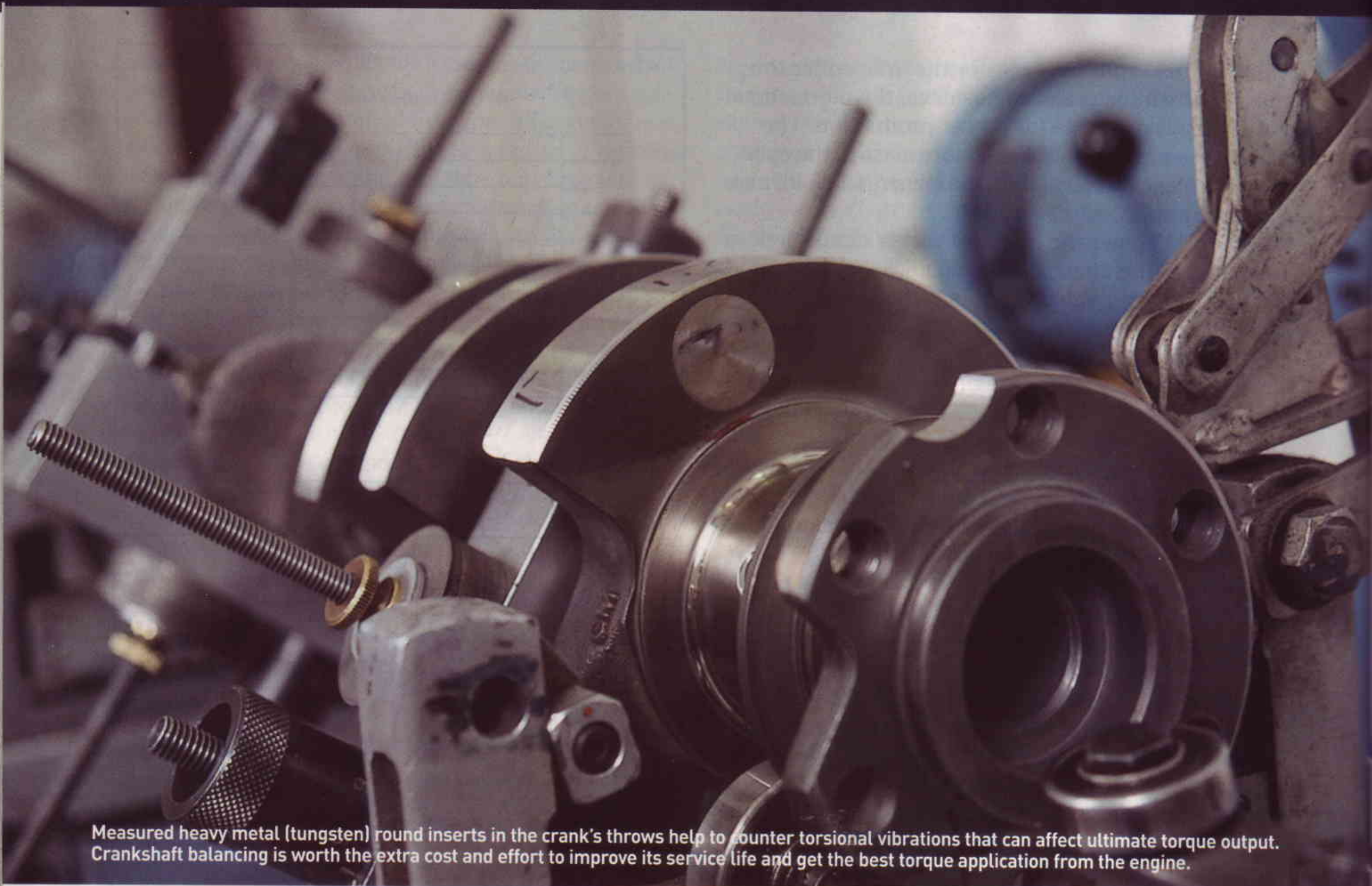


Measured heavy metal (tungsten) round inserts in the crank's throws help to counter torsional vibrations that can affect ultimate torque output. Crankshaft balancing is worth the extra cost and effort to improve its service life and get the best torque application from the engine.

LET'S TORQUE ABOUT CRANKSHAFTS

WHEN STEEL ACTS LIKE RUBBER

TEXT BY JIM MCFARLAND

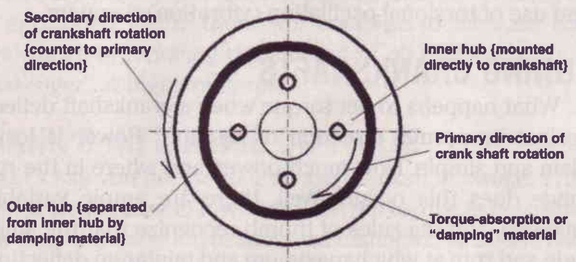
Converting cylinder pressure to crankshaft torque, particularly since these pressures produce intermittent loads, involves a complex set of problems. Too often, it seems we become laced into concerns for crankshaft weight, durability, and balance. Think of this component as a flexible part. As cylinder pressure creates intermittent torsional loads in a crankshaft, there is evidence of continual elasticity within the part—steel begins to act like rubber.

Even though pistons and connecting rods tend to become shock absorbers to these loads, radial deflection (both positive and negative) leads to oscillations created about the crank's axis of rotation. For now, it's important to recognize that crankshafts, as a function of torque produced, tend to become "rubber" in the manner by which reciprocating motion is converted into rotary motion. Crankshafts can have influence on such variables as valve timing, intake manifold selection, and header sizing.

WHAT IS TORQUE?

Torque is the result of a force being applied on an object at some distance from its axis of rotation. If we allow torque to act during a period of time, we observe horsepower. Crankshafts make torque. Cylinder pressure causes torque to be made. In the case of engines, for the most part, how much torque is made depends upon cylinder pressure and the distance from crankshaft axis of rotation to the point of applied force—cylinder pressure acting on a piston/rod assembly. Crankshaft stroke plays a part in this factor. In

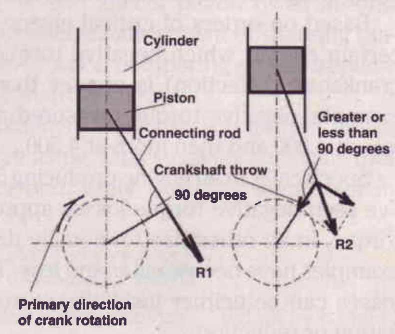
Illustration of Torsional Force/Absorption Characteristics of a Torsional Vibration Damper



NOTE: While this illustration depicts a "conventional" style of crankshaft torsional vibration damper, the functional impact of the damping material can be performed by other means that include fluid couplers, friction discs or other load absorbing/damping mechanisms.

Illustration of Torque Loading on Typical Crankshaft Rod Pin

NOTE: This illustration shows some of the torque load relationships in a typical crank/rod assembly. R1 represents maximum load or torque delivery at an angle of 90 degrees. At angles greater or less than this value, the resultant R2 is composed to two corresponding loads that place forces along the axis of the crankshaft throw. As crank throws are made shorter or longer, piston position at maximum load delivery changes. This is an area mentioned in the story. Companion parts modifications (camshaft, intake, manifold, etc.) can be matched to stroke changes.



other words, the longer the stroke, the greater the distance from the axis of crank rotation, and the more torque produced. Long-stroke engines make more torque at lower rpm than shorter-stroke ones, right?

Now, while this may appear oversimplified, it's important to understand how a crankshaft reacts to torque and the influence this reaction can have on other engine parts and functions.

CRANK MATERIALS AND CONSTRUCTION

Essentially, the range of crankshaft materials runs as follows: billet steel, steel forgings, cast steel, nodular iron, malleable steel or (in some cases) cast iron. If we were to produce one crankshaft design and reproduce it in all these materials, the order of strength would approximately follow the same list. While cast cranks are typically less expensive than forgings, they can be produced in shapes not available with forgings.

The configuration of fillet radii is often a subject of discussion and frequently believed to be critical in the design, modification, and service life of a crankshaft. If we were to perform a stress analysis test that included all other design features and conditions of a given crankshaft, fillet radii could be considered the most critical factor in overall design and/or modification procedure. There is belief among crankshaft manufacturers that the use of fillets of non-constant radius—sometimes called non-circular contours—is preferred over those of constant radius. This is an area worth discussing with your engine builder or crankshaft manufacturer of choice.

LIGHTWEIGHT VS. HEAVYWEIGHT ROTATING MASS

Let's talk about transient torque. For purposes of this discussion, transient torque is a measure of how quickly an engine can accelerate (including under load) through its useful rpm range. Stated another way, how fast an engine will span from low to high rpm under sudden conditions of WOT. From a measurement standpoint, this is torque as measured on an inertia dyno—not a so-called "accel" test as performed on an engine dyno whereby there is a controlled unloading of the power absorption unit. This is "real-to-the-track" torque, and it relates to an engine's ability to overcome its internal resistance (inertia) to gaining rpm.

Based on these considerations, it is fair to say crankshafts don't normally operate at constant rpm. They're either accelerating or decelerating. Their resistance, in either case, includes static weight and dimensional landscape (stroke length, location and distribution of mass, and so on). Technically speaking, in a dynamic environment, crankshafts are continually changing potential energy into kinetic energy. These are all factors that go right to the issue of how much torque is available at the output end of a crankshaft—they need to be considered for power optimization.

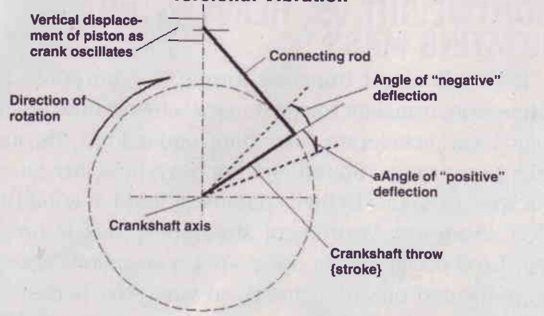
From a practical standpoint, acceleration of a heavy crankshaft absorbs more torque than one of less weight, thereby reducing the amount of net torque available to accelerate the car. But there are trade-offs in terms of durability, flexibility, and potential longevity that should be considered when trimming crankshaft weight. Furthermore, it's not all about weight. Placement of weight, relative to a crank's axis of rotation, is also important. For example, the moment of inertia (resistance to a change in state of rotation or acceleration/deceleration) increases as weight is moved away from the axis of rotation. Even between two crankshafts of the same total static weight, the one with more weight near its axis of rotation will exhibit less resistance to a change in rotational speed; it has a lower moment of inertia. Keep this in mind when adding heavy metal to crankshaft counterweights during the process of dynamic balancing.

Finally, where total crankshaft weight relates to overall flexibility, it's best to err on the side of stiffness if this may be accomplished by selecting a crank that trends toward stiffness in combination with durability and light weight.

TORSIONAL VIBRATION AND DAMPING

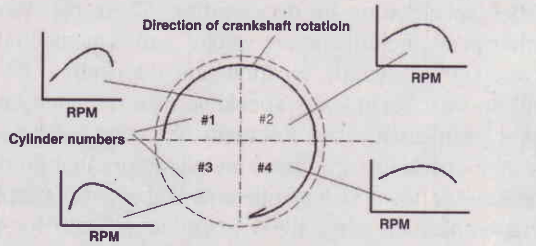
Visualize a single-cylinder engine running in very slow motion. Upon a rapid increase in cylinder pressure, quick application of force is applied to the crankshaft. The throw connected to the piston/rod assembly is deflected in the direction of crank rotation. Stated another way, it gets a "kick in the butt" that amounts to an increase in crankshaft rotational acceleration. In so doing, the crankshaft's throw acts somewhat like a spring in that once its maximum

Illustration of Crankshaft Throw Deflection from Torsional Vibration



NOTE: Use of torsional vibration dampers is intended to minimize crankshaft oscillation throughout rpm range. Negative torque values can approach six to eight percent of positive values.

Illustration of How Individual Cylinder Torque May Vary as a Function of Crankshaft Throw Oscillation



NOTE: Cylinders shown are not in any given firing order. The purpose of this illustration is to show how cylinder-to-cylinder torque output can vary as a function of crankshaft deflection. Graphs are only to illustrate the point. In reality, specific torque values can be determined by several methods, including the use of Engine Cycle Analysis where individual cylinder performance is measured by in-cylinder pressure analysis.

deflection is reached, elasticity of the crankshaft material causes the throw to act against the load that caused its acceleration increase.

Until the next firing cycle and subsequent load on the crankshaft throw, this action and reaction condition continues as an oscillation of the crankshaft throw, even though the crank is in rotational motion. Note the accompanying illustration. If you were to view this example crankshaft along its axis of rotation, the oscillation described would appear as clockwise and counter-clockwise movement of the crank throw, all during normal rotation of the shaft.

Now, transfer this image to a multi-cylinder engine. Since the delivery of each firing impulse causes its respective crankshaft throw to experience torsional oscillation (or vibration), imagine the interaction of these pulses along the length of a crank and you begin to realize the complexity of the overall system. Moreover, since all the pistons are tied to this oscillating crankshaft, interruptions in smooth piston movement result. Plus, if the engine has a carburetor, we have now linked a torsionally vibrating crankshaft to fuel delivery and the corresponding effect this can have on carburetor calibration and power.

Further, if piston motion has been interrupted and is no longer directly coordinated with specific crankshaft angularity position, is it not reasonable to assume the relationship between valve timing and piston position as been upset? Well, it can be. Notwithstanding the fact that camshaft timing chains or gear sets become shock absorbers to the torsional oscillation of crankshafts, it's possible to address this problem by the proper selection and use of torsional oscillation (vibration) dampers.

TUNING CRANKSHAFTS

What happens to net torque when a crankshaft deflects against its normal direction of rotation? Power is lost—plain and simple. How much power, and where in the rpm range does this occur? Well, there are ample variables involved, and the rules of thumb recognize that the amplitude and rpm at which maximum and minimum deflections (and power losses) occur varies and include the following: the level of power produced, range of rpm, dynamic properties of the engine's rotating and reciprocating assembly, static weight of the moving parts, and other factors.

Based on orders of critical engine speed, there will be certain rpm at which negative torque (counter-rotational crankshaft deflection) is greater than at other rpm. For example, negative torque measured at 3,500 rpm may be less at 4,000 and then more at 4,500.

Specifically, in an engine producing 540 shaft horsepower, I've seen negative torque losses approaching 35-40 lb-ft of torque, in an otherwise torsionally damped engine. Other examples have been greater and less. The point is that such losses can be neither insignificant nor unworthy of elimination or reduction.

Because the engine speed and extent of power loss vary, can crankshafts and dampers be tuned to these rpm (or frequencies)? The answer is yes. From a practical standpoint, damper tuning is often more easily accomplished than crank tuning—unless, of course, you're an accomplished engine balancer. Know the range of rpm where the engine will spend most of its on-track time and then target the damper selection accordingly. If you have difficulty obtaining this type of information from your choice of damper manufacturer, be persistent. You will likely come away from the experience with the following: 1) the correct part, 2) an urging that this is unimportant information, 3) it can't be done, or 4) don't split horsepower hairs to this extent. If you're trying to increase parts life and make more power, opt to accomplish point #1.

CRANKSHAFTS AND WINDAGE

Even the use of dry-sump oiling systems does not prevent crankshafts from being influenced by the migration of engine oil from the crankcase to the pan. It's a given that oil will become attached to a spinning crankshaft, adding to its dynamic weight and inertial resistance. In fact, high-speed photography reveals that the oil can look like toffee rope wrapped around the spinning crankshaft. By the use of various oil pan devices, attached oil can be physically removed from crankshaft surfaces. Since tapered edges tend to release/shed oil more easily than "squared off" portions, the shaping of counterweights is another common method of addressing the problem. Special coatings of the type that reduce surface tension, applied to crank throws and counterweights, can also be used. But in any event, assume that oil passing by the crankshaft and pulses of air created by rapidly descending pistons and the volume of air entrapped inside them will combine to increase the importance of reducing the amount of oil that becomes a "passenger" at high crank rpm.

CRANK'S INFLUENCE ON PARTS

Let's say you decide to increase crankshaft stroke. This implies an increase in low- and mid-rpm torque is desirable as well as the selection of an intake manifold, camshaft, and header system that favors torque output in the same range of engine speed. Similar to events from lengthening connecting rods (all else being equal), a stroke increase changes the rate at which intake flow velocities are created (versus crank angle). It also affects piston dwell around TDC and BDC. This suggests an adjustment of sparking timing (at least initial spark) when comparing engine applications of a stroked and unstroked crank.

Maybe you've decided to decrease the inertial resistance of the crank you're using. That suggests an engine that will accelerate quicker and, likely, one that would benefit from an increase in compression ratio. Short of performing single-cylinder dynamic pressure analysis as a function of crank angle (perhaps with Engine Cycle Analysis or comparable in-cylinder measurements), it's possible to recoup some power lost to retarded rear cylinders by juggling rocker ratios that serve them. Consider what you'd do to improve higher rpm power with valve timing that is retarded—maybe have a ratio that is a shade higher for an initial test.

It's safe to assume, although you may not know the exact amount of crankshaft deflection (front to rear), that an engine's rear cylinders are running slower than those in the front. Depending upon how much deflection is occurring, rearward cylinders may be running in a retarded position relative to those in front. Some adjustment to spark timing to these cylinders can be helpful. Camshafts also deflect, so this condition of retard can result from a stacking of events from deflection in both cam and crank. To help minimize this problem, reducing the amount (frequency and amplitude) of crankshaft deflection by the sensible use of a torsional vibration damper is mandatory to extending parts life and optimizing power. **EM**

CAMSHAFT SELECTION

Dennis Wells of Wells Racing Engines often brings practical and valuable insight to the weekly circle tracker. I asked him to expand on points about crankshaft selection.

Why do you think crankshaft balancing is important?

"Clearly, engines need to be balanced during the build-up process. There are dynamic forces that exist in a running engine that probably exceed what many of us might think. Here's an example of forces applied on the crankshaft. At 4 inches from the crankshaft's axis and with 28 grams of unbalance, there's 112 pounds of force at 4,000 rpm. This increases to 448 pounds at 8,000 rpm!"

How important do you consider crankshaft dampers, and why?

"Crankshaft torsional vibration causes crankshaft and flexplate failure, loosened bolts, broken timing chains, and erratic valvetrain and ignition problems. We tested our USAC Silver Crown car on the wheel dyno. We removed an ATI lightweight damper, installed a small aluminum hub, and made five consecutive runs. We saw no horsepower gains. What we discovered when removing the aluminum hub was that the torsional vibration, in only five runs, was so great that the hub was no longer a press fit. It slid off by hand! How much more proof could you want?"

What is your personal choice for torsional dampers, and why?

"The ATI Super Damper. I prefer this unit because you can replace any part that might become worn. They are available with aluminum or steel hubs. We run a steel hub on Silver Crown engines because we crank the engine off the front of the balancer. I have never had a failure out of an ATI damper."

In your opinion, what is the most important consideration when selecting a crankshaft?

"The position of the counterweights, the 'clocking' of the oil holes, the quality of the material, and [the distance of the weight from the centerline]."

Do you have a preference in the type and shape of the fillet radii between bearing surfaces (rods and mains) and flanks?

"I prefer a 0.125-inch radius. Just about all good racing crankshafts have this radius."

What's on your list when it comes to crankshaft installation and maintenance?

"Always inspect a crank closely before performing any machine work. This includes checking straightness, thrust surfaces, checking every journal for taper, size and roundness, confirming the stroke, and passing Magnaflux inspection. Remember, everybody can make a mistake; you just need to catch 'em. It's easier to correct any of these problems before you waste your time balancing, or worse, building the engine and then finding out something is wrong. You must use chamfered bearings on cranks with a radius larger than 0.062 inch. You must 'mic' everything and check every bearing housing for size and roundness."

Any more relevant comments on cranks?

"We do not remove oil pans and only replace the bearings. From years of experience, I've determined this is a bad habit. The reason is bearing housing bores distort to an out-of-round shape. The used bearing distorts with the housing bore, and you have no problem. Then you install a new, round bearing, which doesn't match the distorted housing bore. The new bearing will come in contact with the crankshaft, and you now have an engine failure. Your first thought might be to blame the engine builder or the bearing manufacturer. I've seen a lot of spun bearings in 34 years of building engines, and they are not pretty!"