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Babcox

High Performance ENGINE PARTS & SURFACE FINISH Tech Guide

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INTRODUCTION

The surface finishes in today's high performance engine applications have never been more critical. Technology has made machining operations more precise and allows even the smallest shop to turn out some great engines. This supplement to *Engine Builder* magazine presents feature articles on the relationships between a variety of performance engine parts and their surface finishes and that of the components around them.

Want to give yourself an even better advantage over your competitors? Pay attention to some of your shop's OTHER critical operations as well: Air Handling and Parts Cleaning.

Air Handling

Today's modern engine building facility relies on a steady supply of compressed air to run tools and equipment. The creation, movement and storage of air) is an important – yet often overlooked – aspect of efficient shop operations.

Surprisingly, the biggest investment you'll make when it comes to compressed air is not the compressor. Experts say for every dollar you spend on air, 70 cents will be used for electricity and 15 cents will be used for the maintenance of your compressor. Being able to maintain your air system properly can help ensure the lowest possible operating costs.

While piston compressors are still the most common type found in the automotive service industry, rotary screw compressor technology, like that used by large facilities and industrial manufacturers can offer significant benefits. These compressors are energy efficient and provide an extremely reliable supply of clean, dry compressed air. How do you know what your shop needs? When you're investing in air, here are a few things experts say you should pay particular attention to.

Duty cycle – the percentage of time a compressor may operate without the risk of overheating and causing excessive wear to the compressor.

Air Temperature – since hot air carries more moisture and requires additional components to dry and clean lower operating temperatures are a very important consideration for automotive facilities.

Maintenance Requirements and Performance – is preventive maintenance needed between 2,000 and 5,000 hours to reverse the gradual loss of flow and reduce the oil carry over? Some screw compressors can operate for more than ten times as long as a typical piston compressor before requiring an overhaul.

Noise Levels and Vibration – with its reputation for being loud, the shop compressor is often placed in a separate room, in a forgotten corner, or worse – outside, exposed to the elements. Rotary screw compressors run smoothly and are available with sound-attenuating enclosures featuring anti-vibration mounts. Typical noise levels start at only 65 dB(A) – a significant drop and low enough to have a normal conversation while standing in the immediate vicinity.

Cleaning

From the latest air handling methods to high-tech abrasives to super-effective machining coolants, today's engine builder has a wealth of new technology to make his operation more efficient.

Yet while machining tolerances and performance expectations have changed dramatically over the past few decades, when it comes to getting parts clean, many of those high-tech shops struggle with the same technology they used 30 years ago. The simple fact is, times have changed for parts cleaning, and so have the methods. Engine builders have access to better products, systems and knowledge than ever – however, some shops don't seem to have realized that, say cleaning professionals.

Today, cleaning engine parts – whether they are small parts like fittings and fasteners, bigger parts like connecting rods and pistons, or even cylinder heads on up to engine blocks – requires attention to the three E's: economics, efficiency and environmental awareness. But while shops may have the same ultimate goal – clean parts – the methods they can choose from may be very different.

"One size fits all" may work in some parts of life, but not when it comes to cleaning. That's why it is more important for buyers to do their homework and partner with a reputable company that offers more than one type of parts washer, explain industry suppliers.

Value for the Money

Whether it's clean, compressed air or clean parts, it's about getting the right system for your application. Carefully consider each system component and its impact on the application. No one wants to spend more on equipment than necessary. However, building the right system for your facility and applications now, will more than pay for itself in the long term, especially when you consider reliability, efficiency and improved product quality.

Consider all the facts when setting up a new shop or retrofitting an existing facility. Look at capacity and the potential for growth, and make your selections based on an honest evaluation of available technology. There are many factory-qualified representatives who can advise you on the right system for your applications and your day-to-day needs.

For information on various cleaning methods, see the article in the April 2011 issue of *Engine Builder* written by Larry Carley. Or visit *www.enginebuildermag.com*.

PISTON RINGS & CYLINDER BORES

The job of the piston rings is to seal the pistons to prevent air and oil from being drawn past the rings into the combustion chamber during the intake stroke. During the compression stroke, the rings make sure the air/fuel stays in the combustion chamber and is fully compressed before it is ignited. During the power stroke, the rings prevent pressure from blowing past the pistons as the burning gases shove the piston down. And during the exhaust stroke, the rings make sure all of the spent gases are pushed out of the exhaust port.

Obviously, it's important for them to do their job well. Rings that do not seal well during all four phases of the four-cycle combustion process can reduce an engine's power potential by 20, 30, 40 or more horsepower depending on the engine's displacement, compression ratio and speed.

Rings that leak during the intake stroke will reduce air velocity and volumetric efficiency. Less air and fuel in the cylinder means less power. Rings that leak during the compression stroke will allow some of the air/fuel mixture to escape into the crankcase. Besides reducing compression and power, the unburned fuel that gets into the crankcase will dilute the oil. This will reduce the oil's lubrication qualities while increasing the risk of engine-damaging sludge if the oil isn't changed often.

Rings that leak during the power stroke will allow a loss of pressure that would otherwise be used to shove the piston down. The resulting blowby will also allow soot and moisture to enter the crankcase to further degrade the oil.

Finally, rings that leak during the exhaust stroke will reduce scavenging efficiency, allowing residual exhaust that remains in the cylinder to displace air and fuel during the next intake stroke. Again, more lost power potential. Blowby during the exhaust stroke will also allow more soot and moisture to enter the crankcase. If the engine has a turbocharger that depends on exhaust velocity for intake boost, ring leakage during the exhaust stroke can reduce exhaust flow, which reduces boost and power.

But rings must not only seal, they must do so with a minimum of friction. Consider the amount of friction created by the rings against the walls of the cylinders as the pistons reciprocate up and down. Ring friction eats up more horsepower than the cam and lifters, the cam drive, the rocker arms or the crankshaft.

Of the three rings in a typical ring pack, the oil ring accounts for 60 to 70 percent of the total friction created by the rings. Reducing ring friction by using smaller, thinner low tension rings can allow you to "find" horsepower that was previously lost. Low tension rings reduce friction and allow an engine to produce more usable horsepower.

However, dyno testing has shown that it is possible to reduce static tension on the top ring too much, causing a loss of pumping efficiency (vacuum) on the intake stroke. If you don't get all the air/fuel mixture you can into the cylinder on the intake stroke, it's not there to make power during the power stroke.

Optimizing Ring Sealing

The rings have to work with the pistons to provide the best possible seal. The rings prevent blowby by sealing against the groove in the piston, and against the cylinder wall. So to optimize sealing, the rings should be as flat as possible, fit the piston grooves as tightly as possible, have the least amount of end gap that the engine can safely tolerate, and be as conformable as possible to seal against the cylinder wall.

In late model original equipment stock engines, the rings are often moved closer to the top of the piston to eliminate the crevice where unburned fuel can be trapped. This is done for emission purposes and to help fuel economy. In a performance engine, the same logic applies. The more efficient the combustion process, the more power the engine will produce. But power also produces heat – a LOT of heat in a performance engine. This can be murder on both the top ring and piston groove if the materials are not able to handle the heat. For performance applications, you want a top ring made of ductile iron or steel. Wear resistant side coatings such as PVD or nitriding can help the rings survive this harsh environment. The top groove in the piston may be anodized or coated to minimize micro-welding and wear.

One way to improve ring sealing is to modify the profile of the ring grooves so they provide optimum support for the rings when the pistons get hot. One piston manufacturer uses a piston feature that creates a slight upward tilt to the ring grooves. This reduces blowby and improves oil control.

It is important to make sure the rings are compatible with the pistons you are using. If you buy rings from one supplier and pistons from another, there is always a chance that the piston grooves may be too shallow or too deep for the rings resulting in improper backspacing. Or the piston grooves may not provide the correct side clearance for the rings. Some manufacturers offer piston and ring sets that are precisely matched to provide the best possible seal.

Conformability of the rings increases exponentially as the thickness of the rings is decreased. If you reduce ring thickness by half, conformability goes up 8X. Plus, the reduced tension reduces frictional losses.

In the past, standard oil rings generated about 21.5 lbs. of tension. Today's thinner rings, by comparison, are down about 7 to 8 lbs., or about one third of what they used to be.

Bore Finish

Regardless of how much tension the rings generate, the best possible seal is going to be obtained with a round, straight cylinder bore. A plateau finish is always best. If you don't plateau the finish, it will take longer to break-in and seat the rings. The scrubbing will eventually create a plateau finish anyway, so why not do it from the start?

Cylinder bore distortion can have a negative impact on sealing, so to minimize distortion, ring experts recommend hon-

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ing with torque plates (hot honing is even better!). Always use a new head gasket, and make sure the head bolts are tightened to the same value as when the cylinder head is installed.

Most experts say you should be using a profilometer to measure the various attributes of the surface finish. There are a lot of parameters you can measure, but these three are key:

Rpk = Peak Height
Rk = Core Roughness Depth
Rvk = Valley Depth

A normal plateau finish with Rpk 8 to 12 microinch, Rk 25-35 microinch, Rvk 40 to 50 microinch) is a good starting point for general use. But for a performance application, an optimized finish would have the following parameters: Rpk less than 12 microinches, Rk 20 microinches, and Rvk of 40 microinches. If the application is something like a Pro-Stock or NASCAR engine, where minimum friction is a higher priority than longevity, you would want a smoother plateau with Rpk 3 to 5 microinches, Rk 12 to 18 microinches, and Rvk of 20 to 25 microinches.

To optimize surface finish in hard blocks or sleeves for Pro-Stock, Comp Eliminator, NASCAR or similar engines one honing manufacturer recommends the following:

Hone the bores to size with 270/325 metal bond diamond stones and water based coolant. Hone at 170 rpm and 56 spm with a 35 percent roughing load. Then set the machine to plateau mode with a 20 percent load for four strokes with 600 grit metal bond diamond stone. Keep the machine in plateau mode and change the stroke count to six strokes with 20 percent load. Use special diamond stones in flexible (red) bond. The final step is to plateau for six strokes at 20 percent load using plateau brushes. This process will produce a finish with Rpk of 4 to 6 microinches, Rk 18 to 22 microinches, and Rvk of 28 to 32 microinches.

Ring Selection

Ring selection plays a major role in optimizing horsepower for racing and performance applications. In a maximum effort naturally aspirated engine, you should use the lightest weight and lowest drag ring pack available. In a power adder application, you also need to think about ring materials that can handle increased cylinder pressures and the extreme heat produced by nitrous oxide, superchargers and turbochargers.

A supercharged nitro methane drag race engine can bend a 2.0 mm wide top compression rings right out of the piston groove in less than four seconds! By comparison, a maximum effort naturally aspirated engine of the same displacement can usually get along just fine with a 1.0 mm wide (or thinner) top ring. You need to carefully consider all the aspects of the ring pack, including ring width, radial wall thickness, the base material, the facing material, ring tension and rind end gap when choosing rings for a particular engine.

Reducing the ring-to-piston vertical and groove back clearances can aid in reducing cylinder pressure loss, but it is possible to go too far. The top compression ring needs combustion pressure behind it to hold it out against the cylinder wall during the high pressure portion of the combustion cycle.

Conventional pistons rely on a calculated amount of side clearance to provide a path for combustion pressures to get behind the ring, energize it, and push it out against the cylinder wall. Unless some method, like gas porting, is utilized to route those high pressure gases to the back of the ring, overly tight side clearances can restrict that gas flow and de-stabilize the sealing process.

There's a performance advantage if you can ensure the piston ring sealing surfaces and piston groove sealing surfaces are flat and true. Any variation in either will allow the cylinder pressure to escape, negatively affecting the gains made by minimizing ring-to-piston groove clearances. Optimizing groove fit is well worth the effort in maximum effort naturally aspirated engines.

Gas ported pistons (vertical or lateral) also help with ring sealing. The ports provide a more direct path for cylinder pressure to get behind the top ring. Gas pressure helps force the ring out against the cylinder wall. In high rpm applications, gas porting helps thinner, lighter rings be more stable, reducing the tendency to bounce or flutter in the ring groove (which can break the seal).

End Gaps

The optimal end gap for a top compression ring is when you achieve the smallest gap without butting the ends of the ring together when the rings get hot. A good starting point for the top compression ring is .0045˝ per inch of bore diameter for a naturally aspirated engine, and .006˝ for a power adder application.

The second ring end gap should be .005˝ to .010˝ wider than the top ring gap to prevent gas build up between the top and second rings. This can cause the top ring to flutter or bounce and lose its seal.

In a heavily boosted or nitrous oxide application, the second ring is forced more and more to act like a compression ring. Because of this, it should be gapped nearly the same as the top ring.

Piston ring manufacturers publish end gap recommendations in their catalogs and on their websites. Always refer to these recommendations as they will vary from one manufacturer to another depending on the type of rings used, what the rings are made of, and the application.

As a rule, the higher the power output of the application, the more end gap you should allow for thermal expansion.

Many second compression rings today are a napier style that helps scrape oil off the cylinder wall. Napier rings create a vacuum between the rings, so it's a good idea to open up the gap on the second ring. The second ring end gap should be 0.2 to 0.25 mm larger than the top ring end gap.

The thermal expansion rate of steel rings is less than that of cast iron rings. Consequently, you can generally run somewhat tighter end gaps with steel rings than cast iron rings.

Gapless Rings

The issue of where to set piston ring end gaps is moot if you are using a gapless style top piston ring. One manufacturer says 90 percent of Pro-Stock drag racers are using these rings because of the advantages a gapless ring offers: namely, a reduction in leakdown of 10 to 20 percent over a conventional style piston ring. As a rule, people who run a gapless top piston ring see 3 to 5 percent more horsepower. That's as much as 40 horsepower on a big inch engine.

The gapless design is a patented feature. An engine builder can use a gapless ring for either the top or second ring, according to the manufacturer.

Installation Tips

Insert the rings into a bore and measure the end gap with a feeler gauge. Adjust the gap as needed by filing only one side of the gap. Keep the gap as square as possible. This will allow the rings to run with the smallest possible gap.

Always use a ring expander so you don't twist or deform the rings when mounting them on the pistons. Make sure the rings are installed with the correct side facing up (top is usually marked with a small dot). Also, stagger the location of the end gaps on all three rings 180 degrees apart.

Make certain the cylinder bores are clean before you install the pistons and rings in the block. Use hot soapy water, scrub brush and plenty of elbow grease to thoroughly clean the bores. Wipe with a clean white rag to check for any residue, then lightly oil prior to assembly.

Make sure the ring compressor is properly tightened so the rings don't catch on the edge of the cylinder as the piston is being pushed into the bore.

For engine break-in, use a conventional oil or specific oil designed for breaking in engines. Then switch to a synthetic after 2,500 to 3,000 miles if you want the advantages of a synthetic motor oil.

Proper Geometry

To achieve the best possible bore geometry, late model engines with thinwall castings and performance blocks should always be honed with a heavy steel torque plate and head gasket bolted to the block. The plate simulates the loads placed on the block when the head is installed. Honing the block in this condition will result in better bore geometry when the engine is assembled and run. Good bore geometry also requires good equipment. You can't hope to achieve good bore geometry if your equipment is worn out or not aligned properly.

If you are honing with conventional vitrified abrasives, the operator (or equipment) must compensate for stone wear to keep the cylinders straight. Forget to compensate or compensate by too little or too much and you'll end up with taper in the bore. Diamond honing stones experience minimal wear and will generally produce straighter bores and greater repeatability hole to hole.

A honing machine that offers variable speed stroking and can dwell in the bore while maintaining the same loading reading will produce better bore geometry than a machine that lacks these features.

Using a coolant that is compatible with your honing stones will also improve bore geometry. The coolant flushes away debris while helping the stones maintain a consistent temperature.

Surface Finish Tips

Surface finish recommendations for late model engines vary depending on the application, but are often in the 15 to 20 microinch range Ra (roughness average). For performance engines, the recommendation may be even smoother, say 10 to 15 Ra. Regardless of the Ra number, most rings seal best with a plateau finish in the cylinders.

There are as many recipes for plateau finishing as there are for making pizza. The objective is to create sufficient crosshatch depth in the cylinder wall to retain oil with a relatively flat, smooth flat surface area between the grooves to support the rings.

Rings manufacturers say the best surface finish is often achieved by rough boring a cylinder to within .005″ of final dimensions (or rough honing to within .003″ of final size), then honing with #220 grit stones down to the last .001″, and finishing with a #280 to #400 grit stone (depending on the application).

Brushing the cylinder with a plateau honing tool as the final step removes loose and folded surface debris, and does not alter the dimensions of the bore. EPSFG

VALVE SEATS

Of all the parts inside an engine, the valve seats probably take more abuse than any other component. Besides the constant pounding of the valves against the seats as the valves open and close, the exhaust seats are seared with hot gasses every time the engine exhales.

Hard working diesel engines, performance engines and engines that run on dry fuels such as propane or natural gas produce a lot of heat in the combustion chamber and often require valve seats that are harder and more heat-resistant. Stellite, chromium, cobalt, tungsten and nickel alloy valve seats are commonly used for such high heat applications as are tool-steel valve seats. Beryllium-copper or copper-nickel alloy seats are often used in racing applications, typically with lightweight titanium valves.

Average combustion temperatures in a street performance engine can range from 1,400 to 1,700 degrees F. Nickel alloy cast seats can usually handle 1,400 degrees F with no problem, while cobalt is good for up to 1,650 to 1,700 degrees F. With nitrous oxide, temperatures can soar to 4,400 degrees F, which can make some seats become hard and brittle. This increases the risk of seat cracking and failure.

For ordinary passenger car and light truck engines, however, temperatures are lower, so iron alloy valve seats are perfectly adequate. Iron alloys are less expensive and easier to machine than hard, high temperature alloys. But in recent years, powder metal seats have become the norm for most original equipment passenger car and light truck gasoline engine applications.

Powder metal valve seats are very different from cast alloy seats. Powder metal seats are made by mixing various metal powders and then pressing the powder under pressures as high as 100 tons into a mold. The seat is then baked at high temperature to sinter (partially melt) the ingredients so they stick together and form a homogeneous matrix. The end result is a valve seat that has very consistent and uniform properties, and requires minimal finish machining.

The key thing about powder metal technology is that you can combine various ingredients that would not normally mix together if you were trying to create a cast alloy seat. For example, solid lubricants can be added to the mixture to improve machinability and wear resistance. In addition the powder can be blended differently for different types of applications. Infusing the mix with copper, for example, can improve the seat's ability to conduct heat for high heat applications such as dry fuel engines, marine engines or motorcycle engines.

Powder metal seats often show little wear at high mileage. Consequently, if you are rebuilding a head with powder metal seats, the seats may only need a light touch-up. But because of the work hardening that occurs with powder metal seats, they can be difficult to machine.

The naturally smooth exterior surface finish of a powder metal seat also improves the metal-to-metal contact between the seat and its counterbore in the cylinder head for better thermal conduction. Adding a radius to the outside corner also makes installation easier. The powder metal matrix also has a certain amount of elasticity that helps retain the seat in the head with less interference fit. That's why many original equipment powder metal seats are installed in aluminum heads with only .002″ to .003″ of interference fit.

Replacement Seats

For the most part, the rule of thumb is to replace valve seats with the same material as it came with. However, not all powder metal seats are the same. Some aftermarket manufacturers use better materials in their seats compared to OEM seat materials. So if you replace the OEM powder metal valve seat with one of these aftermarket seats, you are actually upgrading the performance of the seat.

Valve Seat Installation Tips

Interference fit is one of the main concerns when installing valve seats. You want the seat to fit tightly so it doesn't fall out, even if the engine overheats. But you don't want it so tight that there's a danger of cracking either.

On passenger car and light truck engines with aluminum heads, valve seats are usually factory installed with about .002″ to .003″ of interference fit. Some say powder metal seats require a little more interference fit than cast iron alloys, while cobalt alloy seats require a little less because of their higher coefficient of thermal expansion.

Keep in mind these numbers are for brand new heads with brand new seats. After tens of thousands of miles, seat counterbores can become distorted and eroded, requiring an increase in interference to keep the seat tight.

The most common recommendation from valve seat suppliers for cast seats being installed in aluminum heads is .003″ to .005″ of interference fit. If you are installing powder metal seats, use .005″ to .007″ of interference. If you are using beryllium-copper seats, go with .004″ to .0045″ of interference fit.

Powder Metal Seat Installation

If you are replacing powder metal valve seats with the same in a late model gasoline engine, several seat suppliers say you should not have to preheat the cylinder head or chill the seats prior to installation. Most powder metal seats have a radius on the outside corner and do not require as much interference fit as iron alloy cast seats. Most can also be driven in dry, so a lubricant isn't needed.

The amount of interference fit that's required may be slightly more on a rebuilt engine than a new engine, however, due to wear and distortion in the seat counterbore. If the OEM seats were installed with .003″ of interference, it may be necessary to go to .0045″ to .005″ of interference to assure a secure fit.


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Peening should not be necessary, and the use of any type of sealer is not recommended with powder metal seats because it may interfere with good heat transfer between the seat and head.

The valve guides should always be done first to assure the seat will be concentric with the centerline of the valve. The seat can then be finished after it has been pressed in using conventional valve refacing equipment. New powder metal seats typically have a hardness of around Rockwell C 25, so they should cut normally with little or no chatter. Finish the seat angle and width to specifications.

Something else to keep in mind when replacing seats is that any head straightening, crack repairs or welding should be completed before you cut the counterbores and install new seats. The process of straightening a head can often push seats out of round and create misalignment between the seats and guides.

"While the industry has seen a significant increase in the use of powder metal valve seats, many engine builders are asking for a more traditional iron alloy replacement seats because of the difficulty of machining high mileage powder metal seats."

Alloy Valve Seat Installation

How much interference fit is necessary to keep an alloy seat in place? It depends on the application and who you ask. A seat installed in a brand new cylinder head with accurately cut, round smooth counterbores will require less interference than a seat installed in a high mileage head. Removing old seats from a head will often distort the hole requiring slightly more interference when a new seat is installed.

If the counterbore in the head is damaged and has to be machined to accept an oversize seat, the amount of interference fit may be dictated by the size of your counterbore cutter and the availability of a specific oversized seat from your valve seat supplier. For example, if you are machining a counterbore with a 1-5/8″ (1.625″) cutter, and the replacement seat comes with a 1.630″ outside diameter, the interference fit when the seat is installed will be .005″.

Make sure you understand how your valve seat supplier indicates their actual seat O.D. dimensions so you get the correct sized seat and the correct amount of interference fit.

Recommendations for interference fit are often dictated by the type of casting (aluminum or cast iron) as well as the application.

One valve seat supplier said engine builders should use .0045″ to .005″ of interference fit when installing alloy or powder metal valve seats in cast iron heads, and .007″ of interference fit when installing seats in aluminum heads.

Another supplier recommended .004″ to .006″ of interference for seats in cast iron heads, and .005″ to .007″ of interference in an aluminum head. They also said to go with more interference if the application is a performance engine. A third supplier said .003″ to .005″ of interference should work in almost any head (cast iron or aluminum).

Valve seat suppliers say that the use of anaerobic sealer should not be necessary. The interference fit should be sufficient to keep the seats in place. Also, if the hole is round and smooth, there should be adequate metal-to-metal contact between the seat and head for good heat transfer.

Those who use some type of sealer on the seats say the sealer helps fill the gaps between the seat and head to improve heat transfer. Those who oppose the use of sealer say anything between the seat and head can form a barrier that may slow heat transfer from the seat to the head.

Some tips for ensuring good contact between the valve seat and head is to use seats that have a radius or bevel on the outside edge rather than a square edge. This will reduce the risk of galling the counterbore when the seat is driven in. Also, using a lubricant can make for a smoother installation. Preheating the head slightly (160 to 180 degrees F, but no higher) and chilling the seats in a freezer prior to installation can also make the installation go easier while reducing the risk of damaging the counterbore.

PM Seats in Diesels

In recent years, powder metal seats are starting to replace some of the hard alloy seats that have been commonly used in diesel engines, particularly in Europe. Most heavy-duty diesel seats, however, are still made of cobalt, iron or nickel based alloys.

One manufacturer is working to develop a new iron-based alloy seat for diesel engines that were originally equipped with powder metal seats. Stellite- and cobalt-based seats are very durable, but are also very expensive. The company has a proprietary iron-based alloy that work just as well in such applications.

While the industry has seen a significant increase in the use of powder metal valve seats, many engine builders are asking for a more traditional iron alloy replacement seats because of the difficulty of machining high mileage powder metal seats, said one expert. For most automotive gasoline engine applications, an iron-based alloy will work fine.

One supplier said they are seeing more demand for unusually large outside diameter valve seats, such as four-inch seats for industrial engine applications. Such large seats require a special centrifugal casting process to assure there is no porosity in the metal.

One expert said that valve seat prices throughout the industry are on the way up due to the rising cost of nickel. It's a problem that is affecting all valve seat suppliers, so he predicts there will likely be some upward price adjustments by the end of this year.

Seat Refinishing

Once the seats have been installed and the guides have been replaced, relined, or reamed to accept valves with oversized stems, seat concentricity should be checked with a dial indicator. Seats must be as concentric as possible to ensure a vacuum-tight seal with the valves, and to prevent valve flexing, which can cause metal fatigue and valve failure. A good number to aim for is less than .001˝ of runout per inch of seat diameter. Less is always best.

The best way to check concentricity is with a runout gauge. Pulling vacuum on the valve port with the valve in place is another method for checking the mating of the seat and valve. But the ability to hold vacuum is no guarantee of concentricity in itself. That's why both methods should be used to check the quality of your work.

Refinishing powder metal seats requires a slightly different touch than cast alloy seats as a rule. If grinding, you typically need harder stones (ruby, nickel-chrome or stellite). If cutting, you need a good sharp carbide cutter turning at the optimum speed for the type of seat that is being cut. According to S.B. International, increasing the spindle speed up to 50 percent when cutting powder metal seats will give the best results. They recommend a cutting speed of 350 to 400 rpm to achieve the best surface finish.

The one thing you want to avoid when cutting powder metal is any chatter on the seat surface. Powder metal seats can accept a high quality mirror-like finish, but the finish is only as good as the tools that are used to cut them. If your valve guide pilot has too much play for accurate valve work, you won't get a good finish on the valve seats. For performance engine work, the pilot-to-guide clearance should be .0002˝ or less. If it is up around .0004˝, there will be too much play for accurate machining. One way to reduce play is to use a high pressure lubricant on your pilot.

Valve Guides

The valve guide is designed to support the valve during operation as well as transfer heat for cooling. When the guides become worn they will increase oil consumption and lose their ability to transfer heat and that's when you need to replace and resize the valve guide.

Worn guides will draw oil down the valve stem and will coat or coke on the port side of the valve. This will hinder air flow and cause engine performance to be compromised. Too much oil getting down that valve stem and may cause mechanical failure due to the increased possibility of pre-ignition.

Worn valve guides can also be the cause of valve heads breaking off valve stems. When the guide is worn it no longer guides the valve concentrically up and down and actually allows the valve to start flexing and bouncing off the valve seat at various angles. After a while the head breaks off, and suddenly little bits of the piston and combustion chamber all combine like a blender and literally grinding that engine to a halt.

There are various methods for sizing valve guides. Guides are smaller on the ID so you have more material to remove and the guide material is very hard so this really does challenge traditional sizing tools. Guides are also made from various combinations of material ranging from cast iron, bronze, phosphorous bronze and manganese bronze.

Back in the day, aftermarket valve stems and valve guides were all standard sizes, but now they vary ever so slightly. Original equipment-supplied components versus aftermarket-supplied components can leave you needing that in-between sizing tool you don't have on your tool board or it isn't just a stock size that shop supply companies have in inventory. Higher rpms, lighter valves and stronger valve springs all contribute to the stresses your valve guides must stand up to and the best way to deal with that is to size that valve guide properly and accurately.

Proper clearances must be maintained to avoid these types of failures. Engine building veterans have a saying: "If it's too tight it will stick and if it's too loose it will smoke." EPSFG

DECKS & GASKETS

The factors that typically cause a gasket to fail include age, heat, thermal expansion, abrasion, pressure, vibration, corrosion, material breakdown or poor design. Some gaskets go the distance and others do not.

With head gaskets, problems like detonation and engine overheating can damage the gasket very quickly, causing an otherwise good gasket to crack or crush, burn through and fail. A weak OEM gasket design can also increase the risk of early failure. Some historical examples include the head gaskets in GM's 2.3L Quad Four engine, Ford's 3.8L Windstar engine, Dodge's 2.0L engine in the Neon, and Toyota's 3.0L V6 truck engine.

A more recent example of early head gasket failure is 1996-1999 Subaru Outback, Legacy GT, Forester and Impreza RS models with the 2.5L engine. In 1996, Subaru used a composite head gasket on these engines, then changed to a stronger multi-layer steel (MLS) gasket with a graphite overlay in 1999. The early style gaskets often develop leaks that allow coolant and oil to mix. Symptoms include engine overheating from coolant loss, and an oily residue inside the coolant overflow bottle.

Which of today's engines will prove to be leakers down the road is hard to predict because it usually takes a number of years for a head gasket or other gasket to develop a leak. There can always be random leaks or head gasket damage caused by overheating or detonation. But if large numbers of vehicles experience the same kind of gasket failure at approximately the same time or mileage, it usually indicates a weakness in the OEM gasket.

Though most late model engines use MLS head gaskets, you'll also find soft-faced composition head gaskets with a solid or perforated steel core surrounded by graphite or a non-asbestos material. Some have a slippery "non-stick" coating that improves cold sealing and also makes the gasket fairly easy to remove. But others have a sticky silicone coating that adheres to metal surfaces and is difficult to remove.

MLS head gaskets, by comparison, have three to five layers of steel and have a very thin rubber coating on the outside to improve cold sealing. MLS head gaskets are very durable, but if they do have to be replaced the rubber tends to stick to the surface and can be difficult to remove. MLS gaskets also require a very smooth, almost polished surface finish to seal properly. Consequently, you have to be extremely careful not to scratch or gouge the head or block surface when replacing a MLS head gasket on one of these engines.

Intake Gaskets

Some intake manifold gaskets can be prone to trouble. An example would be intake manifold gasket coolant leaks often found on GM 3.1L, 3.4L and 4.3L V6 engines. When many of these engines reach 60,000 to 70,000 miles, the intake manifold starts to leak coolant around the coolant ports in the head. Symptoms include coolant loss and eventually engine overheating. Adding some cooling system sealer to the cooling system may temporarily seal the leak, but in many cases the only lasting fix is to replace the intake manifold gaskets – which on these engines can be a six- to eight-hour job.

These engines are factory-filled with Dex-Cool antifreeze, which uses Organic Acid Technology (OAT) additives to prevent corrosion. But over time, the chemical additives in the coolant attack the gasket material, causing it weaken. Add this to the normal engine vibration, thermal expansion and contraction the gasket must endure, and it eventually leads to coolant leaks. Retightening the intake manifold bolts does not help and only further damages the intake manifold gasket.

Aftermarket gasket manufacturers have developed improved replacement intake manifold gaskets for these leak-prone GM applications. Similar gaskets with more robust materials have also been developed for other leak-prone intake manifold gasket applications, which include 1996-2002 GM 5.0L and 5.7L engines, and various Ford 3.8L, 4.0L and 4.2L engines.

The sealing beads around the coolant passages of these improved gaskets have been redesigned with additional ridges to ensure a long lasting leak-free seal. The port areas are also encapsulated with an elastomer material that can resist chemical attack by OAT-based coolants. The gaskets also have steel grommets so they cannot be overtightened and damaged.

One thing to watch out for when replacing a leaky intake manifold gasket is corrosion around the coolant ports on the cylinder head and/or intake manifold surfaces. If the surface surrounding the port is rough and pitted, the new gasket may not seal any better than the old one. Resurfacing these areas may be required to restore a smooth, flat surface. Another technique that often works is to use a high temperature metal epoxy to fill in the pits and voids around the corroded port. Just be sure to grind away any loose material and clean the surface before applying the epoxy so it will stick to the casting. A light sanding to smooth the surface after it hardens should provide a good surface for the gasket to seal against.

Gasket Removal Tips

Every type of gasket requires a clean, smooth, flat surface to seal properly. The same goes for RTV silicone sealer and anaerobic sealers if no gasket is used. This requires removing all of the old gasket or sealer material prior to installing the new one or applying new sealer.

If the old gasket sticks, flakes apart or does not peel off clean when you remove it, you'll have to remove all of the old gasket before installing the new gasket. The best method for doing this is to spray the old gasket with an aerosol chemical gasket remover, then scrape off the loosened gasket material.

A gasket scraper is the best tool for removing old gaskets. A scraper has a sharp bevel edge that gets under the gasket to shear it away from the surface. Hold the scraper at a shallow angle relative to the surface with the sharp edge down and placed firmly against the metal. Then scrape off the old gasket with a pushing motion away from yourself. Don't use the scraper like a chisel to chip away or dig at the old gasket because you may end up gouging or scratching the casting (which can cause leaks later on). Wear eye protection, too, to keep any debris out of your eyes.

Most aerosol gasket removers take 10 to 20 minutes to soften and loosen old gaskets and sealers. Just make sure you read the directions on the product BEFORE you spray anything. The chemicals in some gasket removers are rather harsh and may attack certain plastics that are used in plastic intake manifolds. Test the product on a piece of similar plastic or on a non-critical area of the manifold to see if etches the plastic. If there's no adverse reaction, it should be safe to use.

Do not use an abrasive disk to whiz off old gasket material. Abrasive sanding disks have many uses in a shop, but cleaning casting and pan mating surfaces should not be one of them. Here's why: the rapid cutting action of an abrasive disk in a drill can easily remove metal as well as gasket residue. If you press too hard or continue grinding too long, especially on soft parts like plastic intake manifolds or aluminum cylinder heads, you risk gouging the surface or creating a depression or low spot that won't seal when you install a new gasket.

Also, on engines with MLS head gaskets, grinding will ruin the polished finish on the head and blocks. This may not matter if the head and block are going to be resurfaced. But why create extra work if the original surfaces are in good condition and don't have to be resurfaced?

Avoiding Repeat Gasket Failures

Examining the old gasket can often provide clues as to why it failed. With head gaskets, look for carbon tracks on the surface of the gasket. Carbon tracks are black deposits that form in areas where the gasket does not seal tightly. You should see carbon tracks around the combustion chamber on a head gasket, but no tracks on the gasket armor or elsewhere.

The presence of such tracks would tell you the gasket was leaking, possibly due to warpage in the cylinder head or block deck surface, or uneven loading due to stretched dirty or damaged head bolts, or bolts that were not torqued in the proper sequence or to specifications.

If the metal armor around the combustion chamber on a head gasket appears to be coated with a bluish or black substance, the engine may have been running lean and experiencing detonation or preignition, or the cooling system may have a problem that caused the engine to run too hot.

Cracks in the head gasket armor around the combustion chamber would likely be the result of a preignition or detonation problem due to a lean air/fuel mixture, carbon buildup in the combustion chamber (possibly due to worn valve guides or seals), overadvanced ignition timing, or loss of exhaust gas recirculation (EGR). The engine may also have damage to the pistons and rings.

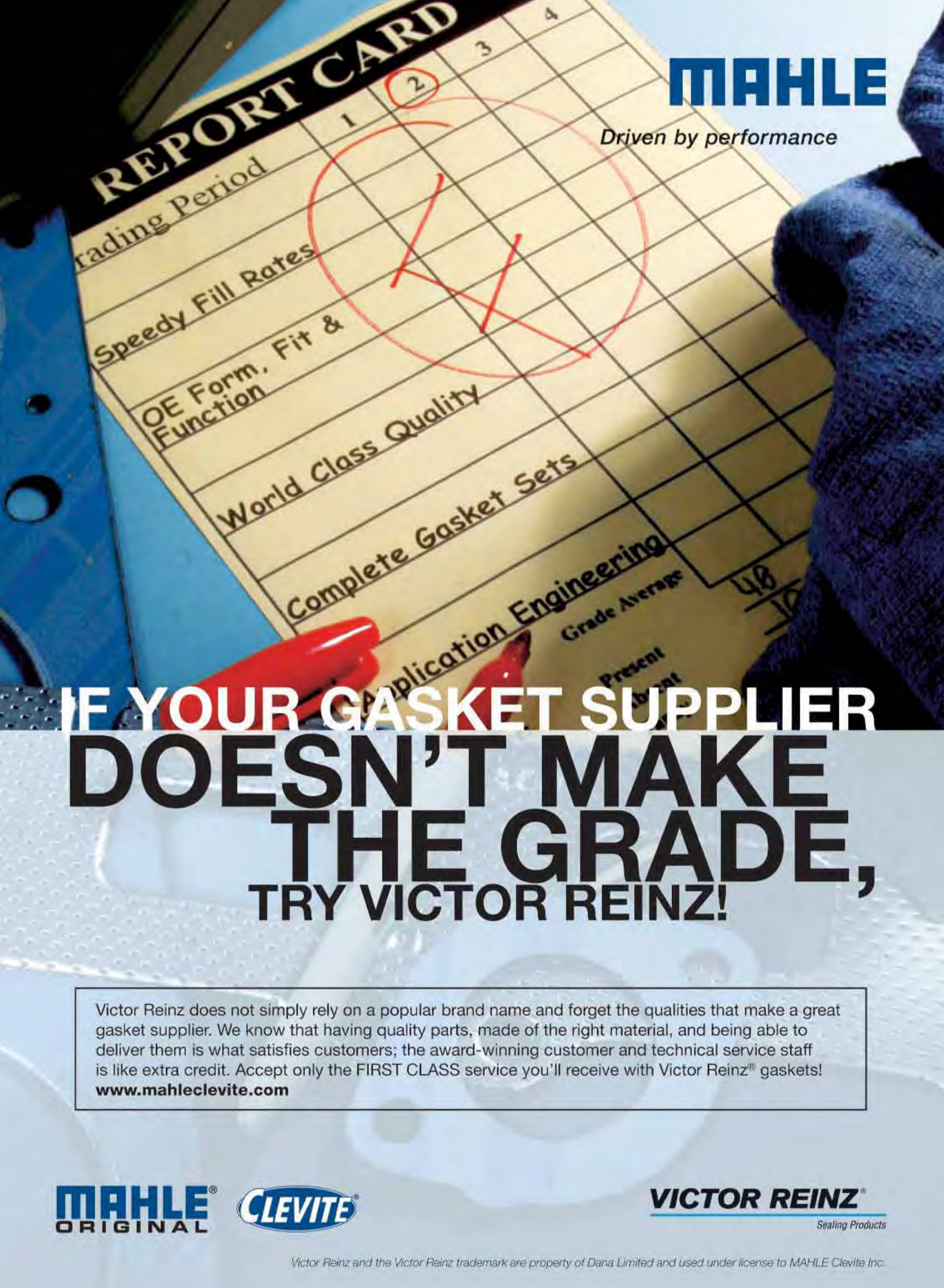
Head gaskets can sometimes be shifted slightly out of position because somebody removed the pilot pins that help position the gasket during installation. The pins may have been removed if the block was resurfaced. Without the pins, the gasket may not line up exactly with the cylinder bores and coolant holes, which can cause problems down the road.

With cork/rubber valve cover and pan gaskets, severe engine overheating can make the gaskets brittle, discolored and hard as a rock. Check for cooling problems that would make the engine run hot. If you find rust at the coolant ports, the coolant has probably been neglected. There may be additional problems with corrosion and sediment in the radiator, heater core and engine cooling jackets.

Surface Finishing Requirements

You used to be able to drag your fingernail across the surface of a cylinder head or engine block to tell if it was smooth enough. It didn't really matter if it wasn't perfect because the composite head gasket would fill any gaps that your equipment or technique left behind. But with MLS gaskets these requirements have changed.

Accurately measuring the surface finish can be done using a profilometer, an electronic instrument that drags a diamond-tipped stylus across the surface to calculate its profile characteristics. The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profilometer then shows various values for the surface including roughness average (Ra), average peak height (Rpk), average valley depth (Rvk) and even waviness.

These critical surface finishes require high quality resurfacing equipment to achieve low Ra numbers. Extremely smooth finishes require high quality resurfacing equipment to achieve really low Ra numbers. It doesn't matter if you use carbide, CBN (cubic boron nitride) or PCD (polycrystalline diamond) tool bits to resurface a head as long as you use the correct feed rate and speed – and the equipment is rigid enough to hold the cutter steady so the tool bit doesn't lift or chatter when it makes in interrupted cut.

For example, a converted grinder may be able to mill heads and blocks. But the spindles and table drives in many of these older machines cannot hold close enough tolerances to achieve a really smooth, flat finish. One equipment manufacturer said grinding and milling machines that are more than a decade old are probably incapable of producing consistent results and should be replaced.

Most of the surfacing equipment that's being sold to shops today has been redesigned for high speed milling with CBN and PCD. The machines have been beefed up with more powerful motors, heavier castings, electrically driven ball screw tables, and tighter assembly tolerances. Some can hold machining tolerances to .0001″.

Abrasive Choices

As great as coated ceramic is for milling operations, CBN is far better, particularly on cast iron. CBN is second in hardness only to diamond. On the Knoop Hardness scale, CBN is rated at 4,700 compared to 7,000 to 9,000 for diamond, 2,400 for silicon carbide and 2,100 for aluminum oxide. As for abrasion resistance, CBN is nearly as good as diamond: 37 for CBN versus 43 for diamond, which is far and above the ratings for silicon carbide (14) or aluminum oxide (9).

CBN inserts for resurfacing applications are usually round and available in 3/8″ and 1/2″ sizes, single- or double-sided. CBN inserts will last much longer than carbide inserts, and are well-suited for applications such as resurfacing diesel cylinder heads with precombustion chambers. Some inserts may shatter when they hit the precombustion chambers, but a 1/2″ diameter solid CBN insert will cut it cleanly without the chatter or streaking that often results when carbide inserts are used for this purpose.

Single-sided CBN inserts are recommended for resurfacing hard castings such as compacted graphite blocks, while the double-sided inserts are good for general resurfacing on ordinary cast iron.

CBN is recommended for machining cast iron, and it can also be used for aluminum, provided a lubricant is used to prevent the metal chips from sticking to the CBN inserts. However, PCD (polycrystalline diamond) inserts are usually the better choice for machining aluminum – and should only be used for aluminum (not cast iron).

Though diamond is harder than CBN, it can't take as much heat as CBN. In a high-speed milling machine, diamond inserts will overheat on cast iron. CBN can withstand higher temperatures before it starts to suffer adverse effects. CBN also dissipates heat about four times faster than carbide, which helps it retain its sharp cutting edge.

What makes PCD the best choice for machining aluminum is the fact that diamond can cut through the hard particles of silicon in the relatively soft aluminum matrix without dulling. CBN can lose its edge rather quickly if it is used to machine a high silicon alloy aluminum head or block.

Troubleshooting Milling Problems

Regardless of what type of inserts you are using to resurface a cylinder head or engine block in a milling machine or CNC machining center, you may not be getting the finish you want. Here are some solutions for common resurfacing problems:

• Chatter – Causes include lack of rigidity (check the rigidity of the spindle and fixturing), excessive cutting force (reduce the feed rate, depth of cut or with of cut, or flex in the part.

• Surface finish too rough – Causes include worn inserts (use a coated insert that resists wear better), built-up edge on insert (increase speed, use a coolant and/or change to a coated insert), or wiper insert set too high (adjust to .0005″ to .002″ above insert).

• Surface finish wavy – Reduce feed rate.

• Surface finish not flat – Use a more positive rake cutter, or a larger diameter cutter head.

Gasket Installation Tips

If you are replacing a head gasket, the surface of BOTH the head and block must be clean, smooth, flat and free from scratches, pits or corrosion. With conventional head gaskets, the recommended surface finish is 60 to 120 microinches with a cast iron head, or 20 to 50 microinches with an aluminum head.

Surface flatness measured with a straight edge and feeler gauge should not be more than:

• .003″ lengthwise or .002″ across on three cylinder and V6 heads;

• .004″ lengthwise or .002″ across of four cylinder and V8 engines;

• .006″ lengthwise or .002″ across on straight six cylinder heads.

If the flatness of a head or block is not within these specifications, it needs to be resurfaced.

With MLS head gaskets, the specifications are even tighter. Because MLS head gaskets don't compress much, the surface on the block and head must be extremely flat: less than .002″ in any direction with aluminum heads.

The surface finish must also be smoother, typically 20 microinches or less for most OEM gaskets, but up to 50 or 60 microinches with some aftermarket MLS gaskets that have a special surface coating to accommodate rougher high mileage surfaces.

When installing a head gasket, follow the recommended procedure for tightening the head bolts (angle gauge or torque-to-yield). Use motor oil or specially formulated head bolt lubricant to obtain the correct loading on the bolts. Dirty or damaged threads, dry threads or threads that have been lubricated with the wrong type of lubricant can all create misleading torque readings that can prevent a head gasket from sealing.

Do not reuse torque-to-yield (TTY)

head bolts. They are one-time use bolts that permanently stretch when tightened. Reusing them is risky because they can break or fail to hold torque. Toss the old TTY head bolts in your scrap metal bin and replace them with new ones.

If you are reusing conventional head bolts, make sure they have not stretched, are not damaged (no nicks or gouges, no distorted threads) and are not corroded. If any bolt appears questionable, replace it.

In high mileage engines, it's also a good idea to clean and retap the cylinder head bolt holes in the block. This will ensure proper loading and accurate torque readings when the head bolts are tightened.

It's also essential to use an accurately calibrated torque wrench. Beam style torque wrenches typically stay in range better than adjustable or dial style torque wrenches, but are harder to read. If a torque wrench has not been checked in over a year, it should be checked to make sure it is still accurate. Various tool vendors can check the accuracy of your torque wrench in their tool truck.

Tighten each cylinder head bolt to specifications in the proper sequence. Make sure you are using the latest torque tables as these may have been revised.

With intake manifold bolts, torque to specifications in a crisscross pattern to make sure the gaskets are evenly loaded and seal tightly. With valve cover and pan gaskets, don't overtighten cork or rubber gaskets. Installing gaskets that have compression-limiting grommets can prevent crushing and gasket damage. Use a sealer and/or adhesive on cork and composite gaskets, but do not use sealer on rubber or coated gaskets.

If you are installing a .020˝ thick copper or steel cylinder head shim to compensate for metal shaved off the head during resurfacing, make sure the openings in the shim match those in the head gasket so the coolant will circulate normally. The shim then goes on the block, and the head gasket is placed on top of the shim. Most shims typically require the application of sealer, but only to the block side. Use the type of sealer recommended by the shim supplier, and apply a thin, even coating.

Seal Installation Tips

Camshaft end seals and crankshaft main bearing seals are just as important to preventing leaks as the gaskets in the rest of the engine. Rubber end plugs must be installed dry without any sealer.

With crankshaft seals, you want plenty of lubrication because a dry start is one of the leading causes rear main seal failure.

The surface of the crankshaft that contacts the lip of the seal must be smooth and clean. Any roughness will quickly wear the seal and cause it to leak. The crank surface may have to be remachined and polished to provide a good surface, or a repair sleeve can be slipped over a worn crank to restore the surface.

Lubricate the seal lip and crankshaft with engine oil before the seal is installed. Use assembly lube or grease if it will be some time before the engine is started.

Seals with a bare metal outer housing generally require an anaerobic sealer on the outside diameter. Do not use RTV on the seal. Seals with a rubber coating on the outer diameter generally do not require any type of sealer when they are installed.

Debur the edge of the block and cap to prevent damage to the back side of the seal when it is installed, and use the proper driver when installing a one-piece seal to prevent seal damage. The seal should go in straight with a slight interference fit.

Here's the last mistake to avoid: installing the seal backwards. The primary sealing lip should be closest to the inside of the engine. Most radial lip seals also have a small garter spring inside the seal. The seal should be installed with the spring facing inward towards the engine. This will allow oil pressure to push against the lip from the inside to maintain a positive seal. **EPSFG**

CRANKSHAFTS & BEARINGS

The metal in today's forged and billet steel cranks is much stronger than the cast irons used in everyday passenger car cranks. Many cast cranks are made of 1053 high-carbon alloy steel. This material has a tensile strength of around 100,000 to 110,000 psi, which is good enough for applications up to about 400 to 450 horsepower (depending on the size of the journals). But for higher horsepower street or racing engines, some type of forged or billet crank is a must.

Some less expensive forged cranks are made of 5140 grade steel (which has a tensile strength rating of 115,000 psi), but most forged and billet performance cranks are 4130, 4340 steel or another high grade alloy steel. Crankshaft suppliers may use different alloys in different product lines, depending on the application and strength requirements.

Cranks made of 4130 alloy have a tensile strength rating of 120,000 to 125,000 psi. Cranks made of 4340 and similar alloys may have a tensile strength of 140,000 to 145,000 psi or higher, and a fatigue strength rating of 160,000 to 165,000 psi or more depending on the heat treatment and the quality of the alloy. The magic ingredients in that boost the strength are chromium, nickel and molybdenum.

The percentages of these ingredients must be carefully controlled and kept within certain limits to achieve these numbers, so quality control is absolutely essential for maximum strength and reliability. The American Society for Metals specifies the ingredients and the percentages of those ingredients that are required to meet the criteria for a specific alloy.

The journals on a high quality performance crank should be perfectly round, and flat side-to-side with no taper, or convex or concave curvature. The location of the journals must be accurately indexed for precise valve timing and ignition.

The counterweights must be accurately positioned and sized to offset the reciprocating mass of the pistons and rods. If a crank meets these criteria, it's a good crank. If it does not, it may require a lot of reworking before it is acceptable to use – and that's something you have to figure into your engine building costs if you end up having to rework a bargain-priced crank.

It's also important to make sure a crank has enough strength for the application. A low-priced entry-level crank will not hold up to the rigors of racing like a high end racing crank.

Why Cranks Break

Too much horsepower with a stock cast crank will almost certainly lead to disaster. Once you go beyond 400 to 450 horsepower with a small block cast crank, or 550 horsepower with a big block cast crank, the risk of breakage goes way up. If you're building an engine that will be blown, boosted or use NOx, you should always upgrade to a forged or billet steel crank.

The more rigid the crank, the stiffer it is and the less it will flex. That's good. But if the journals are too small or too much metal has been removed from the crank to lighten it, flexing increases along with the risk of breakage. Metal fatigue that results from flexing can also cause a crank to break.

Cracks often begin in highly stressed areas like the journal fillets, near oil holes or near the snout where there are high loads from the drive belts or a harmonic balancer that may be out of balance. Most performance cranks are machined with a larger radius in the journal fillets (which may require using chamfered rod and main bearings). Cranks with oversized snouts are also available for blower applications or other applications that place unusually heavy belt loads on the crank.

Balancing

Balancing is absolutely critical in any high revving performance engine. The loads on the crank go up exponentially with rpm. That's why many engine builders want the rotating assembly balanced to within tenths of a gram.

On V6, V8 and V10 engines, the pistons are moving in different planes. This requires crankshaft counterweights to offset the reciprocating weight of the pistons, rings, wrist pins and upper half of the connecting rods. The counterweights smooth out the vibrations but also add weight to the crank. This, in turn, increases the inertia of the crank. So reducing the size and/or number of counterweights is a trick that's often used in lightweight racing cranks designed for circle track and road racing applications where instant throttle response is desirable.

With "internally balanced" engines, the counterweights themselves handle the job of offsetting the reciprocating mass of the pistons and rods. In "externally balanced" engines, additional counterweights on the flywheel and/or harmonic damper help the crank maintain balance. Some engines have to be externally balanced because there isn't enough clearance inside the crankcase to handle counterweights of sufficient size to balance the engine.

This is true of engines with longer strokes and/or large displacements. On some engines, like late model Corvettes with dual-mass flywheels, the engine is partially internally balanced, and externally balanced with movable weights on the flywheel.

If you're rebuilding an engine that is internally balanced, the flywheel and damper have no effect on engine balance and can be balanced separately. What's more, the index position of these parts won't change the internal balance of the engine. Nor will changing flywheels or harmonic balancers (assuming the new parts are zero balanced). But with externally balanced engines, the flywheel and damper must be mounted on the crank prior to balancing. The flywheel and damper must also be indexed to the crank because changing their position


2nd place
is for the
other guy

will upset the balance.

Replacing a flywheel or harmonic balancer will also require rebalancing the engine. If a customer doesn't know that and changes a flywheel or balancer, he may create a balance problem that causes unwanted vibrations and ultimately a crankshaft failure.

Stress Relief

A couple of beers may be all YOU need for stress relief, but a crankshaft requires a more involved process. Heat-treating increases the temperature of the crank to a point where the grain structure in the metal starts to change. Holding the crank at a certain temperature for a certain length of time will relieve the residual stresses. Quenching (cooling) the crank at a controlled rate afterwards retains the positive changes in grain structure that increase tensile and fatigue strength.

The heating and cooling processes must be carefully controlled to achieve the best possible results. Any mistakes here can result in a weaker crank or a brittle crank. A cheaply-made crank may not have a very good heat treatment, and won't as strong or as reliable as one from a supplier who knows what they are doing and who keeps a close eye on the heat treating process.

Shot peening the surface of the crank also helps improve strength and reliability by increasing surface hardness and eliminating stress risers that might form cracks. Cryogenic treatment (freezing to 300 degrees below zero in liquid nitrogen) is also said to relieve residual stress and improve durability.

To improve wear resistance, the journals may be induction hardened or nitrided. Most stock cranks are induction hardened because it is a fast, inexpensive way of hardening the journals. A low frequency electromagnetic induction coil is placed around each journal to heat the metal.

After the metal reaches a temperature where the grain structure undergoes a martensitic transformation, and the desired depth of hardening is achieved, the journal is sprayed with oil to quench the steel and preserve the hardened surface layer. This type of heat treatment typically leaves a hard layer up to .030″ or more in depth (which allows the crank to be reground without removing all of the hardened layer).

Nitriding

To improve the wear resistance of the journals, most performance cranks are nitrided after they have been heat-treated. Some crank manufacturers use a "plasma nitriding" process that vacuum deposits ionized nitrogen on the surface of the crank inside a high temperature oven. Others use a process called Tufftriding that soaks the crank in a hot "ferric nitrocarburizing" salt bath, or heats the crank to 950 degree F in an oven filled with nitrogen.

Nitriding causes nitrogen atoms to penetrate the surface of the metal and make it harder. Nitriding typically doubles the hardness of the journal surface (from 30 to 35 Rockwell C to 60 Rockwell C). This also increases the fatigue life of the crank up to 25% or more. The depth of the hard surface layer may range from as little as a few thousandths up to .025″ inches or more depending on how long the crank was left in the oven or salt bath.

Polishing

Micropolishing is often done on the crank journals after they have been ground to size to improve the surface finish. Crank manufacturers typically aim for a surface finish of 5 microinches or less on the main and rod journals.

Some crank suppliers also polish the entire crankshaft. Not only does this produce a cosmetically attractive finish, it also helps reduce the risk of surface cracks forming by eliminating stress risers. A polished surface also helps shed oil at low rpm, reducing windage and drag. Oil shedding coatings may also be used for the same purpose. But as one crank supplier said, at high rpm there won't be any oil on the crank anyway because it will be flung right off.

Windage

High revving racing cranks typically have counterweights that are shaped to cut wind resistance and drag as the crank spins in the crankcase. Drag slows the crank at high speed and robs power that could otherwise go to the wheels. A vacuum sump can do the same thing.

But if you can't run a dry sump to suck oil and air out of the crankcase, a crank with profiled counterweights is a plus. The most aerodynamic shape is a rounded leading edge on the counterweight, with a knife-edge trailing edge. Knife-edging also helps shed oil more quickly.

Engine Bearings

Bearings, while seemingly simple, are highly engineered to meet specific requirements in relation to the amount of load an engine produces. Experts say you have to look at the type of performance that the engine is intended for before selecting. Is it going to be passenger car, street high performance, competition high performance, heavy duty diesel? Since passenger car engines don't necessarily operate at wide open throttle, they are not usually fully loaded. However, there are many applications where loading is more severe, such as heavy-duty diesel, marine and performance engines.

One bearing expert explained at *Engine Builder's* Bearing Summit held last March that they have seen rod bearings survive in extreme loads such as top fuel drag racing engines where loads can reach 63,000 psi for up to four seconds. He said that bearing longevity is directly related to the amount of load on the bearing. In NASCAR, Formula One and IndyCar loads may exceed 14,000 psi but the average life of those bearings increases to 500 miles or more from a quarter mile. In heavy-duty diesel applications, bearing loads are not as high, around 6,500 psi, but the average lifespan increases substantially to 500,000 miles for these applications.

Bearing experts say the more load you put on a bearing, the more difficult it is to maintain an oil film between the shaft and the bearing. And separate from the level of loading, there are gross loads from combustion and inertia forces that also must be considered.

One of the main things you have to take into consideration is the bearing proportion in comparison to the level of loading. This is where bearing engineers look at unit loading; how many pounds per square inch, not total pounds of load. Not only does bearing proportion determine the level of loading, say experts, it also determines the ability to create a lubricating oil film between the shaft and the bearing. The bearing has to have the proper proportions, and a length-to-diameter ratio of about one-third is pretty much ideal. With this rule of thumb you can look at a bearing and say that it is probably going to work or if you'll likely experience some problems with it.

Engine bearings have the dual function of reducing friction between a rotating part of the engine (the crankshaft) and the stationary part (the main caps and engine block) and supporting the crank.

Because of the stresses caused by the explosions inside the internal combustion engine, the bearing material must be extremely strong, so a durable metal is required.

Reducing friction is accomplished in part by the fact that dissimilar metals slide against each other with less friction and wear than similar materials will. So an alloy bearing material does a much better job of keeping a steel crankshaft moving than a steel or cast iron bearing will.

Although the material itself may give the engine bearing some friction reducing properties, its performance is enhanced by a lubricant between the moving and stationary surfaces. Another of the bearing's duties is to establish and maintain a film of oil.

For all these requirements, the bearings usually do a very good job at keeping the moving parts moving. However, when a bearing fails the results can be spectacular – and catastrophic.

But even when they fail, the fault usually doesn't lie directly with the bearing itself. There is usually another, less obvious culprit behind the crime, which may force engine builders to employ some CSI-like investigatory tactics.

There can be literally dozens of reasons for premature wear or failure of an engine bearing. Luckily, the criminal always leaves a trail. By carefully inspecting the evidence left behind, an engine builder can discover and eliminate the cause of bearing failure.

Some failures will be caused by a combination of factors, but the following clues can help you determine the most likely cause of failure. Photos of typical bearing failures can be found at various engine bearing manufacturers' websites or at *www.enginebuildermag.com*.

Dirt or Debris

Whether it's dirt, dust, grinding remnants, shot or any other particle, debris can cause significant damage to a bearing surface.

If it's in the lubrication system, dirt will usually leave circumferential scratches and often the offending piece will remain lodged in the bearing's surface. Always be sure the lubrication system is flushed thoroughly before reassembling an engine.

Another way dirt can play havoc is if the engine components aren't completely clean. A foreign particle trapped between the bearing back and the housing will cause a raised area in the bearing. This little hump can lead to contact between the bearing and the crank journal. You should always ensure the bearings are installed in clean surfaces.

Insufficient Lubrication

A complete lack of lubrication in the crankcase usually leads to seizure of the bearing and total failure of the engine. But experts say a more frequent issue regarding lubrication is simply inadequate oiling.

The absence of a proper oil film will result in metal-to-metal contact, occasionally to just one bearing or often to a number of them.

When the bearing is damaged by oil starvation you'll find a very shiny surface and evidence of wiping. Remember, the failure of the oil film can be seen in a variety of ways on the bearings. Check for such things as blocked oil passages, a malfunctioning oil pump, improper bearing selection or installation, oil seal failures, fuel dilution (often caused by blowby of fuel and air past the piston rings) or foaming or aeration, caused, ironically, by an overfilled crankcase.

Misassembly

Sometimes, failures are the result of simple installation errors. For example, if a bearing half without an oil hole is improperly put into a position where the hole is needed, that journal will receive no lubrication.

Other types of assembly errors may also be seen. If a connecting rod or main bearing cap is installed in the wrong position, or a bearing isn't set into place securely, lubrication will be insufficient and cause failure.

Careful installation procedures are, of course, critical in every aspect of engine building – careless errors are always expensive.

Machining Issues

As with the installation issues, problems in the machining process can often result in bearing failures. An out-of-round housing bore will cause the bearing to eventually conform to the out-of-roundness. This can decrease the oil clearance enough to cause metal-to-metal contact, resulting in areas of heavy wear. Engine vibration or alternating loading and flexing of the connecting rod can be the cause.

Another cause of bearing failure can be seen in a crankshaft that has been refurbished with a grinding wheel in poor condition. Hourglass-shaped, barrel-shaped or tapered crank journals will result in uneven or improper lubrication. Load distribution across the bearing will also be uneven, and the bearing will show uneven areas of wear.

Fillet ride occurs if the radius of the fillet in the corner of each crank journal is larger than needed. The edges of the bearing can then ride on those fillets rather than fitting neatly between them. This metal-to-metal wear will cause excessive wear and bearing failure.

When grinding the crankshaft, be careful to use a grinding wheel in excellent condition to maintain the necessary geometry of the fillet radii.

There are a number of reasons that the crankshaft and block housings may be misaligned, including improper machining, a bent crankshaft or damaged engine block. Each of these problems will likely cause significant damage to some of the bearings and less to others. Your investigations will focus on the tolerances to ensure the block and parts are within manufacturer specs.

Rebuilders should also always carefully inspect connecting rods to make sure they are not twisted, as this can cause uneven bearing loading and wear.

The term "crush" refers to the outward force created by the portion of the bearing, which extends above the housing bore when the bearing halves are set into place. This "extra" material holds the outside diameter of the bearings firmly against the housing bore when the assembly is torqued to specification. By increasing the surface contact between the bearing and connecting rod housing bore, crush minimizes bearing movement, helps to compensate for bore distortion and aids in heat transfer.

In simple terms, bearing crush is what holds the bearing in place. Think of it as putting 10 pounds of something into a 5 pound bag. The tang or locator tab on the shell that fits the saddle is only for locating the bearing during assembly. Note: some manufacturers have done away with the tang.

When crush is correct, slightly elliptical bearing shells conform to a perfect circle when they're torqued into place. In this way, the crankshaft rotates properly.

However, when there is excessive crush, the additional compressive force causes the bearing to bulge inward at the parting lines causing side pinch.

Excessive crush may be the result of an attempt to reduce oil consumption by filing down the bearing cap, assembling the bearing caps too tightly by over torquing the fasteners or, in some cases, using too few shims. Insufficient crush, on the other hand, will result in bearings that are not held securely in the bore, and remain free to move back and forth within the housing. Because contact between the bearing back and housing bore is necessary for cooling, this condition means heat transfer away from the bearing is impeded, resulting in overheating and deterioration of the bearing surface.

Insufficient crush may be caused by the improper attempt to achieve a better fit by filing the parting faces, by dirt or burrs holding the bearing caps open, improperly torquing the fasteners during installation, improperly sizing the housing bore or (if needed) using too many shims in the assembly process.

Shiny areas will be seen on the back of the bearing due to its rubbing back and forth. In some cases, discoloration may be seen where oil has worked its way between the two surfaces and burned.

Overloading may be caused by vehicle operator error. Excessive idling can result in an oil film that can't support the load needed.

Engine lugging can distort either (or both) the crankcase or crankshaft, affecting either (or both) the connecting rod and/or main bearings.

Hot rodding, or forcing excessive loads, can similarly affect the bearings. Engine tuning and operating conditions should always be followed and appropriate bearing materials chosen for the application.

A vehicle that leaks oil, causing oil starvation, has its share of issues, as we have seen, of course. But some vehicle owners who have cars or trucks that do not leak oil are in an even more potentially serious situation. At least the leaker lets you know it needs oil added now and then, with fresh oil maintaining its levels. The engine that seems to be leak free can be overlooked, yet after a certain amount of time, the oil begins to degrade. The acids in the oil then attack the bearing surface.

Proper selection of bearings will go a long way toward a successful engine build. And checking assembled bearing clearances to make sure the bearings are not too tight or too loose should always be done as a final check to make sure oil clearances are within the desired range for the engine.

Attention to the machining and material selection processes at the front end should help reduce the chance of bearing failure down the road. But armed with these forensic tools, should those mysterious bearing failures occur, you should easily be able to solve the crime. **EPSFG**

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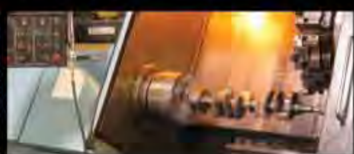

CAMS & BEARINGS

It is often said that the camshaft is the heart of the valve train. It is precisely timed in relation to the crankshaft and pistons, around and around at half the speed of the crankshaft, but high engine speeds can sometimes be too much for stock valve springs to control. When this happens the valves can't shut quickly enough to keep the lifters on the cam. Instead of following the cam lobe profile, the lifters begin to jump off the lobes. And the steeper the cam profile, the worse the problem becomes as engine speeds climb higher.

Another thing that happens when the valve springs can't keep up with the cam, the lifters land harder on the way down and begin to bounce slightly, causing the valves to also bounce as they seat. In addition to increasing wear and the likelihood of fatigue failure, valve bounce also disturbs airflow into and out of the combustion chamber and decreases high rpm performance.

Flat tappet cams have long been the norm for most small block and big block Chevy and Ford V8s. Flat tappet cams are simple and affordable, and offer a choice of solid or hydraulic lifters. Solid lifters are capable of higher rpms and can be adjusted to fine tune the valve train, while hydraulic lifters eliminate valve train noise as well as the need for periodic valve lash adjustments. Hydraulic lifters are usually the best choice for most street engines, but some customers may insist on the clatter and adjustability of high revving solid lifters. Many experts say there is plenty of opportunity for engine builders to convert street performance customers who want driveability to a roller cam and roller rockers, with somewhat stronger springs and stock or slightly higher rocker arm lift ratios.

Roller cams (with solid or hydraulic lifters) offer a significant reduction in friction compared to a flat tapped cam, and can also handle steeper cam lobes for faster valve opening and closing rates. Fast lift, short duration cams are ideal for the street because they make good low and mid-range power for off-the-line performance and everyday driveability. But their added complexity makes them more expensive than flat tappet cams. Even so, several camshaft manufacturers reported that more street engine builders are opting for hydraulic roller cams these days, primarily to avoid lubrication issues with today's motor oils.

The highest load area inside an engine is typically the point where the valve lifter rides on the cam lobe. Roller cams and overhead cams with followers produce much less friction than flat tappet cams, which car makers have not used in engines for many years. Roller cams have much lower loads, so high levels of ZDDP (Zinc Dialkyl Dithio Phosphate) are no longer needed in today's oils.

One engine part supplier said that many engine builder customers are reusing roller cams and lifters during rebuilds since they don't physically wear. But a good cleaning and inspection of the cam and lifters is necessary if these parts are going to be reused. Roller cam lobes don't usually wear but the roller cam journals do. There are many undersized cam bearings available to engine builders who grind and polish damaged roller cam journals to a new and smaller diameter. Grinding and polishing damaged cam journals can save the rebuilder about $150 by not having to purchase a new roller camshaft.

Cam Construction

Flat-tappet camshafts, whether mechanical or hydraulic, are all castings. Those carbides give you a very hard surface for the lifter to wear on. The changes in lubrication technology have impacted the cam and lifter partnership as well as other engine components. Premature wear of cam lobe and lifter faces with flat tappet lifters and cams is a very real problem. We know of some NASCAR teams that are using cams and lifters made out of tool steel because of better wear characteristics.

One cam company said it has 13-14,000 cam designs in its library. So if an engine builder needs a cam that's 260 degrees and .400˝ lift, there are probably 25 cams that fit that. There is a fine line between close and having exactly the right cam with the right lifter and the right pushrod and the rocker arm and valve spring with the right weight valve so the engine will operate properly. By building a relationship with a cam company, they'll be more than likely be able to help you work through your questions.

Duration

Duration is often measured at .050˝ above the base circle of the cam lobe. The .050˝ specs are the ones most commonly cited in aftermarket catalogs. Generally speaking, the longer the duration the higher the rpm where the cam makes power. Short duration cams are good for low speed torque and throttle response while long duration cams hold the valves open longer for better high speed breathing and top end power.

Cams with durations in the 195 to 210 degree range (measured at .050˝ cam lift) are usually considered best for stock unmodified engines and those with computerized engine controls. Once you go beyond 210 to 220 degrees of duration, intake vacuum starts to drop. This upsets idle quality and affects the operation of computerized engine control systems.

Performance cams typically have durations ranging from 220 up to 280 degrees or more. The longer the duration, the choppier the idle and the higher the cam's power range on the rpm scale. A cam with a duration of 240 degrees or higher will typically produce the most power from 3,500 rpm to 7,000 rpm.

Comparing duration specs may be inaccurate because it doesn't tell you anything about the lobes themselves. Though cams from two different manufacturers may have identical lift and duration specs, the lobes on one cam may be ground differently from those on the other. One cam may have more of a peak-shaped lobe while the other has a "fatter" lobe. A "V" shaped lobe will breathe differently

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from a "U" shaped lobe because it doesn't hold the valve at its maximum opening as long.

One lobe profile may also close the valve more softly than the other, to reduce valve bounce at high speed. Valve float can also be a problem with lobes that change shape abruptly unless valve spring pressure is increased. The profile of the lobes on one cam may also be the same on both the up and down sides of the lobe (which is the norm for most stock and street performance cams) compared to an "asymmetrical" grind (different profiles on each side of the lobe) on the other cam.

The only way to really compare cam grinds is to measure and plot lift versus rotation on a graph. This can be done manually with a degree wheel and dial indicator (which is a tedious job), or with an electronic stylus (such as the Cam Doctor) that plots the results on a computer.

Overlap

Another spec you need to look at when selecting a cam is the relative timing of the intake and exhaust valves. This can be expressed either as "valve overlap" (the time during which both the intake and exhaust valves are both open) or "lobe separation" (the number of degrees or angle between the centerlines of the intake and exhaust lobes). Decreasing the lobe separation increases overlap, while increasing the separation decreases overlap.

Most stock replacement cams with durations of less than 200 degrees will have lobe separations of 112 to 114 degrees. Higher duration cams for mid-range performance typically have 110 to 112 degrees of lobe separation. With racing cams, you'll find lobe separations that range from 106 to 108 degrees for more valve overlap.

Overlap occurs when the intake valve starts to open before the exhaust valve has finished closing. Increasing overlap can be a desirable thing in a naturally aspirated high rpm engine because the outgoing exhaust actually helps scavenge the cylinder to draw more air and fuel into the combustion chamber. But too much overlap at low rpm kills low end torque and throttle response by reducing intake vacuum excessively. It can also create idle emission problems by allowing unburned fuel to be drawn through into the exhaust.

Diesel Performance Camshafts

A diesel engine requires a much higher static compression ratio than a gasoline engine, and on most engines there is no intake vacuum because the engine is unthrottled. If a customer asks you to build a performance diesel engine, it's going to take a different approach than building a performance gasoline engine. Valve lift may also be limited by the tight piston-to-valve clearances in most diesel engines. So unlike gasoline engines, you can't go nuts with lift and duration to make more power. A bigger camshaft can provide more power, but only if the lift and duration are right for the application.

The most significant power gains in a diesel engine come from increasing the amount of boost delivered by the turbocharger(s). The camshaft must have the right exhaust characteristics so it will spool up the turbo faster and keep it spinning at peak efficiency in the engine's power band. For some types of pulling, the power band can be quite narrow, say only 2,000 to 3,000 rpm for a big agricultural diesel engine, or maybe 3,000 to 5,000 rpm for a pickup truck. A street truck, by comparison, may make most of its power from 1,800 to 3,200 rpm.

If engine speed drops too low during a truck or tractor pulling event, the turbo can stall or "chirp," causing the boost pressure to suddenly drop. This kills power and may even cause the engine to stall.

"Less is more" is often the best advice when choosing a diesel performance cam, especially if the engine is going to be in a street vehicle. With gasoline engines, you want to increase valve duration to get more power, but this approach doesn't work for diesel engines. One diesel expert said that for street driven daily drivers, you want a camshaft that delivers a lot of cylinder pressure – which means limiting valve overlap. You don't really need a lot of valve lift at low rpm on the street. You also need the right injector timing, pump tuning and turbo sizing.

A mild cam along with some injector and turbo tuning will produce the best power gains for a street truck without sacrificing everyday driveability, according to one diesel expert. However, for racing or pulling, builders must do extensive modifications to the heads, pistons and turbo as well as the camshaft to realize serious power gains.

Cam Bearings

Cam bearings are typically constructed of a babbitt bearing surface with a steel backing. The babbitt allows for particles to embed without damaging the bore, however, it can only withstand so much load. In applications with higher rpms, engine builders often choose cam bearings made with a composite alloy material that is proprietary to each manufacturer. And because the bearings are made of an alloy it maintains its strength throughout the bearing, but it is less forgiving than babbitt.

More than half of cam bearing failures are caused by metallic particles that scratch the journals and tear or weaken the thin babbitt overlays that is in the more conventional cam bearing.

Cam bearings are typically installed first in OHV engines after the engine block has been thoroughly cleaned and prepped.

Cam bearing installation is a relatively simple process, especially with the use of a good quality cam bearing installation tool. It is important to line up the oil feed holes in applications where it is provided. In 360 degree grooved bores it isn't necessary to line up oil holes exactly but the best location for maximum camshaft oil support is around the 60 degree mark.

If you get a tight spot after installing the cam bearings and camshaft, this may be caused by a bearing installation tool's driving arbor that has deformed the bearing surface. You can prevent this from damaging your cam by chamfering both bearing edges on all of the cam bearings with a three cornered scraper before installation.

Be careful not to damage the bearing journals when installing the camshaft. It is recommended that you coat the cam journals with a high quality moly based lubricant or whatever the cam manufacturer prefers. After installation, rotate the camshaft for proper fit. **EPSFG**