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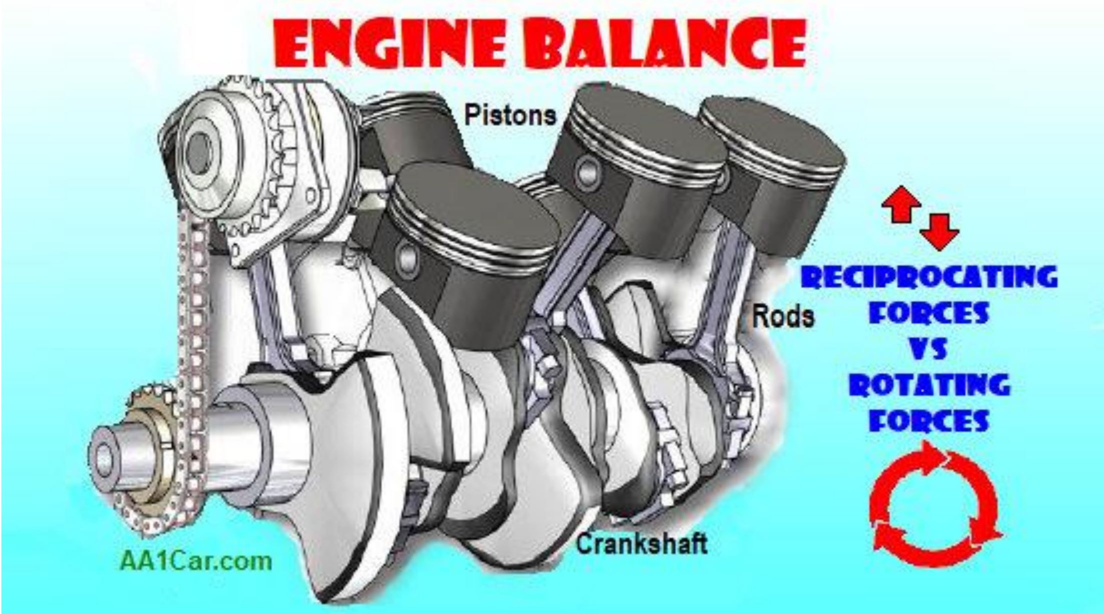

engine Balancing

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You have probably heard that engine balancing is a good thing because it improves engine smoothness and longevity. All engines are balanced from the factory, but some are balanced to much tighter tolerances than others, especially high revving performance engines. Balance is critical in a high revving engine because the forces generated by any imbalance multiply exponentially as engine speed goes up. Over time, these forces can shorten the life of the main and rod bearings, and the crankshaft itself. Vibrations can lead to metal fatigue, and eventually a broken crankshaft.

The reasons why internal combustion engines (both gasoline and diesel) need to be balanced is because they have ROTATING and RECIPROCATING parts. Rotating parts spin around and around, often at extremely high speeds while reciprocating parts move up and down also at high speeds.

ROTATING ENGINE PARTS

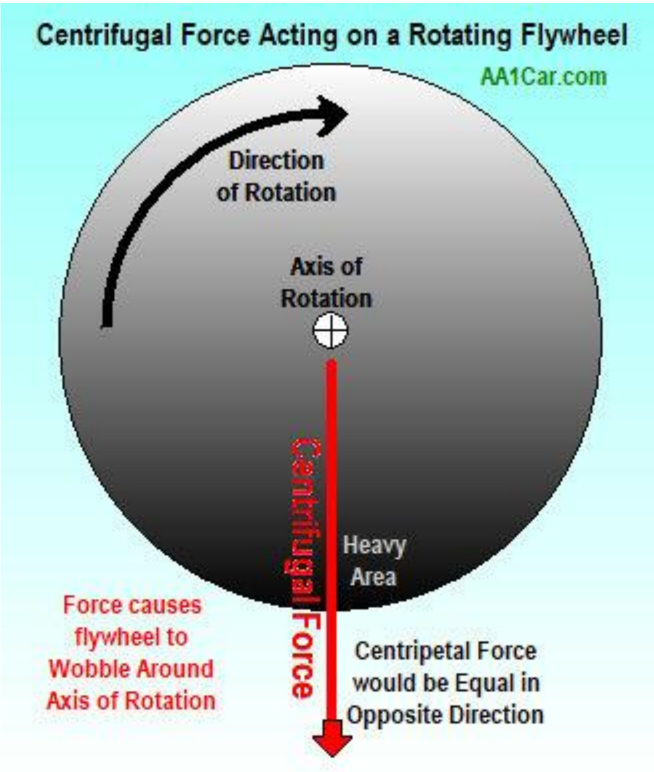
The main rotating parts in an engine are the crankshaft, flywheel, harmonic balancer and crank pulley. The camshaft(s) also rotate but turn at HALF the speed of the crank so any imbalance in a camshaft has much less effect on vibration and wear. Also, a camshaft has a relatively small diameter compared to the crankshaft and flywheel, so again any imbalance has much less of an effect.

Imbalance creates the most force and vibration when the extra mass is located further out from the axis of rotation. The further out the weight, the greater the centripetal force it generates as it rotates. This is what causes a part to wobble as it rotates if it is out of balance. Because of this, a relatively large diameter and heavy flywheel that is out of balance will create more vibration than a pulley, harmonic balancer, cam or crank that has an imbalance.

CENTRIPETAL AND CENTRIFUGAL FORCE

The terms "centripetal" and "centrifugal" force are terms that are often used when talking about engine balance. Basically, both forces are created by the inertia and kinetic energy of a rotating object. Tie a rock on the end of a string and spin it around and you will feel the force pulling on the string.

Centrifugal force is the outward pull a rotating mass exerts on a spinning object. The force goes straight out from the axis of rotation. This is the force that causes a crank, flywheel or harmonic balancer to wobble as it rotates.



Centrifugal force equals the mass of the spinning object (or the heavy spot on a crank or flywheel) times the speed of rotation squared divided by the radius or distance from the axis of rotation.

Force = mass x (speed of rotation squared divided by radius of rotation)

A crankshaft with only two ounce-inches of imbalance at 2,000 RPM will experience a vibrational force of 14.2 lbs. At 4,000 RPM, the force grows to 56.8 lbs. Double the speed again to 8,000 RPM and the force grows exponentially to 227.2 lbs.! That's a lot of force jerking sideways on a crankshaft. The flexing eventually causes metal fatigue, cracking and crankshaft failure.

Centripetal force, by comparison, is the force that prevents the rotating mass from flying off on a path of its own. It is an inward force that offsets the centrifugal force.

RECIPROCATING ENGINE PARTS

The reciprocating parts inside an engine that have the most effect on balance are the pistons and connecting rods. Other parts also reciprocate such as the valve lifters, pushrods, rockers and valves, but any imbalance in these parts have almost no impact on vibration or durability. Why? Because like the camshaft, the valvetrain reciprocates at HALF the rotational speed of the crankshaft. Also, the individual parts are relatively small and very light weight compared to the mass of the spinning crank and flywheel.

When an engine balanced, the pistons, wrist pins, piston rings and upper portions of the connecting rods are all weighed to calculate reciprocating weight. The weights of the large ends of the connecting rods and the rod bearings, on the other hand, are calculated as part of the rotating weight.

Most crankshafts have large COUNTERWEIGHTS as part of the casting or forging. The purpose of these large counterweights is to offset the vibrations crated by the reciprocating weight of the upper rods, wrist pins, pistons and piston rings. As the crank spins around, the location of the counterweights are such that they generate their own centripetal forces to offset or balance the forces generated by the pistons moving up and down. It the engine is accurately balanced, one will perfectly offset the other and there will be minimal or no vibration.

HOW ENGINE BALANCE IS ACHIEVED

The basic procedure for balancing an engine starts by weighing all of the reciprocating components (small ends of the connecting rods, pistons, wrist pins and piston rings) on a highly accurate digital gram scale. Once all the weights of the individual components have been recorded, the parts that are the lightest are identified. The similar parts are then ground or machined to match the weight of the lightest part. The idea is to end up with all of the pistons having the same exact weight, and all of the rods having the same exhaust weight (all big ends the same, and all small ends the same).

Factory mass produced engines parts are approximately weight matched, but how closely a set of pistons or rods actually match the same weight will vary with the manufacturer and the application. For a low revving engine, closely matching the weights of the pistons and rods is less critical than matching piston and rod weights in a high revving engine or a racing engine.

For good balance, pistons and rods are typically match weighted to plus or minus 2 grams. One gram is 1/28th of an ounce, or roughly the same weight as a dollar bill. The closer the match, the better.

The next step depends on the type of engine (inline, V-block or horizontally opposed) and the type of crankshaft. In a straight inline four or six cylinder engine, the next step would be to mount the crankshaft in a balancing machine and spin it to identify any rotating imbalance. The sensors and hardware in an engine balancing machine will pinpoint the location and amount of imbalance so corrections can be made by removing metal from the crankshaft counterweights, or in some cases by adding weights to offset the imbalance.

If a crank has a heavy spot, weight is usually removed by drilling holes in the counterweight(s) near the heavy spot. Or, the outside diameter of the counterweight(s) can be machined down on a lathe as needed to remove the heavy spot.

If a crank needs weight added in an area to achieve balance, this is done by drilling a hole in the counterweight(s) near the light area, then inserting a plug of heavy metal called Mallory metal. Mallory is a 90 percent tungsten alloy that has a density twice that of steel.

Another factor that has to be considered when an engine is balanced is how it is balanced. Many engines are Internally Balanced, which means all of the balancing depends on the crankshaft counterweights. Consequently, only the crank needs to be spun on a balancing machine to identify any imbalances that would cause vibrations.

Other engines are Externally Balanced, which means the balance of the crank also depends on the combined balance of the crank, flywheel and harmonic balancer. Consequently, an externally balanced crank must be spun with the flywheel (or flexplate if the engine is mated to an automatic transmission) and harmonic balancer attached to the crank. Any corrections that are needed may involve drilling holes or adding Mallory not only to the crank counterweights, but also the flywheel and/or harmonic balancer. It depends on the location of a heavy spot and the easiest way to correct it.

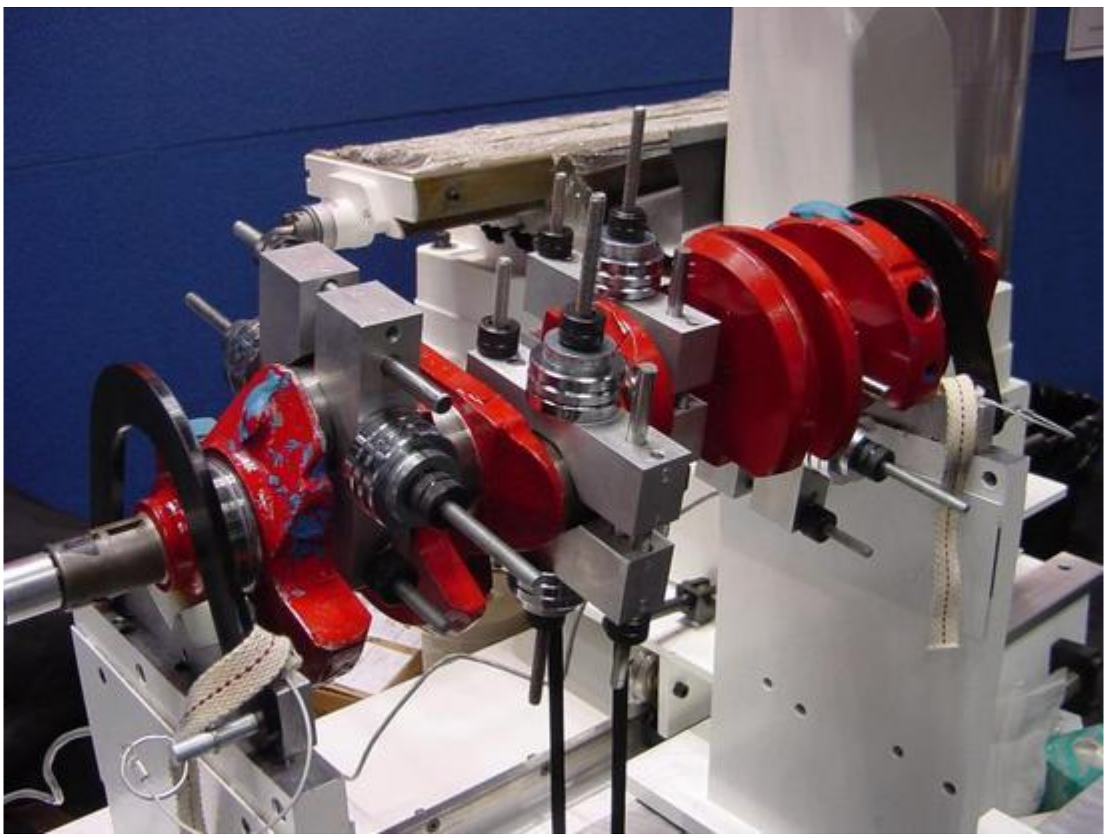
BOBWEIGHTS

Before a crank is spun on a balancing machine, Bobweights are attached to the rod journals on a crankshaft to simulate the rotating and reciprocating mass of the rods and pistons on a V6 or V8 engine. Bobweights are made by stacking weighted shims together and then clamping the bobweights on the crank journals.

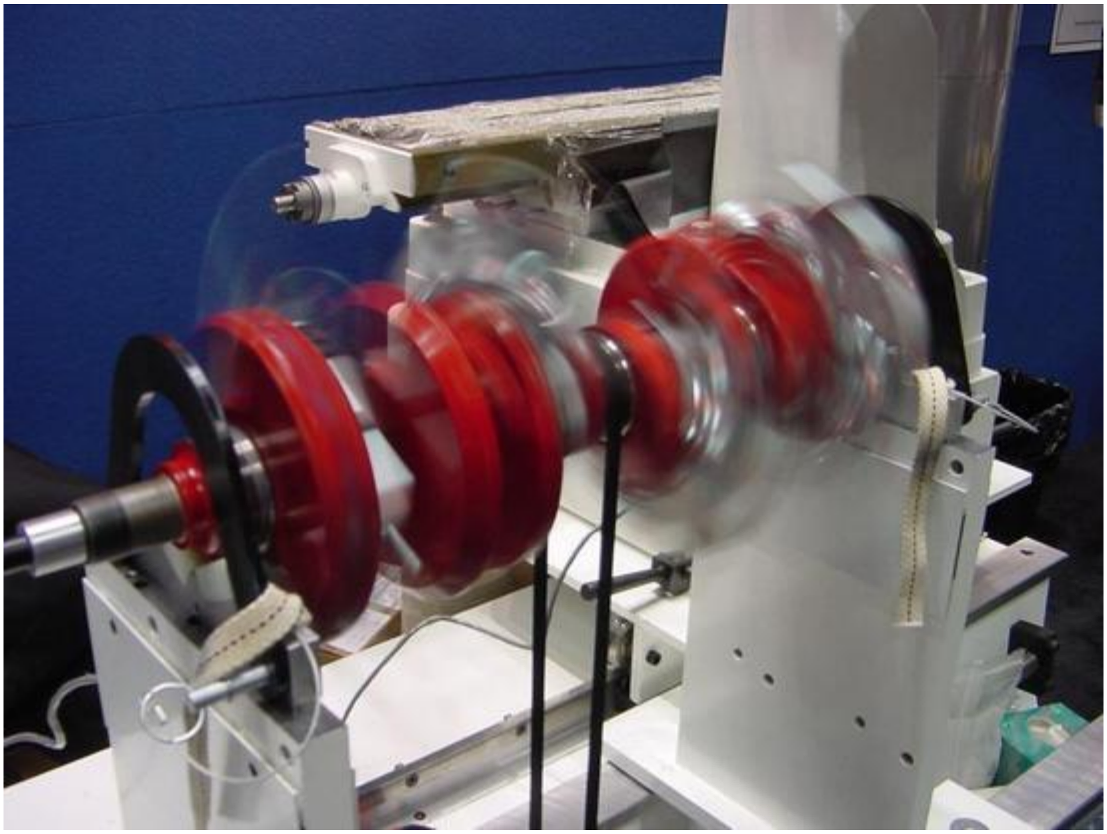
Bobweights are not usually necessary when balancing a flat plane four cylinder crank because the rod journals are positioned 180 degrees apart. This arrangement produces reciprocating forces that naturally offset and cancel each other. The same applies to “boxer” style engines such as Subaru or Porsche where the pistons are positioned horizontally to each other on opposites of the crankshaft. The forces generated by the motions of the opposing pistons offset and cancel each other (assuming they are all close to the same weight).

Bobweights are assembled to equal 100 percent of the rotating weight (big ends of the rods and rod bearings) and 50 percent of the reciprocating weight (small ends of the rods, plus the pistons, wrist pins and piston rings), plus an extra 4 grams for oil.

For high revving performance engines (7000+ RPM), some experts recommend increasing the reciprocating weight amount to 53 percent, or as much as 55 percent if an engine will see the high side of 9000 RPM. This is called “overbalancing” the engine to compensate for combustion forces that can create imbalances of their own.



Bobweights that equal the reciprocating weight of the upper rods and pistons are assembled and mounted on the crankshaft rod journals.



The crankshaft is then spun while sensors on the balancing machine detect vibrations. The software in the balancer calculates where the imbalance is and how much it is so corrections can be made. A second spin after corrections have been made will verify the crank is balanced.

HOW ACCURATE DOES BALANCE HAVE TO BE?

On a typical gasoline four cylinder, straight six, V6 or V8 engine, the factory balance should be one ounce-inch (28.35 grams) or less. Many late model engines are balanced to even closer tolerances: ½ inch-ounce (14 grams) or even ¼ inch ounce (7 grams).

With low revving diesel engines, crankshaft balance is far less important because of the lower RPMs at which these engines typically operate. An imbalance will have less effect on the crank and engine smoothness. Even so, for big heavy-duty truck diesel engines that are built to last many hundreds of thousands of miles, even a little imbalance can take a toll over time.

One ounce-inch means there is one ounce of imbalance one inch from the center of the crank.

For a high revving performance engine, the less imbalance the better. Many of these engines are balanced down to 2 grams or less!

Factory balance tolerances can usually be achieved by spinning the crank once, then making any corrections that are needed, then spinning the crank a second time to verify the corrections fixed the imbalance. But achieving an even more precise level of imbalance requires making multiple spins, corrections and rechecks until the crank is as good as it is going to get. All balance machines have a small margin of error (about half a gram) so there is a limit as to how close to zero imbalance you can get.

REPLACING ENGINE PARTS CHANGES BALANCE

If you are rebuilding an engine and replace one or more pistons or rods with new parts, or replace the crankshaft with another stock crank or a longer stroker crank, the original balance will be lost and all the major the parts should be match weighed and rebalanced to minimize vibrations.

Some aftermarket performance cranks kits are prebalanced with weight matched rods and pistons. This makes engine assembly faster and easier because you don't need the services of a machine shop to balance the parts.

ENGINE VIBRATIONS

If you have an engine vibration problem, chances are it has nothing to do with internal balance but is more likely the result of a broken or collapsed motor mount, or or transmission or transaxle mount. Noticeable vibrations at idle almost always indicate a bad motor mount.

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