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TOOL MAINTENANCE

Let's face it, when you invest in new state-of-the-art equipment, some or most of that investment is in the tooling. Tooling needs proper care – especially if you want your new machine to perform according to the manufacturer's specs. These newer machines don't have a clue that your tooling is dull, bent, nicked, burred, or not the correct size. They do exactly what you direct them to do, and if your tooling is not up to spec you'll trash a work piece in record time.

With this year's *Performance Engine Parts and Surface Finish Guide*, we aim to give you the information you need to do the common jobs successfully – and one of the keys to success is starting well. That means being sure your equipment, and especially tooling, is in top condition. Your tooling often has very special cutter blades, carbide pilots, extremely sensitive leveling systems and upgraded mounting fixtures to provide the best finish – but it takes an effort from you to ensure it lives up to the task.

Most feature a tool board to store and prep the necessary tooling. The tool board organizes the tooling and provides some protection for the tools when not in use, but the operator has a huge responsibility to ensure the tooling is in tip-top condition at all times.

Let's focus on tooling made from carbide because of its universal availability. Carbide tooling comes in a variety of forms. You have carbide counter-bore cutters, valve guide pilots, core drills, core reamers, ID reamers and single or multi angle cutters. Carbide is the most affordable material that provides long life, holds size and can be formed into a variety of shapes and is readily available.

Carbide Pilots – To hold centricity the tooling makers started making pilots out of solid carbide. However, it needs tender loving care. Carbide by its very nature is more brittle than high-speed steel. If you drop a carbide pilot onto a concrete floor you will have many smaller, unusable carbide pilots. Since carbide pilots can cost a pretty good chunk of change, it's in your best interest to treat them with care. At the very least you should put a fatigue mat in front of the work area.

Store your pilots away from each other when not in use. That's what all the little vertical holes in your tool board are for. Don't let them bang away at each other in a drawer. Organize them according to size; mark your tool board so you know when one is missing.

Always wipe the pilots down when done, which cleans the machining dust off and prevents that dust from transferring into the next job. Periodically check the top and bottom size to ensure they are still accurate. They will wear over time. Replace as necessary.

Three angle cutter tips – These little guys are the real worker when it comes to cutting the seats on multi-valve overhead cam type cylinder heads as well as performance and diesel cylinder heads. Although they are readily affordable they are not free.

Take a magnifying glass and inspect the cutting edge, look for nicks, burrs and burn marks. If you find damage, you can sharpen the cutting edge. It won't reshape the degree of angle, it just sharpens the cutting edge.

Keep the tips in a protected environment to prevent them from banging against each other. Be sure to keep the little plastic sleeves that your supplier always ships them in. When you acquire enough of them, take the time to mark the outside of the box and then only store that blade in that box.

Over time you will have a complete and well-organized inventory of tips. In a perfect world you would have your most popular tips installed in holders and ready to go for the next job.

Another tip to prolong the life and improve the cutting action of your tips is to use a cutting fluid. Tool suppliers have some stuff that really works well.

Seat counter-bore cutters – Counter-bore cutters are generally fixed in size and the carbide tips are either indexable and replaceable, or they are brazed. They are available in a variety of sizes and some manufacturers offer a fully adjustable type of counter bore cutter.

Again don't let them come in contact with each other and periodically inspect them for chips or burrs. They can be resharpened or rebuilt by a quality supplier. Always test bore or measure them prior to using them on a customer's cylinder head to insure the counter bore size is correct.

If you run out of room on your tool board, a clever idea is to take a 2x4 and drill 5/16″ holes about 1 to 2″ apart and bolt that 2x4 to your workstation. Then you can mark the board and organize them according to size.

Boring tools – Boring tips or brazed cutters are brittle and need periodic inspection as well as in house resharpening. Always store away from other boring tools and keep them sharp to maintain fast and efficient boring cycles.

Your tools are your machine's best friends. Treat them like it and you'll be able to count on them when you need to. If you don't, that job you need to get out on Friday will be compromised due to the fact that your tooling was not up to the challenge. Remember – take care of your tools and your tools will be ready for the task when you need them. **PPSFG**

HORIZONTALS: CAMS & CRANKS

Engines make horsepower with their camshafts and hold it all together with the crankshaft. It takes a relatively hot cam profile to create significant gains in horsepower, while the crank – and subsequent components – must handle all the stresses of converting up and down motion to reciprocal motion. And when you're talking about a performance engine, those stresses are much higher and consequences of a failure are much greater. Therefore, selecting the right parts for your build is critical to its success.

It's really all about relationships. When the engine is at maximum output, the rods and pistons are trying to shove the crank right out the bottom of the engine, so strength is a prime characteristic of a crankshaft. Concurrently, the camshaft, which is precisely timed in relation to the crankshaft, is spinning around at half the speed of the crank. 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 increase.

Crankshafts

There are currently three types of manufacturing techniques used to make crankshafts – casting, forging and billet machining. The design and materials of the components that you use depend mostly on the engine and vehicle's intended purpose.

Standard, stock cast cranks are fine for mild performance applications, according to many experts. But with the plethora of aftermarket performance parts on the market today, it doesn't take much to push past this mild horsepower threshold. The pounding, twisting forces created by those trick aftermarket heads or supercharger will wreak havoc on the cast crank until it fails.

Most stock cast crankshafts have a tensile strength of 80,000-100,000 psi, depending on how much carbon content is in it. The typical cast crank made of 1053 alloy is appropriate for builds up to 450 horsepower, say most experts.

The biggest difference in the various alloy steel crank materials is the grain structure, heat-treating process and the mixture of elements. Cranks made of 4130 or 4340 for example, have higher amounts of chrome and nickel, which makes them stronger.

If you're building a big horsepower engine you may want to consider upgrading to a forged or billet crank made of 4340 alloy steel. The 4340 billet steel crank has the highest fatigue strength. Some budget forged cranks are made of a little lower grade alloy steel and, consequently, have a lower tensile strength rating than 4340 but still better than cast iron.

The majority of forged and billet performance cranks are 4340 or another high grade alloy steel, and are made something like a cake, to borrow a loose analogy. There may be a lot of chocolate cakes that look the same but the ingredients are slightly different. Manufacturers tend to have their own recipes for the material even though it is 4340 alloy.

To continue that analogy, creating a crankshaft is like baking a cake. Manufacturers choose all the right ingredients and then pop it in the oven to see how it turns out. Using quality ingredients and the right temperature and time for the heat treatment makes for a very tasty part.

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 up to 165,000 psi depending on the heat treatment and the quality of the alloy. The ingredients in the cake that boost the strength are chromium, nickel and molybdenum.

Heat Treatment

Heat treatments in general can raise tensile strength of an alloy steel from as low as 55,000 psi to nearly 300,000 psi in some cases. As far as crankshafts are concerned, 165,000 psi is about the strongest crank available from billet steel alloy.

Crankshafts should have the ability to stretch and bend and then return back to their original shape without any distortion. Higher end cranks are made of materials that allow elongation and have greater fatigue strength so they can withstand the constant pounding forces of combustion without failing.

Most OE cast cranks use the induction heat treating method because it hardens the surface for the lowest cost, and is generally easier to incorporate in a production environment. It also allows the crankshaft to be reground without having to undergo any further heat treatments. But high performance or racing crankshafts made of forged alloy steel or billet tend to use the nitridization process instead of induction heat treatment. Nitridization is slower, as well as more costly, and it puts certain demands on the alloying metals in the steel in order to be able to create stable nitrides. The advantage with nitriding is that it can be done at low temperatures, it produces a very hard surface and the process will leave some compressive residual stress in the surface, which is good for the fatigue properties of the crankshaft.

The nitridization process involves injecting nitrogen into the surface of the crank to a depth of about .010″ at a controlled heat. Air is vacuumed out and replaced with a chemical that penetrates the surface of the part, which included cranks and cams for automotive applications. One of the drawbacks of nitriding is that the part has to be re-treated if you do any machine work.

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 nitrocarburizing

process 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 and Coating

After a crank has been ground to size, the journals are often micropolished to improve the surface finish. Some crank suppliers have said the ideal surface finish for rod and main journals should be 5 microinches or less.

Some crank suppliers also polish the entire crankshaft. This process will not only make for an attractive finish, it also helps reduce the risk of surface cracks forming from stress risers left over from the manufacturing process. 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 one crank supplier said, at high rpm there won't be any oil on the crank anyway because it will be flung off in operation.

But there are still power gains to be found from polishing, according to some experts. One company that applies a unique finishing process to their cranks that leaves a bright, chrome-like finish says the reduction in friction and oil retention is good for 1 to 3% more horsepower in a SB Chevy with no other changes, and up to a 4% increase in horsepower on a BB Chevy.

Less Drag

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 be put to the ground though the drivetrain. A vacuum sump can do the same thing. However, if you can't run a dry sump, 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.

Alignment Check

Experts recommend checking the main bearing housing bores (as well as the cam bores) carefully. If they are in close alignment and the diameter is in the factory specified tolerance, it may not need to be align honed, depending on your expected level of performance. If everything checks out, the block may only need to be bored and honed – but if it's even slightly in doubt, err on the side of precision.

For high horsepower applications, you must be more particular about tolerances. The main bearing housing bores are machined with a boring tool from the factory. This leaves a moderately rough finish for the bearing to rest against, so the actual contact area is reduced to where the bearing contacts the high spots on the surface of the bearing seat. For any high horsepower application, the block should be align honed. This ensures that the bores will be in perfect alignment and also provides a very flat, smooth bearing seat.

Camshafts

The development of new camshaft profiles is an ongoing process that will never stagnate. There are a lot of proven grinds that work well in various engines and combinations. Many of these grinds have been popular for years.

But with so many stroker engines being built these days, and a proliferation of high-flow aftermarket cylinder heads for a growing number of older engines, cam grinders are always looking for the next innovation that can give their customers a performance edge over what's currently available from their competitors.

The camshaft is the main component that will help enhance the performance characteristics of an engine, but it is important to understand what role the cam plays in the engine and how the cam specs can be changed to optimize the performance. The cam causes the valves to open and close, and that regulates how much air and fuel enters and exits the combustion chamber.

There are two basic types of camshafts used commonly in most OHV V8 performance street applications. Most of your older, traditional cams are designed to be used with flat tappet hydraulic lifters, while most newer cams work in concert with a hydraulic roller lifter. While it is commonly thought that the decrease in friction is the main advantage of the roller cam, experts say the benefit is actually that the roller design allows the valve to be opened and closed at a much faster rate, resulting in more area under the curve with shorter seat timing.

Cam experts say it is very important to understand how the cams are rated prior to comparing a stock cam to an aftermarket cam, and before selecting a cam. The very beginning and end of the lift curve on a stock cam is usually such that the valve opens slowly and sits down very gently on the seat. This setup is mostly used by the OEs to reduce noise and seat recession, as well as improve overall durability. It is the area in which the performance aftermarket cam makers exploit in order to increase performance and give you that mean sound most of your customers want.

Even with similar lift as a stock cam, many performance cams can have considerably more area under the curve with quite a decrease in seat duration. To provide a better comparison of duration and engine power, the aftermarket industry has settled on .050″ duration as a standard. While the seat timing tends to have greater influence on characteristics such as idle stability and vacuum, the .050″ duration provides the clearest indication of where the engine will produce peak torque and power.

This holds true even when the ramp designs are far different, resulting in substantial differences in seat timing. This makes it possible for engine builders to compare the .050″ durations when selecting a camshaft's size, and use the advertised seat durations for approximating how quickly the profile gets the valves on and off the seat.

Getting the valve off and on the seat more quickly sets the stage for either less seat timing and more area, or the more common goal of similar seat timing and much more area.

As with any valve train, experts say there are limits on the maximum velocity of the valve, either due to the tappet design or how much velocity (and energy) the valve spring can control. In either case, getting the valve off the seat quickly allows the valve to reach maximum velocity sooner, gives it more time to turn around, and results in increased area. It is somewhat analogous to the effect of 0 to 60 mph time on quarter-mile time. If a Top Fuel dragster took 6 seconds to get from 0 to 60 mph, like a respectable passenger car, it would be impossible for it to run a 4.5-second quarter-mile time. Similarly, the cam profile design cannot take all day to get off the seat and still expect to have enough area under the curve to allow the airflow needed to optimized high rpm power.

The biggest mistake most engine builders make when selecting a cam is over-camming the engine with too much lift and/or duration. Big numbers look impressive, and you may have a customer who insists having the wildest cam he can find for his engine, but is it the best cam for the application?

The best all-around cam for a street performance engines would be one that has its peak power and torque curve in the 1,500 to 3,000 rpm range. Most domestic iron V8 street engines don't get revved over 5,000 rpms. But if you are building a race motor you might want a cam that produces peak power and torque in the rpm range where the car will be running most of the time.

Most stock and lightly modified heads won't flow any more air once valve lift reaches about 0.550″. Pushing the valves open any further won't produce any more power, and may actually lose some off the top end because of reversionary air flow. On the other hand, if you're building a big race motor with highly modified heads and huge ports that can handle gobs of air, increasing valve lift to the physical limits of the engine will be necessary to make the most power possible.

Another decision that has to be made is how much lift do you want from the cam and rockers? For any given lift, you can use various combinations of cam lift and rocker arm ratio to achieve the same numbers. According to one cam supplier we interviewed, the best approach is to get more lift with the rocker arms and less with the cam. Why? Because higher lift cams are more highly loaded cams that experience more wear.

Consequently, you are more apt to round off a lobe on a high lift cam that has big lobes than one which uses smaller lobes with higher ratio rocker arms. The valvetrain also tends to be more stable when a higher percentage of the valve lift is generated by the rocker arms rather than the cam lobes, lifters and pushrods.

OHC Cam Bores

In an overhead cam application, line boring and an oversize cam may be necessary to restore the cam bores. Most late-model OHC engines don't have cam bearing inserts. If the engine was overheated, cam bore damage is very common. Usually the middle bores are the most damaged because the head bows up in the middle. There are a number of ways to salvage a damaged head. One is to line bore or hone the OHC cam bores to accept a new cam with oversized journals, or to removed the cam journal caps and grind down the face of the caps and machine them back to standard size. If there are no caps, the cam bores can be enlarged to accept bearing inserts, if they are available for the application.

Another problem to watch out for is a bent cam. It only takes a few thousandths of an inch of misalignment for the cam to bind in the head. To check cam straightness, place the cam in a pair of V-blocks (one at each end), then rotate the cam with a dial indicator placed on the middle journal. If runout exceeds specs, the cam is bent and needs to be straightened or replaced. **PPSFG**

VALVE, SEATS & GUIDES

In stock production engines, the exhaust valve is designed to endure the rigors of daily commuting for 150,000 miles or more. But try going more than a few hundred miles with a racing engine and you're pushing your luck. Depending on whether or not your racing engine has been over-revved, the valves may last only a few races.

In a NASCAR engine where most teams are now running titanium valves, they might be replaced every race. In Pro Stock or Top Fuel drag racing, valves might be replaced every half dozen runs. While a street/strip engine may last more than a season, it all depends on the conditions under which the engines operate.

One supplier of valve train components says that with the exception of Inconel big block Chevy marine and supercharged valves, their performance valves are typically made from 21-4N stainless material. The explanation is that there are many grades of stainless steel, and just having a valve made of "stainless" doesn't mean a lot. However, industry experts we have consulted note that 21-4N stainless steel is generally accepted as a quality material for performance valves.

There are many minor variations on the typical performance valve made of 21-4N, and there are at least a half a dozen different alloy variations of this metal. The manufacturer may find that they can do something a little less expensive or make the valve last a little longer by putting a hardening agent in it or some other treatment. The intake valves are all basically made from one type of material and exhaust valves are made from another. But some manufacturers will make all the valves from a 21-4N derivative regardless of which valve it is. The reason for this, according to our expert, is because they end up buying in more bulk and therefore a more significant discount than if the manufacturer bought half of one and half of another type of material.

While most racing and performance engines use a stainless valve of some sort, that all changes when you get into high end pro racing. At the top levels of the sport, experts say titanium or Inconel materials are preferred for their light weight and durability, and where cost is not an issue.

When should you upgrade valve materials? Engine builders are usually encouraged to look at upgrading materials when they use more aggressive cam profiles or if the rpm band of the engine is increased. From a seat and guide standpoint, you should look for something that will withstand the higher rpms and loading of the guide from side load from a high lift cam and seats for the combination of rpm and spring pressure. Titanium or hollow-stem valves are always a consideration when trying to lighten up the valve train.

Titanium

Titanium valves are the lightest valves available, weighing about 40 percent less than stainless steel valves of the same size with solid stems. Titanium valves are mostly used in high revving engines with more aggressive cam profiles that open and close the valves more quickly. But titanium valves are not for everybody because they are more expensive than stainless.

Many titanium valves are custom machined rather than produced to stock dimensions for specific heads: the head diameter, stem length and diameter, and tip are all machined to whatever specifications you choose. This allows you to get exactly what you want, and eliminates the need for suppliers to produce and stock inventory for applications that may not be popular items.

Valve Blanks

With the proliferation of aftermarket cylinder heads that require unique valve sizes, it has become difficult for some suppliers to keep up in recent years. Most of the street performance heads use the same size valves as OEM heads, but many racing heads do not. The head may require a valve that is slightly longer than a standard valve, or one with a different head or stem diameter. As a result, valve suppliers now have to carry a greater variety of valve head and stem diameters, and lengths, or custom make the valves as needed. Some valve suppliers say they can turn around a custom order in a week thanks to CNC tooling that allows blanks to be easily machined to specifications.

Sodium-Filled Valves

Sodium-filled hollow stem valves are available for higher heat applications, and are typically used for the exhaust valves. The sodium inside the valve stem melts and absorbs heat from the valve heat. As the valve opens and closes, the sodium sloshes up and down inside the valve to transfer heat from the valve head to the stem. This helps the head run cooler to reduce the risk of valve burning, preignition and detonation.

The difference in cooling is significant. With a conventional solid stem exhaust valve, 75 percent of the cooling takes place across the valve seat and 25 percent through the stem. In a sodium-filled exhaust valve, 40 percent of the cooling is through the stem so the valve can tolerate more heat.

Hollow Stem Valves

One way valve suppliers are taking additional weight out of intake (and exhaust) valves today is offering "hollow stem" valves. The valve stem is gun-drilled and micropolished to make it hollow like a pushrod. The drilling is only done in the upper 2/3 of the stem where rigidity is less of a factor than the area just above the valve head. After the stem has been drilled out, a hardened tip is welded onto the top of the stem. The result is a valve that is typically 20 to 22 percent lighter than a valve with a solid stem.

According to one supplier of hollow stem performance valves, the valves are

VALVE SEAT TECHNOLOGY HAS CHANGED

GM is equipping the LS3 heads with high tech sintered copper-infiltrated valve seats. High-Performance European engines like BMW and Mercedes also use this technology. This is a powder metal valve seat with a copper wafer that is infiltrated into the valve seat. This creates a unique product of 15% free copper in the microstructure of the seat. Allowing heat to be quickly transferred and performance greatly improved.

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good for 300 to 350 more rpm with no other modifications (same springs, rockers, pushrods, etc.).

Coatings

During discussions with suppliers, we have been told that coatings are being used in more and more applications these days. When it comes to valves, a number of coatings may be employed, including special coatings for titanium valves.

In some cases, a metal treatment, rather than a coating, is used with premium valves. In the case of one supplier, treated valves go through a five step liquid nitriding process which introduces nitrogen into the surface of the valve, resulting in a thin, high hardness case that is both wear- and corrosion-resistant. The valve's dimensions are not changed by the treatment. In addition, the lower coefficient of friction from this coating leads to better sliding, less risk of scuffing at the guides and improved durability against wear on both the guide and the stem.

Valve Guides

Bronze valve guides are most widely used in European and racing applications. Powdered metal (PM) guides are mostly used in stock automotive engines as well as cast iron guides. Diesel engines often use coatings on cast iron guides to combat the wear in newer, low sulfur diesel applications.

One race engine expert pointed out some interesting observations he has made over the years. He believes worn valve guides cost more horsepower on the dyno than you might think. In one experiment with a test engine, he went from .002″ to .004″ to .006″ on intake valve clearance. The results revealed that the engine had dropped four horsepower from .002″ to .004″. He lost one horsepower per cylinder on a 4-cylinder test mule, and from .004″ to .006″ he lost another nine horsepower. According to this expert, that's not going to be the case for every single engine out there, but the test mule responded very similarly to a small block Chevy.

Additionally, he says that 40 percent of the heat is conducted out through the valve guide. If the clearance goes up by much, the conductivity from the stem to the guide will drop like a rock – transferring it all to the guide. And that's why it's better to use bronze guides because they conduct heat away more effectively from the water jacket even if it goes through cast iron first. Since the surface area of the guide is about 4 times that of the valve stem, conducting heat into 4 times the area of cast iron will cut that temperature dramatically.

Valve Seats

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.

Every valve seat supplier makes a big deal about the advantages of their proprietary alloys – and rightly so. The strength, hardness, wear resistance and thermal properties of a valve seat alloy can make or break it depending on the application.

An alloy that lacks the hardness and wear resistance for a high-heat, high-load engine application won't hold up very well. As a general rule, the higher the operating temperature of the engine and the higher heat loads it must endure, the higher the grade of seat alloy that will be required to handle the job. Cut corners here with a set

of cheap replacement seats and you'll probably regret it later.

Titanium valves do not cool as well as stainless steel valves, so they require valve seats that conduct heat at a much higher rate. For many years, the seat alloy of choice for titanium valves was beryllium copper, which conducts heat three to as much as six times faster than most iron alloys.

Beryllium copper valve seat alloys typically contain only about 1.5 to 2.5 percent beryllium. But that's enough to create a seat material that provides high thermal conductivity along with the durability required for titanium valves in a high performance engine.

Some Be-Cu valve seats are 97% copper with 1.8 to 2.0% beryllium, and have a hardness of 38 to 41 Rockwell C. Other alloys contain less beryllium (0.2 to 0.6%) but add nickel (1.4 to 2.2%) to reduce hardness to 20 Rockwell C. By comparison, ductile iron seats typically have a hardness of around 32 Rockwell C.

But beryllium copper seats have some drawbacks. One is that the alloys are expensive. Another is that beryllium is a toxic metal. There's no risk in handling the seats, but any dust that's created with machining the seats can be hazardous.

In recent years, proprietary copper-nickel alloy valve seats have replaced Be-Cu seats in many performance and high heat applications. Some of these new copper-nickel alloys have a thermal conductivity rating of up to 90 BTU per foot per hour per degrees F, which is more than enough to provide adequate cooling for titanium valves or stainless steel valves in high output or high heat engines.

Seat Installation, Finish Tips

On a high performance engine, a multi-angle valve job is an absolute must to optimize the breathing potential of the cylinder head.

But first you must install or recondition the valve guides before you do any seat work. The center line of the valve guide will determine the location and concentricity of the valve seat.

Using a valve-and-seat machine that is in good condition will ensure you can hold tight tolerances. Being off due to poor equipment won't do your valve job or reputation any good. The pilot-to-guide clearance should be .0002″ or less for accurate machining. One way to achieve that is to use a high pressure lubricant on the pilot.

The seat cutter must be sharp and spun at a high enough speed to produce a high quality finish on the seat. Any chatter while cutting a seat may be from too much play between the pilot and valve guide, slow cutter speed, or the machine isn't level. Using a coolant when cutting hard seats will also reduce chatter.

The commonly used 30-45-60 degree three-angle performance cut will flow better than a seat with a single 45 degree cut. But more angles breathe even better. Adding additional cuts under the seat, and using steeper angles generally helps the airflow numbers even more. Some well-known performance engine builders say they see the best flow numbers using a 58° undercut below the primary seat, and a 70° cut below that. Using a steeper top angle of 33° to 37° on the intake seats also helps reduce turbulence as the air enters the combustion chamber. Others use special cutters with an infinite radius or a CNC-controlled single point cutter to contour the seat above and below the primary 45° seat to optimize flow.

Unfortunately, there's no tried-and-true formula that works best for every engine. It takes a lot of time on a dry or wet flow bench to figure out which angles are going to produce the best results. And sometimes what looks good on a flow bench doesn't always produce more power because of fuel separation problems at the valve and seat interface. Because of this, experts say it often takes some trial-and-error experimentation to find the optimum combination of angles or seat profile that delivers the most power and throttle response. **PPSFG**

CYLINDER HEADS & MANIFOLDS

The top end of the engine is all about moving air and fuel to the combustion chamber as efficiently as possible and to produce as much power as possible in performance applications. Today's aftermarket cylinder heads and intake manifolds offer engine builders a lot of options – but choosing the right components for your build is more than just finding the biggest flow numbers.

Experts say it is important to match the head and intake to your application and intended use, specifically relating to rpm range. If your customer is an occasional drag strip competitor but mostly drives his showpiece to the local diner for car club nights, you may want to choose something that will be more streetable but still have reasonable performance from stoplight to stoplight. Of course, today's performance components blur the lines between street and racing more than ever, so you must know how to read between the lines for your customers.

Cylinder Heads

There are a lot of people who believe in the "bigger is better" philosophy when it comes to selecting cylinder heads. Aftermarket cylinder head manufacturers and head porting specialists like to brag about the latest cubic feet per minute (cfm) flow numbers they're able to achieve using the magic of flow bench testing and CNC machining. But even with the big flow numbers, the numbers can sometimes be misleading because of the way they are measured.

Heads do make horsepower, but they don't make it all by themselves. A set of killer aftermarket performance heads that is mismatched with a camshaft, valve train or induction system will never realize the engine's full potential. It's all about achieving optimum airflow and velocity within the rpm range where the engine is built to produce power.

That's where many street performance engine builders have gone astray. They overbuild the engine with components that are designed to deliver high rpm power for racing applications instead of building the engine to produce more low-end and mid-range torque. Even in all-out racing the engine with the biggest heads and biggest flow numbers doesn't always win the race.

Experts say cylinder head performance is not just about huge flow numbers and port volumes, it is the proper sizing and velocity that determines how well a cylinder head performs. As time has gone on, the lines between street and race have become so blurred that it depends on whom you talk to whether an engine or component is for race or street.

The best way to compare cylinder heads is to bolt them on an engine and do a series of dyno test runs to see how they perform. The best head is not necessarily the one that makes the most peak horsepower in a narrow rpm range, but the one that delivers the best power and torque curves for the intended application. If you're building a motor for a drag car, then peak high rpm power is what you want. If the engine is going into a circle track car, you want good throttle response and peak power in the mid to high rpm range. For a street application, a broad, flat torque curve and lots of low- and mid-range torque works best.

Airflow depends on valve lift, valve area, air density and the test pressure. There are industry-standard methods for calibrating flow benches and correcting airflow numbers to compensate for differences in air density. But airflow values can vary somewhat from one flow bench to another, depending on the methodology and equipment that is used. Most flow benches have a margin of error of around plus or minus one percent. On a cylinder head that flows 400 cfm, the margin of error could be plus or minus 4 cfm either way.

Another point to keep in mind when comparing airflow numbers is that the valves reach maximum lift only once during the intake and exhaust strokes. Flow numbers at peak valve lift may be impressive, but what's usually more important is how well the head flows at partial valve lift as the valves are opening and closing. Better flow characteristics at partial valve lift can have more of an effect on power and torque than big airflow numbers at peak lift.

Accurate cylinder head comparisons mean you should look at the entire flow curve from low lift to maximum lift. Once you've done that, you will have a much better picture of how the head will actually perform on the motor you are building.

Also, there's more to airflow than big cfm numbers. Air velocity and swirl are also important. A port that's sized properly for the engine displacement and rpm range will keep the air moving at higher velocity, resulting in more complete cylinder filling and more power. Air velocity affects both throttle response and low-end torque. That's why heads with port runner volumes that are too large for a given engine application may not perform as well as a stock cylinder head.

Swirl helps route air into the cylinder more efficiently and promotes better air and fuel mixing for better combustion. Swirl and turbulence can also cause air and fuel separation in the combustion chamber, which is something that can be visualized by wet flow testing.

Valve angle (the angle of the valve stem with respect to the deck surface) also affects airflow, and here shallower is usually better. The configuration of the combustion chamber, valve shrouding and even the diameter of the cylinder bore are additional factors that also affect airflow and a head's ability to make power.

What's Hot

The 600 cubic inch "monster motors" of a few years ago seem somewhat insignificant compared to the 850 and 900 cubic inch motors that are now commonplace in the market. There's even a 1,000 cubic inch naturally aspirated engine that makes over 2,150 horsepower and 1,550 lbs. of

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torque. It's hard to tell how far this trend will push engine displacements in the years ahead.

The bigger these engines get, the more air the cylinder heads have to flow to handle the added cubic inches. The availability of aftermarket engine blocks with wider bore spacing continues to expand, and with it the availability of larger cylinder heads to fit these engines.

Another trend that is more prevalent in today's cylinder heads is reduced valve stem angles and raised ports for increased airflow. This often requires custom fabricated intake manifolds or special intake manifold castings to mate with the modified heads. With these types of heads, installation is not a simple swap. Changing the head may also require changing the intake and exhaust manifolds, and possibly even the valve train configuration.

For small block Chevy applications, splayed valve symmetrical heads are available to replace siamese-style SBC heads. The symmetrical heads seal better and reduce the risk of head gasket failure in the hot spot area between adjacent exhaust valves on siamese style heads. The ports also provide a straighter shot at the valves than the ports on siamese heads.

Another feature that is abundant in performance cylinder heads is CNC profile heads. These heads are developed, typically by hand, through porting, grinding and then testing them out to see how they perform. Once a head is shaped by hand it is mapped by computer for its characteristics and port configurations of that application. People who do this kind of work build up a digital library of port configurations that work well with various head castings, camshaft and engine combinations. This allows them to replicate a proven port configuration by entering the data into a CNC machine and removing the unwanted metal to modify the cylinder head.

There is some debate as to whether or not ports in an "as cast" cylinder head flow as well as those in a CNC machined head. Many aftermarket performance cylinder heads that are sold with "as cast" ports are capable of delivering excellent performance out of the box with no additional modifications. The same goes for some stock heads (such as Chevy LS1 heads) that flow very well in their stock configuration. But there's always room for improvement by either hand porting or CNC machining "as cast" heads to change the contours of their ports, bowls and combustion chambers for better flow. It depends on what you are trying to achieve.

Is the end result better than the best "as cast" head for a given engine application? It depends on the castings that are available and how well they flow compared to an optimized CNC port configuration for the same setup. With most high-end performance heads, a raw casting is CNC machined to specific dimensions for that application to deliver peak performance.

Cylinder head performance is not just about huge flow numbers and port volumes, it is the proper sizing and velocity that determines how well a cylinder head performs.

Manifolds

A well-designed manifold that is properly matched to the engine's requirements will make more torque and horsepower than a manifold that is mismatched to the engine. An intake manifold is more than the plumbing that connects the carburetor or throttle body to the ports in the cylinder head. It is an integral part of the induction system that has to match the airflow characteristics of the cylinder head and camshaft, as well as the displacement and rpm range of the engine.

The sole purpose of your intake manifold is to provide the best possible passageway for air and fuel from your carburetor to your cylinder heads. Performance intake manifold manufacturers offer several different options to get air and fuel from carb to heads.

Intake Styles

Carbureted intake manifolds come in a variety of styles: dual-plane, single-plane, air-gap, tunnel ram and others. Choosing the right design comes down to matching the intake style to your customer's vehicle and intended rpm operating range.

Dual-plane intake manifolds, also sometimes called 180-degree intake manifolds, have two separate plenums that accept air/fuel from the carburetor. Each one of the plenums, or openings, feed four cylinders on a V8 engine. This divided design ensures that each bank of four cylinders only sees every other firing pulse (or 180 degrees of crank rotation), so there's less overlap between induction pulses. The result is a cleaner induction pulse, particularly at low rpm. Dual-plane intake manifolds also typically have longer intake runners, making them ideal for low and midrange power production.

Choose a dual-plane manifold for:

• Low-rpm response, power in the 1,500-6,500 rpm range
• Good idle quality
• Street performance, mild racing

Single-plane intake manifolds use a single open plenum, which feeds all eight cylinders on a V8 engine. Although this design doesn't provide the dual-plane's clean induction pulse in the low-rpm range, it generally allows for better, more equal flow distribution between cylinders. In addition, single-plane intakes typically have shorter, more-direct runners, so they're able to move higher amounts of air from the carb to the heads.

Choose a single-plane intake manifold for:

• High-rpm horsepower through 8,000 rpm
• Racing applications

While dual-plane and single-plane intake manifolds are the most common intake styles, there are a few additional options available. "Air-Gap"-style intake manifolds, reportedly improve on the typical dual-plane design by raising the intake runners. By adding extra space between the bottom of the intake and the engine, the runners are kept cooler and the intake charge remains colder and denser.

Choose an Air-Gap-style intake for:

• More power from idle-5,500 rpm
• Street performance

Tunnel ram intakes are dual-carb intakes that became popular on dragstrips in the 1960s and '70s. These distinctively tall single-plane intakes utilize longer runners than typical single-plane manifolds, effectively expanding the rpm powerband. Keep in mind, the dual-carb design calls for additional tuning, and the dimensions of the intake require more space.

Choose a tunnel ram intake for:

• High-rpm power
• Racing and wild street applications
• Aggressive look

Depending on your application, you can also find a wide range of dual-quad and tri-power intake manifolds for multi-carb setups. Like single-carb manifolds, these intakes are available in dual-plane, single-plane and even Air-Gap designs.

The Right Fit

Once you've selected the right intake manifold style for your application, you need to choose a manifold that fits your engine. Whether you're shopping for a carbureted or fuel-injection intake manifold, consider the following factors:

• Hood clearance
• Cylinder head port design
• Carburetor/throttle body mounting

For street applications, hood clearance is a major consideration. If your customer wants to retain the use of his hood, measure the height of the stock manifold and try to remain close to that dimension when choosing a performance intake manifold. Your customer can accommodate higher intake manifolds by using a hood scoop, low-profile air cleaner assembly, or other means. But remember, this will result in added time and cost.

Cylinder head port design is also an important consideration. For example, big block Chevy heads are available with multiple ports designs, including rectangular, oval, and peanut-style. Always make sure the intake runner ports match up with the intake ports on your cylinder heads.

On the top end, you need to make sure your new intake manifold will work with the carburetor's mounting pad configuration. Four-barrel carbs, for example, are available with three basic mounting pads: square bore, spread bore, and Dominator style. Check to see what type of mounting pad your carburetor uses and then make sure the intake matches up with it. If you're buying a fuel-injected manifold, make sure the throttle body inlet works with the throttle body size.

Fine Tune

Once you and your customer have settled on a general intake style, confirmed the proper port style, and verified the carb mounting pattern, you may decide to look at all the little details that separate each intake manifold. If you live in an area that employs special emissions regulations (i.e., California), look for a CARB E.O.-certified intake manifold. You can also compare

port cross-section, plenum volume, and specific runner lengths to really narrow down your choice.

Machining and Sealing

Sealing problems are inherent in bi-metallic engines because aluminum cylinder heads heat up much faster than cast-iron cylinder blocks during the warm-up cycle. The metallurgical differences mean the aluminum cylinder head tends to expand at a much faster than the cylinder block does throughout the entire engine cycle. This difference in expansion rates between aluminum and cast iron creates a scrubbing effect that eventually wears out the stainless steel "fire ring" that keeps combustion gases from entering the cooling system.

Because the cumulative effect of these repeated thermal events results in failed cylinder head gaskets, most aftermarket gasket manufacturers have designed head gaskets using space-age materials that resist scuffing wear in bi-metallic applications.

Head gaskets require a surface that is smooth and flat to cold seal and hold a lasting seal.

When multi-layer steel (MLS) head gaskets became commonplace a number of years ago, there was a lot of concern that aftermarket surfacing procedures might not be able to reproduce the mirror-like finish that the vehicle manufacturers said was absolutely necessary to seal MLS head gaskets. The challenge was to duplicate the factory finish using outdated equipment and methods that may or may not produce the desired results.

Aftermarket equipment suppliers rose to the occasion and introduced a new generation of high speed precision milling machines that could meet or exceed the factory surface finish requirements for original equipment MLS head gaskets. Wet grinding was out and dry milling was in as the new way to surface cylinder blocks and heads. Wet grinding was capable of producing high quality surface finishes when done properly. But it has been called, somewhat conservatively, perhaps, a "very messy" process compared to dry milling.

Grinding requires pressure to cut metal. Dry milling does not, it shaves metal as it sweeps across the surface. If you're wet grinding a block, the pressure and cutting action of the stones can change as the grinding head rides over the surface. The metal between the cylinder bores creates more resistance and cuts differently than the areas around the cylinder bores. This may leave a lot of waviness across the surface of the block. You won't get that with dry milling. It will cut the block flat with no high spots.

Experts contend that the type of process or equipment used to surface a head or block doesn't usually matter as long as it leaves a good finish. Engine builders can dry mill or wet grind or sand and get good results when the resurfacing is done right. However, for performance applications, smoother is better.

Industry spokespeople say increasingly often there's a growing need to de-emphasize Ra numbers and focus more on Rz when discussing surface finish. Roughness Average (Ra) can actually have a wide variance across a given surface profile. Rz, which is the average difference between the peak height and valley depth, is a more accurate representation of true surface topography.

While still important, today's surface finish requirements are not are critical as they were even recently, say experts. In the past, manufacturers recommended an 8 to 10 Ra finish to seal the head gasket. But according to one prominent gasket manufacturer, the coatings on today's aftermarket MLS gaskets can handle anything in the 40 to 70 Ra range with no problems.

Smoother is better for many applications, but is not absolutely necessary, depending on application. For example, if you're building a high-end race engine that tends to run hotter, a surface finish of 30 Ra or less is better and recommended. But for a typical street or strip application, it is acceptable to use an MLS gasket with a coating that is more conformable to handle a more traditional surface finish.

Some coated MLS gaskets can handle surface finishes from 70 to 80 Ra. More conventional coatings that are designed for surface finishes of 30 Ra or less are also available in the aftermarket. **PPSFG**

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VERTICALS: PISTONS, RINGS & BORES

Good bore geometry improves ring sealing to maximize power while minimizing blowby, compression losses, emissions and oil consumption. Most engine builders know that if you don't bore and hone the block with a torque plate that creates a simulated load, the hole won't stay perfectly round. As soon as the head is installed and bolted down, the head bolts will pull the bore out of round, which could affect the sealing ability of the rings between the bore wall. And this is especially true in performance engines that are eking out every bit of power through thin, low tension rings.

The main function of the cylinder bore is to provide a wear-resistant bearing surface to support the piston and rings, and retain enough oil to keep the rings lubricated. When boring and honing cylinders, the following criteria are absolutely critical in order to achieve the best results:

• Bore geometry and straightness. This is necessary for good ring seating and sealing, the straightness of the sides of the bore (to minimize ring flex as the piston moves up and down), and its alignment to the bore center and crankshaft. The bore must also be accurate dimensionally so the piston will fit with proper side clearances.

• Surface finish. The average roughness, peak height and valley depth of the surface must be compatible with the type of rings that are used.

• Crosshatch angle. Should be within a specified range for the application to provide proper lubrication and oil control.

Too much cylinder bore taper can cause the rings to flex in and out as the piston slides up and down, which is not good. Excessive taper can lead to ring breakage as well as interference problems if the ring end gap butts together or is not able to handle the change in bore diameter. With gapless rings, good bore geometry and taper are even more important to minimize blowby and compression losses and to maximize the benefits provided by this type of ring.

You can check bore geometry with a gauge to measure the inside diameter of the cylinder, but that won't let you see what the bore actually looks like in three dimensions. A bore that appears to be round may actually have some taper, distortion or misalignment in various areas as you go from the top of the bore to the bottom. Most shops don't have the equipment to do three dimensional mapping – all you can do is make sure you are using proper honing and finishing procedures so hopefully the bore will be round and straight.

Diamond honing stones typically deliver the best bore geometry because diamond is more consistent than vitrified honing abrasives – especially with less experienced honing machine operators. Consequently, there's less risk of machining taper into a cylinder bore when honing with diamonds because there is almost no wear on the stone. Diamond honing stones are easier, faster and last much longer than vitrified abrasives, but they are also quite a bit more expensive. But a set of diamond stones can typically hone up to 10,000 holes before they wear out.

A honing machine that offers variable speed stroking and can dwell in the bore while maintaining the same load 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. You can use synthetic water based coolants or honing oil with diamond, but honing oil only with vitrified abrasives.

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.

Tips

For performance engines, experts recommend surface finishes that are a bit smoother than stock, but regardless of the specification, the best rings seal is achieved by plateau finishing 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. A plateau finish will essentially mimic a broken-in cylinder. This will drastically reduce the time it takes for new rings to seat, and also minimize ring wear during the break-in process for longer overall ring life.

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.

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face finish in a freshly honed cylinder requires an instrument called a profilometer. The profilometer drags a diamond-tipped stylus across the surface to calculate a number of important parameters including: roughness average (Ra), peak height (Rpk), valley depth (Rvk), core roughness depth (Rk) and highest peak to valley. Many piston ring manufacturers specify a surface finish of 15 to 20 Ra for moly faced rings, which can be achieved by finish honing with #280 grit stones.

If cylinders are honed with #325 to #400 diamond stones, the finish should be in the 22 to 24 Ra range – which is too rough for moly faced rings, so a second finishing step is usually necessary. Plateau finishing the cylinders with #600 grit stones, or a plateau honing tool or brush will improve the finish and lower the numbers to the desired range of 20 or less.

A plateau cylinder bore finish is a good one because it combines all the "good" numbers to create plenty of area to support the rings, and adequate valley (crosshatch) for good oil retention and lubrication.

Some performance engine builders run somewhat higher Rvk (valley depth) numbers in the crosshatch to improve oil retention in high revving engines. According to one ring manufacturer, the recommended surface numbers for a performance engine with a hard block or cylinders (like a typical Pro Stock or NASCAR motor) are:

- Rpk = 4 to 6
- Rk = 18 to 22
- Rvk = 28 to 32

To achieve these numbers, the bores are rough honed to size with 270/325 metal bond diamond stones at 170 rpm and 35% load. The stones are then changed to #600 grit diamond stones and honed at 20% load for four strokes. The final step is to brush the cylinders with a plateau finishing tool for six strokes at 20% load.

The recommended numbers for other types of racing such as sprint cars and drag cars would be a little rougher:

- Rpk 8 to 10
- Rk = 25 to 30
- Rvk = 35 to 40

The same rough honing procedure as before would be used, but the second step would be six strokes with #550 grit diamond stones, followed by six strokes with a plateau brush at 20% load.

Crosshatch recommendations also vary according to the application. The typical automotive application calls for a 42 to 45 degree (included angle) crosshatch, while 20 to 30 degrees is often recommended for performance engines. If the engine has a nickle/silicon carbide coating, even less cross hatch is needed, typically 10 to 15 degrees.

Also, don't forget to scrub out the cylinders with hot soapy water and a brush. Rinsing with solvent alone won't remove the metal and abrasive residue.

Pistons

On the outside, pistons tend to look the same. They are round slugs of metal with grooves and bores for the rings and wrist pin.

That is about where the similarities end, however. Today, every manufacturer has its own recipe for making a better piston, and the days of pouring a molten liquid into a mold is largely a thing of the past, at least for the performance side of things. Cast pistons may work fine in your vintage, mild street rod but pushing them much further than 400 horsepower will leave you with a new pile of automotive art.

Today, there are numerous manufacturers in the aftermarket from which to choose a racing or high performance piston, so it can be a bit overwhelming for engine builders who are shopping for pistons. But all pistons are the same, right? That statement is, of course, completely false.

There's a lot that goes into the design of a piston, whether it's an off-the-shelf part or a specifically designed piece for a high horsepower racing application. Pistons come in all shapes and sizes from flat top to dish, domed, cast aluminum, forged, hypereutectic, short skirt, full round, and even asymmetrical.

What you choose for your next race engine build depends on what type of racing your customer does and if he or she has a budget or if there are rule restrictions

that limit your choices, because piston manufacturers can make just about anything you want.

The trend in piston design today has been evolving for many years with pistons being made lighter and lighter with each passing year. But today there are a number of technologies and materials at a piston designer's disposal to make designing a lightweight piston that has enough strength to last the distance and anti-friction properties to keep it from robbing any of the precious horsepower you so carefully assembled.

The high performance race engine by definition means that the limits are going to be pushed to the edge for most of its life. For piston designers, the limit is peak cylinder pressure. Maximizing cylinder pressure will give the most gains in horsepower, and can be reached by increasing the compression ratio through piston design with either a domed or flat top piston or a dished piston in the case of a power adder such as a supercharger, which dramatically increases cylinder pressures.

Ordinary cast aluminum stock-type OEM or aftermarket pistons are fine for budget rebuilds and even slightly modified engines. But such pistons may not be available in the oversize you want if you're boring out the block, or the compression ratio you want. The valve reliefs in the tops of the pistons may not be deep enough to provide adequate clearance for larger intake valves, a high lift camshaft or high lift rocker arms.

Your ring choices may also be limited depending on the dimensions of the ring grooves that are available. The location of the wrist pin may also limit what you can do with rod length and stroke if you want to build a stroker motor, and the thickness of the piston crown may limit how much metal can be safely removed to adjust deck height or compression. Finally, stock or cast aftermarket pistons may not be strong enough to handle a significant boost in horsepower.

Hypereutectic

Hypereutectic pistons are also cast pistons, but are made of a high silicon content alloy. The extra silicon makes them harder, stronger and more wear resistant so they can handle higher loads and temperatures reliably.

The pistons also have a lower coefficient of expansion than most forged alloys, so you can run closer piston-to-cylinder clearances to reduce piston rock and noise. Some hypereutectic pistons are made of 390 alloy and T6 heat treated to improve their strength up to 30 percent over untreated hypereutectic pistons.

Best of all, hypereutectic pistons are an affordable upgrade for many engines, and typically cost 25 to 30 percent less than forged pistons. But for a motor that's going to make serious horsepower, say anything much beyond 450 to 500 hp, forged pistons are usually a must.

Forged

Forged pistons are made by stamping a slug of aluminum in a high-pressure die. This usually requires several steps. The forging is then machined to its final dimensions and heat treated to produce the desired strength and hardness characteristics.

The alloys used to create forgings are ductile, which allows them to deform rather than crack or shatter under extreme loads. In a high performance engine, this quality adds a degree of insurance because it can allow the block to survive if the timing chain breaks or the engine sucks a valve. The valve may beat up the top of the piston, but the piston usually won't break and fall into the crankcase.

The grain structure created by the forging process also improves the strength and heat flow characteristics of the piston. In a high performance engine, this is important because the pistons have to handle much higher combustion temperatures and loads.

The two most commonly used aluminum alloys in forged pistons are 4032 and 2618. Pistons made of 4032 are mostly designed for street performance applications, but are also popular with many entry-level drag racers and sportsman circle track racers. It's a durable alloy that will last more than one season of racing, and

will hold up well on the street. It can also handle up to 650 to 700 hp, provided the engine has a good tune and does not go into detonation.

For serious racing, the preferred alloy is usually 2618. This alloy is more malleable than 4032, which allows it to resist detonation better than 4032. It also has a higher coefficient of thermal expansion than 4032, so pistons made of 2618 aluminum require more wall clearance and make more piston noise while a cold engine is warming up. The alloy also tends to degrade more over time than 4032, which means the pistons may have to be replaced after a season of racing.

Designs

If you're building a high revving engine, lighter is always better. Lighter pistons reduce the stretching forces on the connecting rods and improve throttle response. Weight is typically reduced by shortening the length of the piston skirt and using a shorter, lighter wrist pin. The pistons also have to be strong enough to handle higher loads so many use box-type struts inside the piston to reinforce the skirts.

The side profile of the piston is also important so it can handle the heat. The top of the piston is exposed to the heat of combustion, so the upper area of the piston that undergoes the greatest thermal expansion. Tapering the side profile of the piston in slightly toward the top compensates for the increased thermal expansion while allowing tighter wall clearances without scuffing.

The location of the rings on the piston is also a factor to consider. Moving the ring pack higher up on the piston improves sealing and reduces the "crevice volume" that can trap unburned fuel and air. On a performance engine, a higher ring location exposes the top ring to more heat and increases the risk of micro-welding the ring to the piston land or cylinder wall. To help counter these effects, piston manufacturers may use phosphate coatings or hard anodize the upper ring grooves to reduce micro-welding.

Rings

The top ring end gap is often the culprit whenever there are piston issues. Most top land damage appears to lift the land into the combustion chamber. The reason is that the top ring ends butt and lock the piston at TDC. Crank rotation pulls the piston down the cylinder while leaving at least part of the ring and top land at TDC.

The end gap will vary depending on the engine heat load when it is in operation. Piston alloy, fuel mixture, spark advance, compression, cooling system capacity, duty cycle and horsepower per cubic inch all combine to determine an engine's heat load.

Ring end gap and cylinder wall survface finish are just two of the critical factors you'll need to account for to ensure proper combustion efficiency.

Most new generation pistons incorporate the top compression ring high on the piston. The high ring location cools the piston top more effectively, reduces detonation, smog, and increases horsepower. If detonation or other excess heat situations develop, a top ring end gap set toward the tight side will butt, with piston and cylinder damage soon to follow.

High location rings require extra end gap because they stop at a higher temperature portion of the cylinder at TDC and they have less shielding from the heat of combustion. At TDC the ring is usually above the cylinder water jacket. However, many of today's current designs do a better job of keeping the rings cool, according to one manufacturer.

High ring locations work well in stock and street performance applications, and it helps reduce the crevice area for lower emissions and better fuel economy. But in really high power applications (blown or turbocharged engines, or nitrous), many piston manufacturers recommend a piston design that has the top ring somewhat lower on the piston to keep the ring away from the heat. They say this improves the durability of the piston and top ring.

If a ring end gap is measured on the high side, you improve detonation tolerance in two ways: One, the engine will run longer under detonation before ring butt. Two, some leak down appears to benefit oil control by clearing the rings from oil loading. A small amount of chamber oil will cause detonation and significant horsepower loss. The correct top ring end gap with some pistons can be 50% to 100% more than the manufacturer's specs, says an expert.

Ring options of 1/16″ or stock 5/64″ are offered in many applications. The 1/16″ option reduces friction slightly and seals better at high rpm but the drawback is that it's considerably more expensive. Stock (usually 5/64″ compression rings) work well and won't break your customer's budget. Metric ring options are also becoming more common.

The accumulator groove that is machined groove between the first and second compression ring on some performance pistons is there to stop pressure spikes from getting trapped between the first and second compression rings that will unseat the top ring. If this happens, you may get ring flutter and momentarily lose ring seal. The space created by this groove between the rings should be about equal to the average combustion spike, keeping the pressure low enough to prevent lifting the top ring while maintaining some pre-load on the second ring. **PPSFG**

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IMPORTANCE OF TRAINING

When I first started in business, I worked next door to a person who was trying to convert a hobby into a business. He became involved in a certain class of BMWs that all suffered premature engine failure. He was adept at taking the engines apart and putting them together again, so he would quote the basic price of putting rings and bearings in the engine, call it an overhaul, and take in the job.

However, every single one of these engines ended up needing far more work. The finished price to do it right was roughly four times his estimates and his customers felt betrayed, since he had the engine in buckets by the time he finally gave them a real total. They were literally over a barrel and couldn't use their vehicle or cancel the transaction.

He continued to complain about "how unreasonable" all these customers were. He said they should understand that it just wasn't possible to know if extra work was needed ahead of time. But after a few very unpleasant confrontations with very unhappy owners, he should have figured out that he wasn't doing these estimates correctly. Since nearly every one of these did need the work, he should have advised them of that possiblity in advance. That way he could avoid "the big surprise."

Despite complaining to me constantly and ignoring my suggestions, his approach grew grim and he came to regard his customers as adversaries, who were just out to get him (He actually turned out to be right). He never learned a thing and he was forced out of business. It wasn't that he couldn't learn, it was that he *wouldn't* learn.

People like this may say that they have 10 years experience, but the reality is, they just got one year's experience 10 times. They never got past the basics.

What is so difficult to comprehend about evaluating the possible things that might go wrong with a job, totaling up what that might cost and advising the customer of those things ahead of time?

My shop neighbor seemed to think that this was too difficult to learn and that it was easier to lose his house, his credit rating and develop health problems over it.

Arguing is a lot of work and requires far too much mental effort. In addition, it usually follows you home and keeps creeping into your brain. Arguing with mad customers is something you don't have to do. You can stop as soon as you decide you want to. In fact, you do it by your own free choice.

I was told that there are three types of men – those who learn by watching, those who learn by listening and those who just have to test that it's an electric fence themselves.

Whatever happens to be your business problem, you must first decide what it is you wish to fix and then find the training that will solve that problem.

Understand that your brain will naturally be resistant to any new ideas, even if they're good. You're generally most receptive when you reach the "threshold of pain" that pushes you over the edge. Once you realize that you will be skeptical and you will resist new thoughts, it will be easier to begin to look for ways the idea will work, rather than ways it won't. We all know that getting a shot hurts but we accept it because it will make us better.

Often false beliefs are our worst enemy. I once believed that doing major engine work was not profitable, because I couldn't charge enough. Others in the industry suggested that I price the work so that it paid the same per hour as replacing brake pads. So, I did that and the estimate for simply installing a rebuilt engine was very high, but it paid the same per hour as doing brake work. I made it even higher by including extras that would come up, like a new water pump, oil seals, thermostat and so on. It was substantially more than I'd ever thought it would be, and the customer still said yes.

I was stunned that I got the job. I learned that sometimes you price a job that you don't want to do so it will go away – if it doesn't, it pays enough to make you want to do it. Through the years, I've sold a lot of these jobs the same way. The beauty is, if it does go away, it's no big deal to me.

There aren't really that many big changes that we can make to our businesses that will accomplish a world of good, but there are literally hundreds of little things that we can do that will add up to big changes in how our business operates.

I tell people who take my classes to look at the material as a buffet line. They will find some things very appealing and some things downright appalling. I ask them to take the things they like and leave the things they don't. The worst thing you can do is to obsess about things you don't like. It causes you to lose your focus.

The reality is, your own "threshold of pain" will determine what ideas you are receptive to right now. You'll like those. Other ideas you will just not be ready for today. At some future point, you may develop and find a need for these. A very successful shop owner will find most good ideas have been implemented and the pickings are slim. If you can take a 2-week vacation and find the place humming right along, with no problems and record sales for the period when you return, you are where you want to be.

Until then, think about where your thresholds of pain might be and seek out some possible solutions to evaluate. Training is available at live conventions or events, live sessions led by an Instructor, DVDs, magazines or online. A good shop will constantly be evaluating what goes on and how it can be done easier. No one can afford to exist without change and no one has it all figured out. Once you figure *that* out, you can stop learning about electric fences. **PPSFG**

Becky Witt, AAM, is nationally recognized as a leading industry expert. She is a real repair shop owner, who talks to customers every day. She is an approved instructor for the Automotive Management Institute (AMI) and has earned ratings as one of their most popular instructors. Her innovative solutions to complex problems make real-world sense and are easily learned and implemented. She is best known for being very entertaining and throwing donuts.

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