ENGINE BLUEPRINTING

This term is routinely misused and misunderstood. The goal is to maximize performance and durability.

BY **MIKE MAVRIGIAN**

While seasoned engine builders understand what the term "blueprinting" means, chances are most of their customers don't. Too many neophytes think that balancing and blueprinting go hand-in-hand (they blindly assume that if the crank has been balanced, that must mean that the engine has been blueprinted).

If you scan your local newspaper's automotive classifieds section, you're bound to see three or four ads offering "blueprinted" engines. They may be part of a restored muscle car, or they may be offered alone, but nonetheless, there they are, in black and white.

In 99% of the cases, the ads are probably wrong. We're not implying that 99% of the folks who placed the ads are lying. Instead, these folks are generally misguided. A blueprinted engine represents an enormous amount of highly skilled labor, usually far beyond the average enthusiast's understanding or budget. Just as the term "turbocharged" has been abused (turbo sunglasses, turbocharged golf balls, etc.), such is the case with engine blueprinting.

Some enthusiasts consider an engine that's been treated to a rebuild and balance as "blueprinted" (their outlook may be that since they paid $2,000 or so for the rebuild, they're entitled to use any label they deem appropriate in bragging about that particular motor, especially at the time of sale).

Engine blueprinting involves a specific list of specialty work that, in a nutshell, vastly increases the efficiency of an engine.

The typical production engine represents a combination of cast, forged and machined components assembled in mass quantities, sometimes adhering to only the broadest interpretation of the original design spec. While the design of a small-block V8 may call for a perfectly identical dimension from the crank centerline to the deck surfaces along the entire length of each deck, mass-production reality often dictates that vague proximity is close enough. While, in theory, all lifter bores in a OHV V-block should be perfectly spaced center-to-center and aligned to a specific centerline location relative to the cam lobes, again the close-enough reality takes precedence at the OE level.

Automakers have good intentions. They'd love to produce a perfect on-spec engine for every vehicle it creates. But, since tolerances exist due to the inherent dulling of milling bits, wearout of abrasive stones and wear and calibration of machining equipment, the engine manufacturer must, out of necessity, expect a range of the design specifications. While some automakers are better at maintaining proximity to the intended spec that others, every carmaker must accept the reality of the situation. Building a "perfect" engine on a production basis is a very hard nut to crunch.

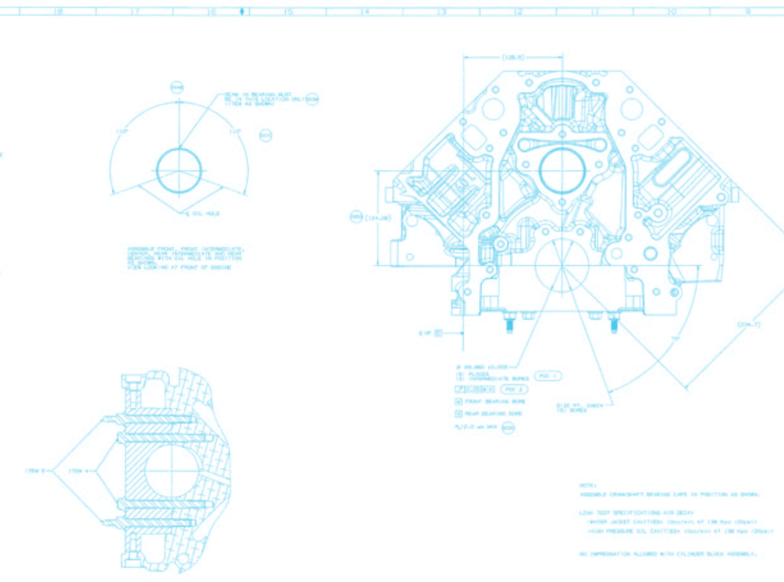
In the blueprinting program, our intent is to correct all of the large and small discrepancies within the entire scope of the engine assembly in an effort to arrive, as closely as possible, at a zero-resistance machine. This is no easy task, but it is approachable.

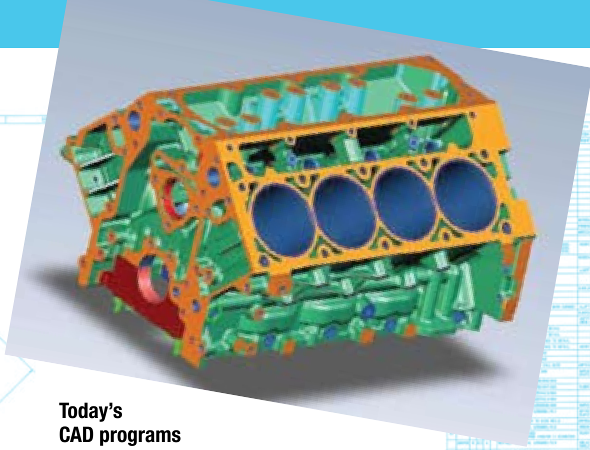
Blueprinting can, but does not necessarily mean that we'll pursue the "factory" spec. Rather, it means that we'll pursue the most efficient operation for the engine in question. In some cases, that may be the OE spec, while in others, a newly-developed spec may be more sensible.

Target Areas

(where corrective areas are addressed)

- Quality-selection of the appropriate parts (block, heads, etc.)
- Positioning and alignment of the main bores, in every axis, relative to the block casting as a whole.
- Correction of the crankshaft's main journal alignment and spacing, end-play, rod journal alignment and spacing, stroke throw length and clock-position of each throw (angularity of the rod throws)
- Size and alignment of each cylinder bore, relative to the corrected centerline of the crankshaft
- The plane and height of each deck, relative to the corrected centerline of the crankshaft
- Correction of dynamic balance
- Diameter sizing of main and rod journals
- Bore sizing and equalization of each connecting rod, in terms of center-to-center length, squareness and balance
- Piston skirt sizing, pin centerline to dome verification and weight equalization
- Camshaft check/correction for shaft straightness, alignment, lobe spacing, clock position, ramp angles, lift heights, etc.
- Inspection of pushrods, lifters, for length, diameter
- Inspection and equalization of cylinder head combustion chamber volume





Today's CAD programs offer definitive X, Y and Z axis depictions of specific blocks (providing you have access to these programs).

Blueprint specifications (shown here is a GM LS block) include all dimensional aspects of a component per the design parameters.

Block manufacturers such as Dart provide blocks that are already correct, in terms of bore centerlines and deck dimensions and planes. When dealing with such high quality aftermarket blocks, only finish machining to achieve desired clearances is needed. In essence such blocks are already "blueprinted" in terms of crank centerline, cam bore location, cylinder bore and lifter bore centerlines and angles and deck symmetry and height.

Measure each piston skirt diameter and record. This allows you to custom-hone each cylinder bore (if needed) to maintain consistent clearances.

(modifications to chamber and/or dome required to achieve a specific total volume and compression ratio)

- Possible equalization of all intake valve and exhaust valve stem lengths, head diameters, weight
- Achieving a specific (and equal) valve seating depth at each valve
- Centerline positioning, aligning and sizing each valve guide
- Achieving desired valve seat pressure
- Checking/achieving specific valvetrain geometry
- Improving efficiency of oiling system and cooling system
- Flaw inspection and strength improvement of all parts
- Checking all operation clearances (piston skirt to crank counterweights, piston to wall, etc.)
- Checking and achieving a specific desired compression ratio
- Alignment of intake ports (head to manifold)

You can summarize the above list in one simple sentence. Never assume that any part is dimensionally exact to its design. Understand exactly what is required (the goal) in each and every component, and use the appropriate specialty fixtures and quality machinery to achieve that goal.

In a sense, you're starting over from scratch, sometimes using the core materials that are available. Measure everything and assume nothing. Modify each part to arrive at your theoretical goal, instead of allowing an existing block or crank to dictate the quality of the assembly. Treat each part as "raw," accepting the fact that you've only been given a starting point. For instance, inspect all connecting rods (new or used) for center-to-center length. If you find one or more rods that are shorter than the spec, those rods may need to be replaced. The goal is to achieve a set of rods that precisely match in terms of center-to-center length. If you can adopt that outlook, you can blueprint an engine. If you automatically assume that the automaker cast and machined a perfect block, or that a new set of components are dimensionally correct and match, you're out of the game.

There are two practical reality levels of blueprinting. At the light end, you can correct the major areas: create a centered, aligned home for the crank; make sure the crank dimensions are correct; square the block decks and equalize their plane relative to the crank; match-balance the rods and pistons and balance the crank; correct lifter bore alignment; and equalize the heads' combustion chambers. At the heavy end, you can nit-pick every dimension of every part, every bolt and every gasket. The heavy approach will apply only to the well-funded crowd.

While the procedure of blueprinting is an exact science, the approach may not be. Blueprinting is an ever-evolving realm, where new and beneficial discoveries are taking place every day. In the grand effort to perfect the operation of the internal combustion engine, the "blueprinter" must keep an open mind.

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The use of a CNC machine (pictured right) makes life so much easier in terms of accurizing a block. BELOW: Indexing bars in the main and cam bores allows easy referencing of these centerlines.

Part Selection

A successful blueprint job is reliant on not only the corrective work involved, but the initial selection of each part in the very beginning. Naturally, since the goal is to create a maximum-efficiency motor, we want to avoid the use of inferior parts from the outset.

Towards this end, a strict program of flaw detection is mandatory. Each and every part should be flaw-checked and inspected. The block must be checked for cracks and for cylinder wall thickness (use a sonic gauge for easy and reliable measurement of metal thickness), the crank and the connecting rods should be wet mag checked, and cylinder heads should be pressure-tested, at the very least.

It just doesn't make sense to invest time and money in a part that you don't know anything about. Your first order of business should be to weed out any potentially flawed parts before you begin the task of precision machining.

Also, choose the appropriate type of part for each situation. Consider the use of cast, versus forged, versus billet parts. Depending on the situation, the selection of an inherently stronger version of a part can dictate the difference between long-term success and short-term disaster.

In other words, invest some thought into the selection of parts that will be used. Blueprinting is time-consuming, and it makes sense to use only the components that are appropriate for the application.

Examples of Per-Component Tasks

BLOCK

Naturally, perform a flaw detection to check for cracks.

Sonic-check all cylinder walls and record thickness at a minimum of three height locations and at four clock positions, and record the data (this will provide a heads-up prior to overboring).

Inspect and correct (if necessary) every threaded hole in the block for thread integrity and condition.

Align hone the block. This will create the centerline that everything else will reference.

Cut the decks to obtain a square block…where both decks are the same height from the main bore centerline and parallel to the main bore centerline.

Check and correct cylinder bore spacing and angle. If corrections are needed, this will require either an overbore or overbore correction followed by installation of sleeves, resized to original bore diameter (depending on the build plan).

Check and correct camshaft bore centerline if needed (may require the use of oversize-OD cam bearings).

Check and correct all lifter bores for centerline location and angle. Correction may require overboring, installation of bronze liners and resizing for proper lifter clearance.

CRANKSHAFT

Check for flaws (on a used crank), preferably on a magnetic particle station.

Inspect for runout.

Inspect each main and rod journal for diameter, taper and out of round.

Inspect each rod throw for angle.

Correct if needed by grinding and polishing, or selecting another crank.

CONNECTING RODS

Measure center-to-center length of each rod and record the data.

Measure big end diameter (and check for out of round).

Measure pin bore diameter.

Check used rods for flaws (cracks), and for straightness and twist.

Correct any center-to-center deviations by resizing or replacing the rod.(Each rod should feature precisely the same length.)

PISTONS

Measure each for diameter (at the specified location recommended by the piston maker).

Measure the compression distance (center of the pin bore to dome).

Measure each piston's pin bore diameter.

CAMSHAFT

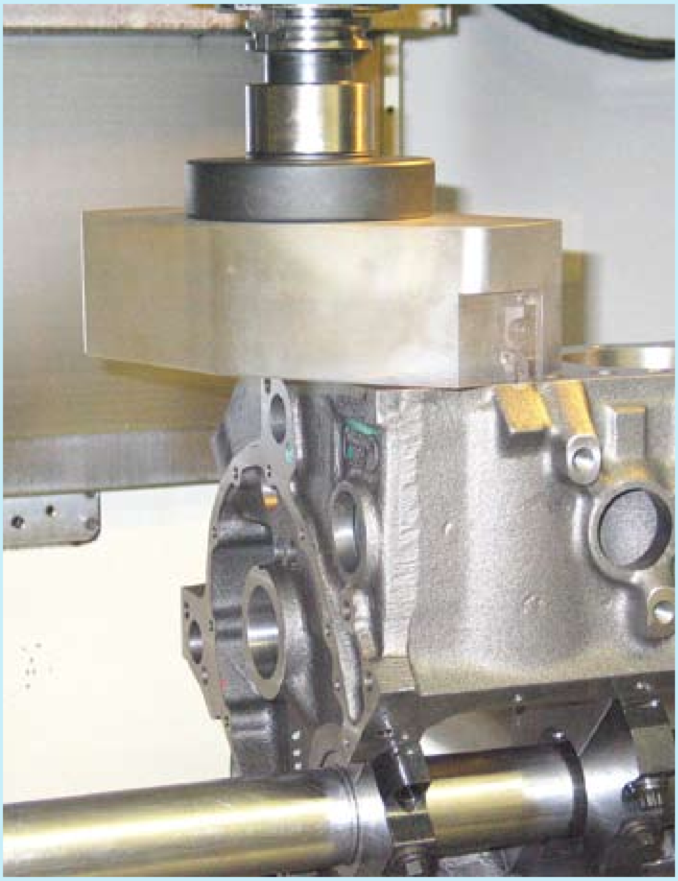
Using a dial indicator stand, check for runout and for lobe height (relative to the base circle).

Perform a degree check during engine test fitting.

Here the CNC probe measures (and records) existing deck surface height and angles.

Here a block is mounted in a CNC machine, ready for measuring and machining.

CNC probing records existing cylinder bore location. This derived dimension can then be compared to design data, instructing the machine to then bore to correct centerline and angle if needed.



Here the CNC surfaces the block. Using pre-measured data, the decks are machined perfectly parallel to the main bore centerline, while correcting any deviations in deck angles. Each deck is also height-matched (with both decks exactly the same distance from the main centerline).

The CNC boring fixture machines each cylinder bore not only to the desired diameter, but corrects any alignment issues as well, in terms of bore centerline location and bore angle.

Today's engine-builder-specific CNC machines offer ready-made programs for machining specific make/model blocks for achieving precise dimensional control.

Lifter bore correction (in terms of centerline location and bore angle) can be accomplished either with a specialty fixture dedicated to a specific block, or via CNC program.

Again, in order to retain consistency, the final-assembly-intended cylinder head fasteners should be used during torque plate installation prior to cylinder bore honing.

Cylinder honing must always be performed with the block "stressed" with torque plates installed to simulate the installed cylinder heads.

The main cap fasteners that will be employed during the final assembly should be used throughout the machining process, from start to finish, to eliminate any potential variables in terms of main web/cap applied stresses.

CYLINDER HEADS

Measure head thickness and compare to spec.

Inspect (used head) for cracks and straightness. Remove all burrs and sharp edges in the combustion chambers and ports. Inspect all threaded holes for condition.

Using a burette, measure the volume of each combustion chamber (with spark plug and valves installed). Record each volume measurement. Using the largest chamber volume as the reference point, polish/grind all other chambers to achieve the same volume as the reference chamber. Depending on your compression requirements, resurface the heads to achieve the desired chamber volume.

Perform a seat and guide check, inspecting for guide diameter, valve concentricity and seat angles as part of your normal cylinder head prep routine.

Obviously, add to this the procedures that you'll routinely follow during cylinder head valve and spring setup. Be sure to check each valve spring for open and closed height/pressure. Replace individual springs if necessary to create a closely matched set.

TEST FIT

Test fit the rotating assembly and dedicate each piston, ring package, lifter and rod per cylinder location. Even though you've corrected the block and all components measure to your spec, take the time to carefully test fit everything. This will provide the opportunity to match each piston, rod, lifter, etc. to the specific location that provides the optimum clearance.

While the rotating assembly is in place, verify each piston's TDC height location and record the data. This will alert you to any areas of concern that may have been missed during previous checks.

Naturally, perform a degree check of the camshaft, and follow your normal checks for intake and exhaust valve clearances, etc.

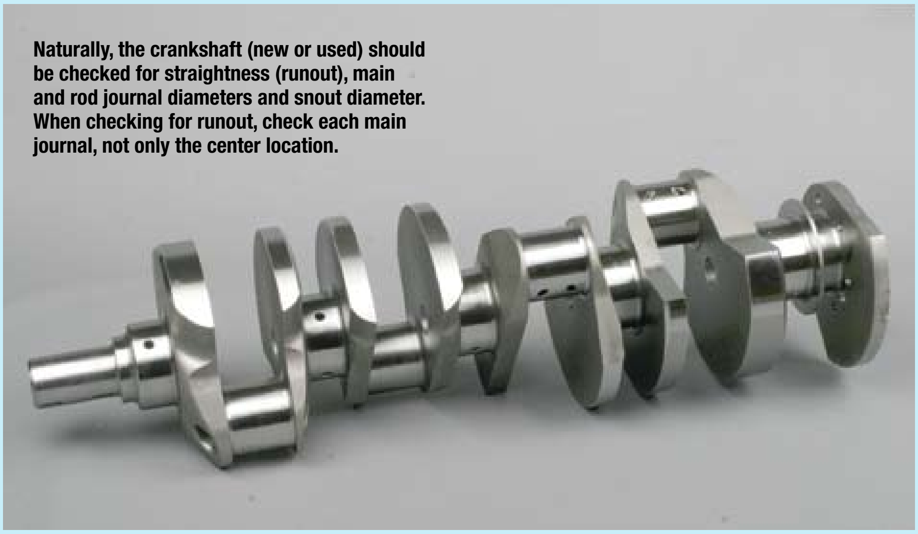
PUSHRODS

Even if the valvetrain theoretically requires "standard" production length pushrods, again, don't assume anything. Test-install the heads (fully torqued to spec, with exactly the type of head gaskets that will be used in final assembly). Using a pushrod checker, individually measure for optimum pushrod length at every intake and exhaust location (don't assume that checking only one intake and exhaust location is sufficient). Record the results, and if necessary, order custom-length pushrods accordingly. Again, what we're trying to accomplish is to greatly minimize or eliminate a "tolerance range." Will this make a difference in the final result? Maybe or maybe-not. The point is to eliminate as many variables (however small) as possible.

BALANCING

The need for this should be obvious. Once all components have been verified for use and all primary machining and fitment has been accomplished, perform the balancing procedure. Instead of weighing only a single piston, a single rod, etc., take the time to weigh each component in order to weight-match all pistons and all rods. Follow basic weight matching guidelines (use the lightest piston as the reference and remove weight from all remaining pistons to match, etc.).

Even when performing an internal balance, don't assume that the zero-balance damper or flywheel is in fact balanced to zero. Spin-balance the



Naturally, the crankshaft (new or used) should be checked for straightness (runout), main and rod journal diameters and snout diameter. When checking for runout, check each main journal, not only the center location.

Checking each main journal diameter and record.

Check each rod journal not only for diameter, but for centerline (stroke) distance relative to the main centerline.

Today's quality aftermarket performance connecting rods are known for exceptional quality control. Regardless, measure each rod for pin bore and big-end bore diameters and center-to-center length.

Once all pistons, rods, rings and bearings have been test fitted and assigned cylinder locations, keep them organized.

Weigh and weight-match all components. Don't assume that all rods, pistons, etc. will be identical.

Measure free-length of each rod bolt as reference, and keep them organized.

If tightening via the stretch method, measure and record each rod bolt's installed length.

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During assembly, use the same cylinder head bolts or studs that were used during cylinder honing.

With valves installed, measure each combustion chamber's volume and record. Remove material from the chamber with the smallest volume to equalize all chambers (if needed).

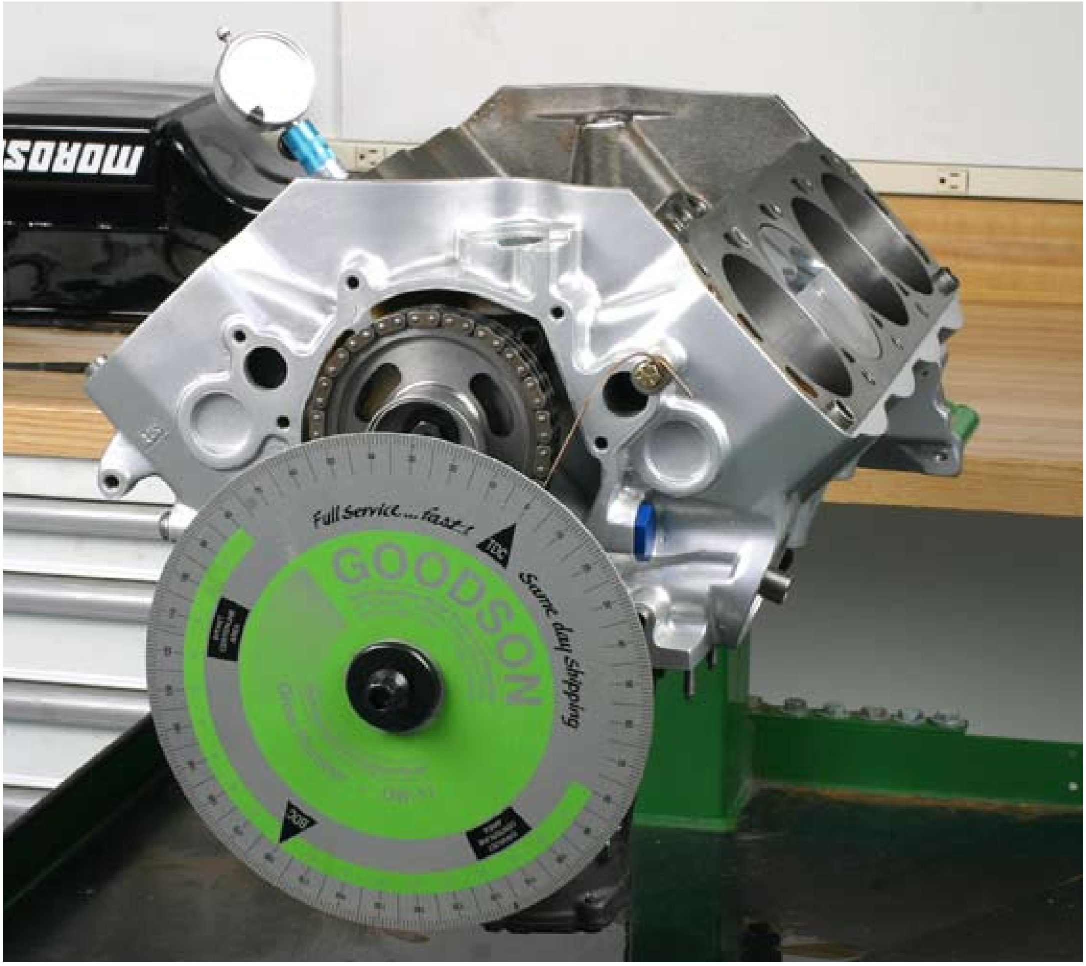
An adjustable checking pushrod is a must to determine specific pushrod lengths for each lifter/ rocker location.

After measuring pushrod length per location, keep the lifters and rockers dedicated to those positions to avoid any variables.

Using dye on valve stem tips, install the rockers and pushrods and roll the engine to check for each rocker's "footprint" at the valve stem tip.

Custom pushrods are available from a variety of quality manufacturers.

While most quality aftermarket rockers will be extremely well matched (duplicates), it's still a good idea to keep them organized per location once test fitting is accomplished.



Naturally, degree-checking of the camshaft is mandatory. If the build is intended for a "showroom stock" racing class and the camshaft doesn't precisely meet the intended specifications, a custom cam may be required, or you might try other camshafts of the same part number in an effort to meet assigned specifications.

damper and flywheel independently as well, correcting if needed. Note: If, by chance, the damper will be painted, spin it again after the paint job to verify that no severe paint-thickness inconsistencies are present that affect balance. I realize how nit-picky that sounds, but again this illustrates our intent…to achieve as perfect a balance as possible.

Mixing and Matching

In many cases, the task of blueprinting can be eased by sifting through a number of production parts (here we include both OE and aftermarket) in an effort to locate the closest match to a specific need. For the sake of simplicity, let's examine the needs of a "showroom stock" racer. This type of competitor may be forced, via sanctioning body rules, to use an "unmodified" engine that meets OE spec. While the rules may not allow him to change engine specs, he can take advantage of having everything corrected to the "good" side of the tolerance range.

For example, once you know what the published cam specs are, you can then measure the existing cam. If that cam is off of spec to the detriment of performance (maybe lift isn't as high as OE tolerance allows, for example), you might be able to find a better-performing cam by checking a few others of the same part number. The same goes for connecting rod lengths, block wall thicknesses, etc. If you're presented with an engine that (because of race rules) limits machining procedures, you can always compare a few "identical" parts in an effort to find the most suitable from a performance standpoint, and then continue your allowable blueprinting corrective work.

Specialty Fixtures and CNC

In order to correct a given block, you'll either need an array of specialty fixtures in order to conduct a blueprinting exercise, or have access to a CNC machine. While some specialty tools and fixtures will apply generically to a number of engines (camshaft degreeing wheel, dial indicators, valve spring testers, etc.), you'll need an array of fixtures that are dedicated to specific motors. However, by simple programming of a CNC machine, the same operations can be accomplished without the need to purchase these dedicated specialty machining fixtures.

Of course, honing plates are mandatory. These thick slabs of steel or aluminum are torqued to a block's deck in order to simulate the stresses of an installed head. With this plate in place, the bores will be honed round when the block is distorted much closer to the conditions that the block will see during operation. Even though a block's bores are honed perfectly round in a relaxed state, as soon as cylinder heads are installed, the bores will likely distort to an out-of-round condition. Many experienced blueprinters go so far as to bolt-on a variety of components to a block, prior to honing, including not only deck plates, but bellhousing and motor mounts as well. The purpose: to create round cylinders when considering all potential bore distortion factors.

A camshaft line-boring fixture will allow you to assure a cam bore tunnel that is perfectly parallel to the crank main bore. This consists of a series of bolt-together precision-machined plates that correctly positions the cam tunnel boring bar relative to the crank mains.

If you don't have access to a CNC machine, a block truing kit (again, each kit is dedicated to a specific block) allows you to correct a number of out-of-whack angle dimensions on the block itself, including twisted blocks, uneven deck clearance, bore angle, cam timing variation and intake manifold fit on V-blocks. Many factory blocks are machined using the oil pan rails as the major reference. A block-truing fixture will allow you to instead index everything from the crank centerline, a much more accurate method.

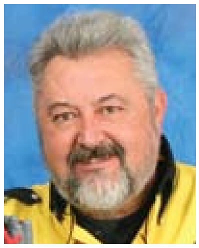
Again, if you don't have access to a CNC machine, lifter bore accurizing is achieved with a special fixture that also indexes from the centerline of the crank. This type of fixture will consist of two face plates (one at the front of the block, one at the rear), indexed with a crank main bore bar, and connected with a bridge plate that offers true positioning for the lifter bores. Using this bridge plate as a guide, the lifter bores are overbored (creating an ideal centerline both in terms of centerline location but relative bore angle as well). Once the bores are centerline corrected, bronze sleeves are installed and resized for the lifters to be used. This machining process will create an ideal alignment and angle position for lifter-to-lobe contact.

A variety of additional fixtures exist, including bolt-on plates to facilitate easier measuring of deck heights, plates that allow consistent (head-to-head) port matching of heads to intake manifolds, piston measurement stands, connecting rod length checkers, valve stem height indicators, V-block cylinder head-to-intake manifold angle checkers, tabletop fixtures that allow you to accurately measure center-to-center of timing sets, and much more.

We've only scratched the surface in this article. The detail involved in blueprinting one specific engine would take up more pages than we have available in this article.

Here, we've tried to present a basic understanding of what a "blueprint" involves. From an overall sense, the goal is to maximize the fit, efficiency and durability of every engine component, both in terms of an individual part and of the assembled engine.

In essence, blueprinting is the task of using existing parts as cores, in an effort to create an ideal model of efficiency and durability. It's the fun of making things right, and the ultimate exercise for those of us who simply refuse to believe that close enough is good enough. This is something that the customer needs to understand. A true blueprint job is an involved process that requires an excess of shop time, and those customers who expect this extra level of perfection must be made to understand that shop time costs money. If they wanna play, they've got to be willing to pay. ■



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