VALVES & SEATS

There's more than meets the eye

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The valves and seats in an internal combustion engine play a central role in engine breathing, compression, performance and longevity. It doesn't matter if an engine has two, three, four or even five valves per cylinder or if the engine is gas or diesel because the valves all do the same thing: they open and close to allow air into the cylinders and exhaust to exit the cylinders. When the valves are closed, they have to seal tightly to prevent compression losses otherwise the engine will misfire and lose power. Even though the basic task is relatively simple, the effect that valves and seats have on compression, power, fuel economy and emissions is enormous.

A single valve that is leaking compression can cause a significant drop in power - up to 25 percent in a four cylinder engine! It doesn't matter if the compression leak is because the valve is bent, worn, eroded or cracked, or if the valve face or seat are not concentric or are out-of-round, the end result is still the same.

These kinds of problems can be avoided by carefully inspecting all the valves before reusing in a stock engine rebuild. The temptation is to save money by reusing and reconditioning as many of the original valves as possible. Valves that are bent, cracked, eroded or have excessive stem wear obviously need to be replaced.

New valves are available from a variety of sources. Stick with a brand name supplier who has a reputation for quality and consistency. Some cheaply made offshore valves are not reliable products because of questionable metallurgy, dimensional accuracy or stem finish. Just because a valve looks good doesn't mean it is the same as an OEM valve or a quality aftermarket valve.

Remanufactured valves can be an economical alternative to new valves if cost is an issue, especially in diesel engine applications. Worn valve stems can be re-chromed to restore stock dimensions, or the chrome plating can be built up to oversize so worn valve guides can be reamed out to accept oversized valve stems.

Valve stem wear is very common in high mileage engines regardless of whether they are gas or diesel. The factory flash chrome plating on many valve stems is not very thick, only about 7 microns, so it doesn't take a lot of wear to rub away the chrome plating. Stems can also develop a lobe-shaped wear pattern depending on how much sideways thrust they experience inside the engine. Too much stem-to-guide clearance is not good because it allows the valve to wobble every time it opens and closes. This, in turn, can cause the valve head to flex when it closes against the seat. Over time, the constant flexing can lead to metal fatigue, cracking and valve failure.

Stem finish is important on a valve because if affects friction and wear. Smoother is usually better. Chrome plating is a good material for wear resistance, but so too are many of the new "high tech" PVD, DLC and moly-based coatings.

One new technology we've seen is a stem finish that has small wavy grooves machined into the surface with a polymer filling to retain oil. The "snakeskin" finish is said to reduce friction while increasing wear resistance with no change in stem tolerances.

Preventing Valve Problems

Valve-related failures are often blamed on factors like detonation, poor quality or defective parts, over-revving the engine, or the end user failing to set or maintain proper valve lash, etc. Many of these things can contribute to or even cause valve failures, but so can sloppy machining tolerances.

The concentricity of the valve seat with respect to the valve guide and valve is essential for proper alignment and a tight compression seal. Accurate seat refinishing requires a valve-and-seat machine that is in good condition and can hold tight tolerances. You can't have a couple thousandths of an inch of slop and expect the valves to seal tightly. 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 also be sharp and spun at a high enough speed to produce a high-quality finish on the seat. If you're getting chatter while cutting a seat, the problem may be too much play between the pilot and valve guide, the speed of the cutter, or the machine is out of level. Using a coolant when cutting hard seats will reduce chatter.

How well the valves and seats are mating after both have been machined can be easily checked using a hand pump to pull vacuum on each of the head ports with the valves in place. If there's full contact between the valve face and seat, the port should hold vacuum. If you can't pull vacuum on the port, the valve and seat are not concentric or are not making full contact all the way around. You need to correct the problem before the head or engine go out the door. Hand lapping the valves to the seats can help improve a marginal seal, but should not be necessary if the valves and seats were machined accurately in the first place.

Some production engine rebuilders as well as custom performance builders use a Spintron machine to check compression and valvetrain operation in a newly assembled engine. A Spintron uses an electric motor to spin the engine as if it were running. The RPM can be varied as needed all the way up to redline. The software and instrumentation on the Spintron monitor what's happening with the valvetrain so any problems that might affect the reliability or performance of the engine can be detected and corrected before it leaves the shop.

Valve Types & Materials

For stock gasoline engines, some type of one or two-piece stainless steel alloy is typically used for original equipment valves. These include "NV" low-alloy and "HNV" high alloy intake valves, "EV" austenitic exhaust valves, and "HEV" high-strength exhaust valve alloy. The exhaust valve has to withstand much higher temperatures than the intake valves so they are usually made of a stronger high temperature alloy.

Most aftermarket performance valves are 21-2N or 21-4N stainless alloys, although some suppliers also offer a 23-8N alloy valve or their own proprietary alloy for high temperature exhaust valve applications. There's a lot of secrecy regarding the specifics of some of these alloys, but we can tell you that 21-2N stainless steel contains 21% chromium and 2% nickel. 21-4N has the same chromium content but contains almost twice as much nickel (3.75%) for greater heat resistance. The 23-8N contains 23% chromium and 8% nickel. The higher the nickel content, the more expensive the alloy, and the more heat it can safely handle in a demanding racing environment. Valves made of 21-4N can handle temperatures up to 1600 degrees F.

For more demanding applications (engines with nitrous oxide, turbochargers or superchargers), a higher temperature super alloy such as Inconel 751 or Nimonic 80A could be used. Inconel includes a range of high temperature alloys that generally contain 15% - 16% chromium and 2.4% - 3.0% titanium.

One aftermarket cylinder head supplier told us that they use 21-4N intake and exhaust valves in all of their cylinder heads from street performance to all-out big block race heads. "The valves have a smooth finish with chrome plated stems and are used with ductile iron valve seats. We've seen no problems with valve durability using these parts, but we do offer upgrades if a customer wants Inconel exhaust valves or light weight titanium valves (which also require copper valve seats)."

Titanium valves are an expensive alternative to stainless steel valves but are one of the best upgrades anyone can make for high RPM valvetrain stability and performance. Titanium reduces the mass of the valve by nearly 40 percent, which means you can use much less spring pressure for the same engine speed, or more RPMs using the same springs as before. Reducing the weight of the valves increases spring life, and reduces the stress on the rockers, pushrods, lifters, cam and cam drive.

How well do titanium valves hold up? They are used in some production engines like Corvette Z06 and ZR1 so there's no question about the ability to hold up under prolonged street or racing conditions. For wear resistance, titanium valves may be coated with a variety of materials including yellow titanium nitride (TiN), moly or chrome nitride. The coatings reduce friction, help dissipate heat and improve the surface hardness and wear resistance of the valve.

Titanium valves tend to hold more heat than stainless steel valves so they require upgrading the seats to some type of copper alloy. Copper provides good thermal conductivity to pull heat out of the valve when the valve is closed. For many years, copper-beryllium alloy seats were used with titanium valves. Copper-beryllium alloys typically contain less than 3% beryllium. Even so, beryllium dust is dangerous and requires special precautions when machining seats. Using a cutting oil or coolant is recommended along with an OSHA-approved dust mask.

In recent years, beryllium-free copper alloys that contain extra nickel and silicon have been developed that deliver the same performance without the health risks. Moldstar 90 is a beryllium-free copper alloy that can be used with ANY type of valve (titanium or stainless) or any fuel where high heat transfer is desired.

If a customer can't afford titanium valves, another way to reduce valve weight significantly is to go with hollow stem stainless steel valves. Hollow stem valves can reduce weight 10% or more to achieve some of the same benefits as titanium valves without the cost. To improve cooling, the hollow stems on exhaust valves may be partially filled with sodium. Sodium melts at 200 degrees F and improves heat flow up through the valve stem 40% or more. This helps pull heat away from the head of the valve for longer valve life and greater

The higher the nickel content of the valve, the more expensive the alloy, and the more heat it can safely handle in a racing environment.

reliability. It also allows the engine to handle more heat and spark advance.

CAUTION: Sodium is highly reactive when it comes into contact with water. If a sodium-filled valve is cracked and is placed in an aqueous cleaning tank, the sodium may fizz out of the valve or even make the valve pop and crack in two.

Sodium-filled hollow stem valves are a good performance upgrade, but we've heard of some valve failures in certain production engines that are using these valves. If you surf the Corvette forums, you'll find numerous posts talking about low mileage exhaust valve failures with the factory sodium-filled hollow stem valves. Some have blamed the problem on a quality control issue with the valve manufacturing process. There are photos of valves that have been cut open that reveal the center hole was drilled considerably off-center resulting in inconsistent wall thickness with one side being much thinner than the other. Some of the hollow stems also show scoring inside from the drilling process, which creates stress risers that can lead to cracks and valve breakage. That's why it's essential to carefully inspect every valve for cracks before it is reused regardless of its mileage. Others have blamed the valve failure problem on valve seat concentricity issues, excessive valve guide wear or poor control of stem-to-guide tolerances from the factory. Excess guide clearance allows the valve to wobble and flex with every valve cycle. Some Corvette owners have replaced their stock guides with aftermarket bronze valve guides.

In diesel engines, Stellite faced valves are often used to handle high exhaust temperatures. Stellite may also be used on the intake valves, too. Stellite is a cobalt and chromium alloy that increases the surface hardness of the valve face to about 55 to 59 Rockwell C. A thin coating is applied to the seat area of the valve and valve tip (the valve is usually a 21-4N stainless alloy or similar material). The Stellite coating greatly improves wear resistance at high temperatures. If you are rebuilding a diesel engine that is factory-equipped with Stellite faced valves, use the same type of replacement valves, never ordinary valves.

Valve Seat Materials

Valve seats have to be compatible with the type of valves in the engine. With most cast iron heads, the seats are integral and induction-hardened for wear resistance. With aluminum heads, the seats may be some type of cast iron alloy, powder metal or high copper (for high temperature performance engines or titanium valves).

Valve seat suppliers offer a variety of seat materials, so work with your supplier to determine which alloy is best for the engine you are building.

A high chrome alloy iron alloy with a Rockwell hardness of RC40 should be more than adequate for your typical unleaded fuel gasoline engine, stock or performance. This type of alloy holds up well in applications with exhaust temperatures up to 1150 degree F.

For natural gas or propane fueled engines, or turbocharged, supercharged or nitrous motors, a higher temperature nickel-based alloy would be recommended. Such a material can handle exhaust temperature up to 1600 degrees F.

For applications where additional high temperature wear resistance is required (like a heavy-duty diesel), a Stellite faced seat alloy might be required.

Moving on to powder metal (PM) seats, these are used as original equipment in many late model gasoline (and some diesel) engines. The car makers like PM seats because they are less expensive than alloy seats, can be molded close to finished dimensions, and are easy to machine (when new). PM seats work harden as they age, which is good for wear resistance, but it also makes the seats more difficult to machine if the seats need touching up at a later date. PM seats can be replaced with the same, or with cast iron seats or other alloy seats if desired.

Valve Seat Installation

The big question here is how much interference fit should you use when installing a new valve seat? The seats in some OEM heads may have as little as .002 inch of interference fit – which is enough when you are working with brand new heads and new seats. But more interference fit is usually needed in high mileage heads or ones that will be subjected to high horsepower levels. A common recommendation for installing new seats in used heads or aftermarket performance heads is .005 to .006 inches of interference for aluminum heads, or .003 to .005 inches of interference for cast iron heads. Additional peening or staking of the seats should not be necessary if the correct amount of interference fit is used.

To make installation easier, preheat the heads in an oven to about 200 degrees F (no need to go any hotter), and chill the seats in a freezer. Also, make sure the seats have a chamfer on the bottom outside edge and use a lubricant if the seats are a tight fit. Use a pilot and guide when installing the seats so they go in straight and don't cock.

Valve & Seat Refinishing

The angles on the valve face and seat can really make or break an engine's performance potential. A single 45 degree angle cut on the valves and seats won't provide the same airflow, throttle response and power as a three angle (30-45-60) performance valve job, or four angle valve job or a 45 degree seat with a radius undercut.

There are a lot of variables that influence airflow through the port and bowl area of a cylinder head. Valves with undercut stems just above the head or smaller outside stem diameters theoretically improve flow by reducing restriction in the valve port. However, they may or may not actually deliver a measurable gain in power over an ordinary valve with a straight stem. The same goes for valves with a swirl polish on the top of the valve head, a tulip-shaped head or a tapered stem just above the head. Sometimes these "enhancements" improve power and sometimes they don't. Every engine responds differently so there is no pat answer as to what type of valve always delivers the best performance.

We don't have the space here to dive into the theory of airflow except to say that a well done high performance valve job with the right valves and angles for the application can make a big difference in throttle response and power. Get it right and your customer will love the results. Get it wrong, and the engine will never perform up to its full potential.

Maximizing airflow in CFM on a flow bench doesn't guarantee peak power and performance. In fact, too much airflow can actually hurt power and throttle response because of reduced air velocity. The goal is to optimize airflow in the RPM range where the engine benefits the most. Finding the optimum valve and seat angles often takes a lot of trial-and-error experimentation. ■