.

Care should be taken not to weaken or compromise the strength of the piston. If an oil control ring is located at the lower end of the skirt, extreme care should be taken in removing weight, so as not to seriously weaken the piston at its thinnest section. The piston weight should be recorded not only for determining the weight of the bobweights, but also for future reference, should a piston need replacement at some future date.

Tolerance: Either all +½ gram or -½ gram.

*NOTE: Most piston manufacturers provide pads from which weight can be removed.

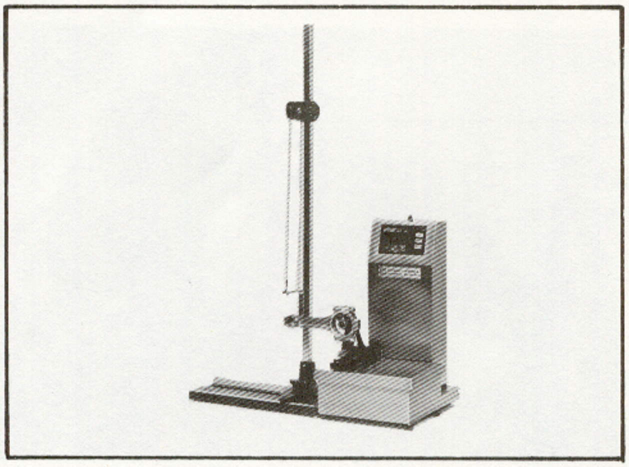

FIGURE 3: Weighing Crank Ends of Connecting Rod

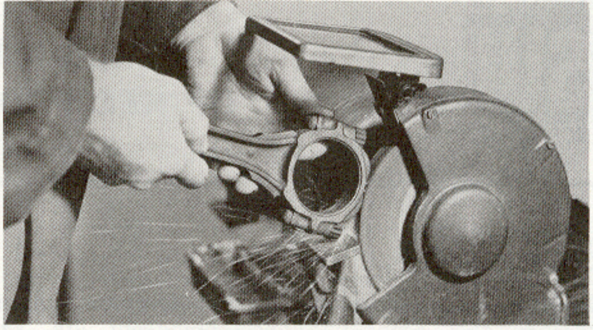

FIGURE 4: Removing Weight from Crank End of Connecting Rod

MATCH WEIGHING CONNECTING ROD

To achieve a good balance, first the crank ends and then the pin ends of the rods must be made equal in weight.

Tolerance: Either all +½ gram or -½ gram.

This match weighing is accomplished by using a precision scale, plus the #329521 Rod Weighing Device with the #329526 (car) or #329527 (truck) Rod Adapter. When mounting the rod on the adapter, care should be taken so that free movement of the adapter is not hindered by the bearings contacting an oil hole, or parting line.

A grinder, or preferably a belt sander, should be used to remove weight from rods. The manufacturer provides balance pads of additional material for easier weight removal. (If pads are not available, all the grinding should be made along the length of the rod, never across from side-to-side, since decreasing thickness affects the strength directly, decreasing the depth affects the strength many times more.)

Weigh all of the crank ends of the connecting rods as shown in Figure 3. When the weight of the crank ends of the rods have been found, the heavier crank ends should be matched by removing weight (See Figure 4.), so that they are made equal in weight with the lightest crank end of the connecting rods. This weight should then be recorded for future reference and for determining the weight of the bobweight.

The pin ends of the connecting rod should be matched weighed using the same procedure as was used on the crank ends of the rods. (See Figure 5.) The weight of the pin end of the rods should be recorded for future reference and for determining the weight of the bobweight.

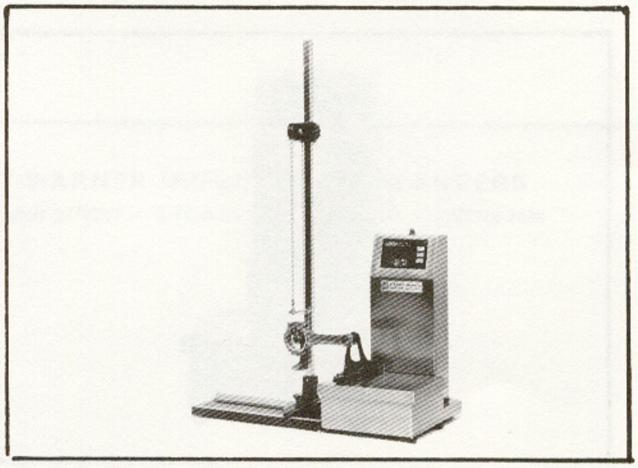

FIGURE 5: Weighing Pin Ends of Connecting Rods

MAKING UP THE BOBWEIGHT

Bobweights are devices attached to the throws of the crankshaft to simulate the affect of the rod and piston assembly.

Bobweights consist of two halves which are held together on the throws by two calibrated nuts on threaded studs. Calibrated nuts cannot be interchanged from bobweight to bobweight, or stud to stud. (Letter on the calibrated nuts are matched to the correct half where a matching letter is stamped.) It is important that the calibrated nuts always be on their proper stud and bobweight half, or an unbalance may result. Each half has a threaded perpendicular stud and nut. The addition of matched weights to these studs increased the bobweights to its correct amount. Calibration of a bobweight may be checked by closing the bobweight and hand-tightening the calibrated nuts. The calibrated nut reading should be the same on both nuts.

Place one complete bobweight on the scale and build two equal stacks of matchweights until the scale reads the required total. Assemble the matchweight on the bobweight and replace bobweight on the scale and zero the scale and repeat the process for the remaining bobweights.

Certain precautions in assembling and mounting the bobweights are necessary. The matched weights should be placed symmetrically on the weight studs. The bobweight may be placed at any angle on the throw, however, for safety and ease of correction, they are usually aligned with the weight studs parallel to the nearest counterweight. (See Figure 6.)

It is important that the match weights are centered through the throw. To obtain this when the halves are mounted on the throw, match the numbers on the calibrated nuts so that both nuts on the bobweight read the same. This automatically centers the match weights on the throw.

The bobweights should be placed all to the right, left, or center. Any of the three ways is acceptable, but make sure that they are all in the same position.

CRANKSHAFT BALANCING PROCEDURE

The crankshaft should be placed on the trunnion bearings and the bobweights installed. Adjust the crankshaft holddown on the oil slinger so that the crankshaft will not shift and there is no drag.

Follow the normal set-up procedure described in the instruction manual.

Once the crankshaft has been balanced to the correct tolerance, then the other components are added, flywheel, dampener, clutch pressure plate, one at a time, and balanced down to the correct tolerance. (Remember, if the flywheel and dampener are counterweighted, they must be on the crankshaft when it is balanced.)

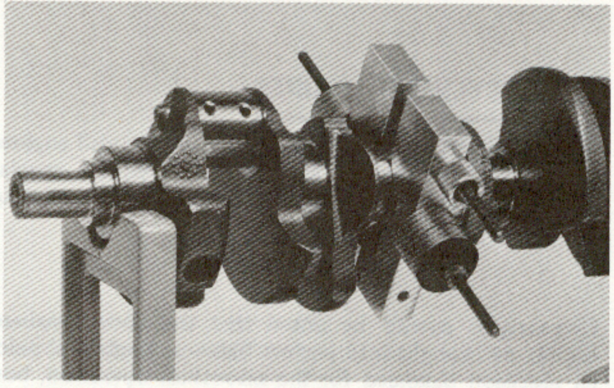

FIGURE 6: Bobweight Mounted on Crankshaft Throw

METHODS OF CORRECTION

Normally, corrections on the crankshaft are made on the counterweights using a ½-inch drill. However, there are circumstances when the counterweight will show light. Usually this is when modifications have been made to the engine such as stroking the crank or going from an external to an internal balance. If there are previous drill holes in the counterweight, you may add material, lead weld, lead wool, etc. If there are no holes in the proper position, you will have to drill and add a heavier material. A very excellent material to add is a heavy metal which is a tungsten alloy.* This material is millable and machineable and is approximately 1½ times heavier than lead. There are several ways to adding this material to the counterweights. You may drill and put a plug in the hole and weld a cap on, or drill and tap a hole and screw a plug into the counterweight. Probably the safest way is to drill a hole parallel to the axis of the crankshaft, and press the plug in then peen over the ends or pin it.

If the crankshaft is externally balanced, counterweighted flywheel and dampener, corrections can be made on the flywheel and dampener.

It is important that when balancing the flywheels and clutch pressure plate as an assembly on the crankshaft, that they be indicated so that when the engine is assembled they will be in the same position as when they were balanced.

Clutch pressure plates may be corrected by drilling on the studs on which the clutch springs are located or adding weight by welding or plugging.

It is usually not necessary to balance the clutch disc, but if it is done it should be balanced on a mandrel and the correction made by grinding on the edge of the disc.

Tolerances: For racing .2-ounce inches per end, for street use .5-ounce inches per end. (These same tolerances are used for each part added to the crankshaft when balancing and also when these parts are balanced by themselves.)

*ABS Products, South Gate, CA
MI-TECH Metals, Indianapolis, IN

SINGLE CYLINDER ENGINES

Single cylinder and other inherently unbalanced engines (motorcycle, outboard, go-cart, etc.) require special balancing procedures because of their high operating speeds.

However, it should be noted that the above engines cannot be brought into perfect balance. Engines should be precision balanced for the smoothest operation, but they will never be as vibration-free as six or eight cylinder engines.

When determining bobweights for a single cylinder or inherently unbalanced engine, use 100% of the rotating weight (the same as for a V-8 engine), but use a higher percentage of the reciprocating weight. (V-8 engines usually use 50% of the reciprocating weight.) This higher percentage of the reciprocating weight is shown in the following chart.

Percentage of Reciprocating Weight
By Operating RPM Ranges

Operating RPM	Percentage of Reciprocating Weight
7,500 - 8,000	55% - 58%
8,000 - 10,000	60%
10,000 - 12,000	65%

Bobweights can then be calculated according to the following weights:

Crank End of Rod ______
Crank End of Insert Bearing ______
Oil in Oil Hole of Throw (est.) ______
Total Rotating Weight: ______

Pin End of Rod ______
Piston ______
Piston Pin ______
Pin Locks (Both) ______
Rings (Set) ______
Total Reciprocating Weight: ______

____ % of Reciprocating Weight: ______
(See Chart)

BOBWEIGHT TOTAL:* - - - - - - - - - - - - - - - - ______

*NOTE: When more than one rod and piston is mounted per throw, multiply this weight by the number of the rod and piston assemblies on the throw.

The small size of the throws on a small engine usually require that special bobweights be built. A simple way of manufacturing these bobweights is to measure the diameter and the length of the crankshaft throw. With this information, plus the knowledge of the required weight of the bobweight, a simple substitution into the following formula will give the approximate outside diameter of a brass bobweight.

$$\text{Outside Diameter of Brass Bobweight} = \text{I.D.} + \sqrt{\frac{BW}{(109)(L)}}$$

I.D. - Diameter of crankshaft throw in inches. (See Figure 7)

L - Length of crankshaft throw in inches.

BW - Computed Bobweight in grams.

The finished bobweight is then sawed in half so that it may be assembled on the crankshaft throw. When the bobweight is assembled on the crankshaft throw it can be held by wrapping with fiberglass type tape. This type of tape is strong and should restrain all movement of the bobweight during the balancing operation.

In most cases, small engines lack sufficient internal clearance for a counterweight of the size necessary to do a good balancing job. In these cases, weight will have to be added to the counterweight by tack welding a piece of 1/8" steel plate to the sides of the counterweight. (NOTE: Before cutting or welding be sure that these plates do not interfere with the action of the connecting rod.) Even with this additional weight there may not be enough total weight to accomplish the highest degree of precision balancing. In spite of this restriction, the crankshaft should be balanced to either the normal crankshaft tolerances, or as close as possible within the limitations set by the amount of counterweight available.

Although the results will not give a precision balance, the end result will considerably improve the performance of the engine.

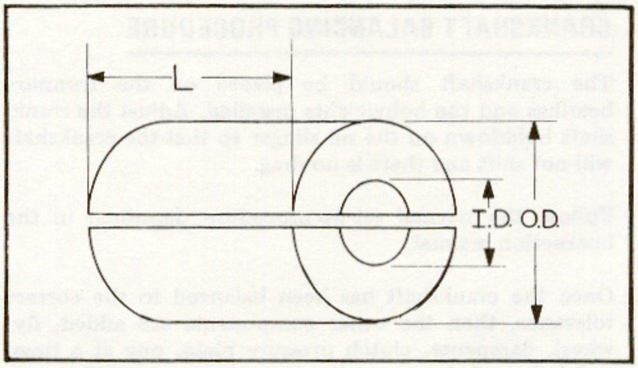

FIGURE 7: Bobweight Dimensions

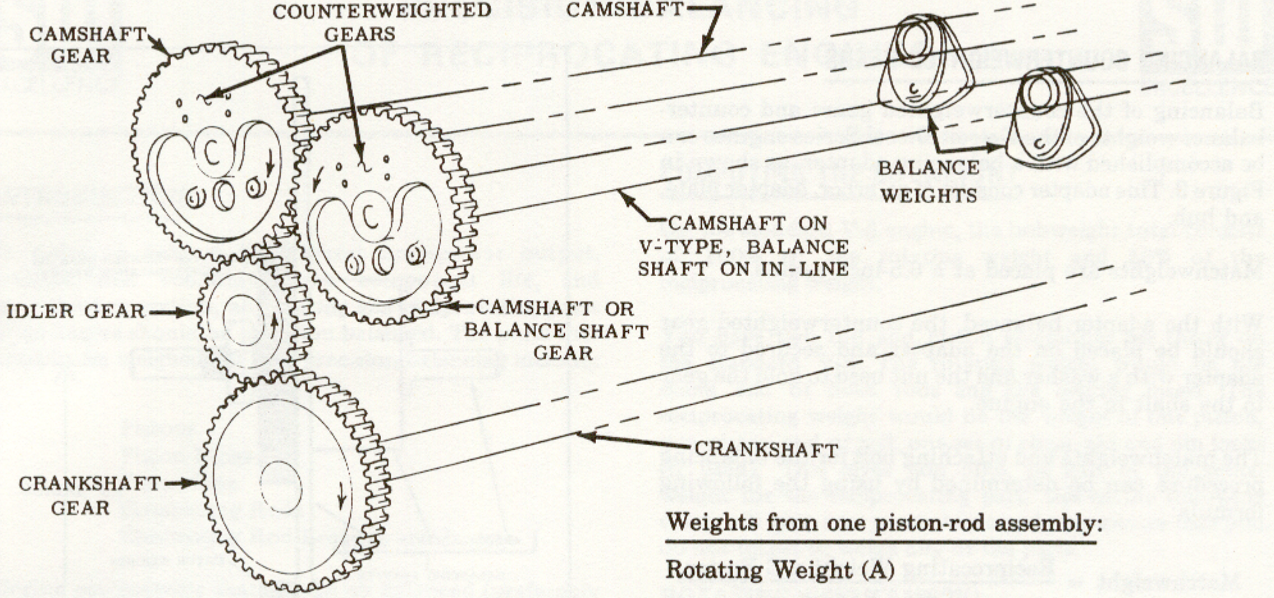

FIGURE 8: Detroit Diesel Series Engine

DETROIT DIESEL 53, 71, 92 SERIES ENGINES

The balancing of the Detroit Diesel Series engines requires special consideration due to the somewhat unusual design.

The Detroit Diesel Series engines are counterbalanced by a combination of balance weights on the camshafts (on the in-line engine one camshaft and a balance shaft are used. See Figure 8.)

Connected to the crankshaft through a small gear are a pair of shafts driven by gears the same size as that on the crankshaft. On in-line engines, the first shaft is the camshaft, the second is the balance shaft. On V-type engines, both are camshafts. The gears on these shafts are counterweighted. Also, on the far end of each shaft is located a counterweight diametrically opposed to the counterweight on the gear. The amount of counterweight of one end should counterbalance that of the other end.

Theoretically, all four ends, gears, and balance weights, should have identical ounce-inch amounts of unbalance. Because these parts (gears and balance weights) are diametrically opposed, the shaft, when assembled, should have no force unbalance, but a desired high couple unbalance.

Therefore, in order to properly balance a Detroit Diesel Series engine, bobweights must be used on the crankshaft, and the counterweighted gears and the counterbalance weights must be balanced on a special fixture. (See Figure 9.)

DETERMINING BOBWEIGHTS

In order to make bobweights for the crankshaft on the Detroit Diesel Series engines, the following weights must be recorded.

Weights from one piston-rod assembly:

Rotating Weight (A)

- Connecting Rod Crank End ______
- Cotter Pins ______
- Set Bearing Inserts ______
- Oil (estimated) ______
- ______
- ROTATING WEIGHT (should be approx. 1460 grams) ______

Reciprocating Weight (B)

- Pin Locks ______
- Connecting Rod Pin End ______
- Piston ______
- Piston Pin ______
- Rings (set) ______
- RECIPROCATING WEIGHT (should be approx. 4421 grams) ______

V-TYPE DETROIT DIESEL 53 SERIES ENGINES

These engines have two piston-connecting rod assemblies per crankshaft throw. The weight of the bobweight will be equal to the rotating weight (found in A above) x two plus the reciprocating weight (found in B above) x two x bobweight %.

The bobweight % is:

V-53 Series = .3025
V-71 Series = .277
V-92 Series = .277

Example: V-71 Series

Rotating weight	1460 x 2	= 2920
Reciprocating weight	4421 x 2 x .277	= 2449
Bobweight Total		= 5369 grams

In-line Type Detroit Diesel Series engines Bobweight = Rotating weight (found in A above).

CRANKSHAFT BALANCING

After the weight of the bobweights has been determined, they should be mounted on the crankshaft. The crankshaft should then be balanced, using the left and right system of balancing to the desired tolerance.

BALANCING COUNTERWEIGHTED GEARS

Balancing of the counterweighted gears and counterbalance weights of the Detroit Diesel Series engines can be accomplished with a balancing adapter, as shown in Figure 9. This adapter consists of an arbor, adapter plate, and hub.

Matchweights are placed at a 6.5-inch radius.

With the adapter balanced, the counterweighted gear should be placed on the adapter and secured to the adapter with a washer and the nut used to hold the gear to the shaft in the engine.

The matchweights and attaching bolt for the balancing procedure can be determined by using the following formula:

$$\text{Matchweight} = \frac{\text{Reciprocating Weight x Z Factor}}{6.5'' \text{ Radius}}$$

The following table lists the Z factors:

Engine	Z factor	Engine	Z factor
2-53	.402	6-71	.621
3-53	.536	6V-71	.444
4-53	.773	*8V-71	.656
6V-53	.370	12V-71	.135
2-71	.513	16V-71	.049
3-71	.545	V-92	N/A
4-71	.797		

Sample calculation:
*Engine Model No - 8V-71
Reciprocating weight from one piston & pin assembly (see page 5) 4421 Grams

Formula:

$$\text{Matchweight} = \frac{\text{Reciprocating Weight x .656}}{6.5}$$

$$= \frac{4421 \text{ x } .656}{6.5} = {**}446 \text{ grams}$$

**Made up of Matchweight, bolt & nut

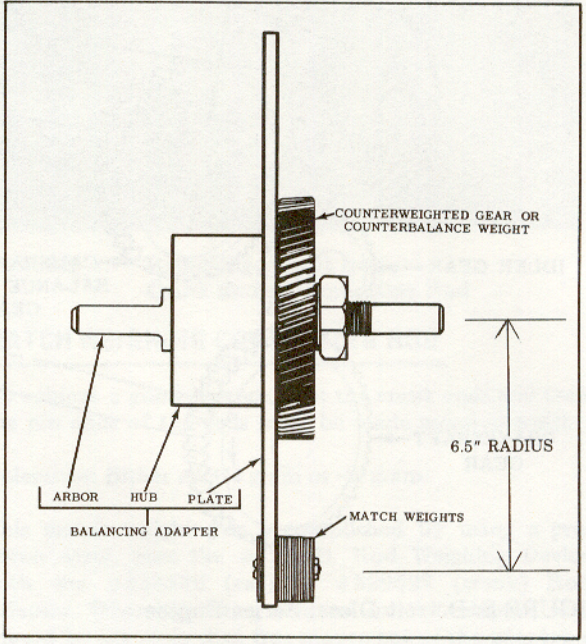

FIGURE 9: Counterweighted Gear and Matchweights on Balancing Fixture

BALANCING THE COUNTERBALANCE WEIGHT

On shafts with removable counterbalance weights the counterbalance weight is balanced with the same procedure as that used for the counterweighted gear. Use the same balancing adaptor and matchweight as was used to balance the counterweighted gear. Corrections for unbalance should be made by removing or adding weight to the counterbalance weight.

Those shafts without removable counterbalance weights will need to be static balanced once the counterweighted gears have been balanced. Mount the balanced gear onto the shaft. Make necessary corrections on the counterbalance weight to static balance the assembly.

All four components, two counterweighted gears and two counterbalance weights, should be equal in weight when this procedure is followed. This reduces the "force" (static) unbalance but puts in a desired "couple" unbalance based on a proportional amount of the reciprocating weight of that particular engine.