VALVES & VALVE SEATS Guide

The relationship between various engine components is well-recognized, and the valves and valve seats are no exception. The valves are the choke point past which all the air that flows in and out of the engine must circumnavigate. Valves that increase air flow and allow the engine to rev higher will increase volumetric efficiency and horsepower.

But for the valves, being closed is just as important as being open. The valve seats are a critical engine component because they are the foundation of the valvetrain. The seats provide a surface for the valves to seal against when they close so there's no loss of compression or pressure from the combustion chamber. The seats also help cool the valves by conducting heat away from valves into the cylinder head.

The seats also support the valves and determine installed valve height, which affects valvetrain geometry and valve lash. The diameter of the seats and the contour of the angles that are machined into the face of the seats also limit how much air the engine can flow at any given valve lift and rpm. Because of all these factors, the valves and valve seats deserve a lot of attention whether you are rebuilding a stock engine or building a performance engine.

The weight of each valve is also important. Consider that each one may only weigh ounces – yet in many engines there are as many as five valves per cylinder. And at an average rotational speed of 3,600 revolutions per minute, the valves of a gasoline engine open and close 30 times a second. The mass of the valves is accelerated and again decelerated with every revolution of the camshaft. This rotating mass can be significant, so smaller diameter stems are often used.

A valve with an undersized stem typically weighs about 8 to 10 percent less than one with a standard-sized stem; and a lighter valve means the engine can rev higher, pump more air and produce more horsepower. A lighter valve also means less stress on the valve springs, retainers, rocker arms, pushrods, lifters and cam lobes.

Intake valves are usually heavier than exhaust valves because of their larger head diameter. Consequently, the weight of the intake valves is more of a limiting factor on the rpm potential of the engine than the exhaust valves. Even a few grams less weight can make a lot of difference in an engine that's running at 8,500 to 9,000 rpm.

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 20 to 22 percent lighter than a valve with a solid stem.

According to one supplier of hollow stem performance valves, the valves are good for 300 to 350 more rpm with no other modifications (same springs, rockers, pushrods, etc.).

Drilling out the valve stem to lighten the valve obviously sacrifices some strength, so a slightly stronger valve alloy may be used to maintain the same strength as before. Durability of hollow stem valves is not likely to be an issue in naturally aspirated performance engines, but hollow stem valves are not usually specified in turbocharged or supercharged engines, or in engines using nitrous oxide, because of the increased heat.

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 quite dramatic. 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.

One of the issues facing all aftermarket valve suppliers today – whether they make titanium valves or stainless steel valves – is the need to cover the most popular applications. This includes a growing number of aftermarket performance heads. Most of the street performance heads use the same sized valves as OEM heads, but many racing heads do not. The head may require a valve that is slightly longer than a standard Chevy SB or BB 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 on demand. 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.

Most of the valve suppliers we have spoken with say stainless steel valves made of 21-2N or 21-4N continue to be their most popular alloys for street, dirt track and drag racing engines. Both are austenitic stainless steel alloys that can handle high temperatures. 21-2N stainless steel contains 21 percent chromium and 2 percent nickel. 21-4N has the same chromium content but contains almost twice as much nickel (3.75 percent), making it a more expensive alloy. 21-4N is usually considered to be the premium material for performance exhaust valves and can handle temperatures up to 1,600 degrees F. 21-4N steel also meets the Society of Automotive Engineers' (SAE) "EV8" specification for exhaust valves.

SAE classifies valve alloys with a code system: "NV" is the prefix code for a low-alloy intake valve, "HNV" is a high alloy intake valve material, "EV" is an austenitic exhaust valve alloy and "HEV" is a high-strength exhaust valve alloy.

One of the advantages of using a higher grade of stainless such as 21-4N or a similar high grade stainless alloy is that the margin on the valve head can be made thinner with less danger of cracking or burning.

For more demanding applications (engines with nitrous oxide, turbochargers or superchargers), higher temperature alloys such as inconel or similar materials may be required. Inconel is a "superalloy" material that is sometimes used for exhaust valves because of its superior high temperature strength. Inconel is a nickel base alloy with 15 to 16 percent chromium and 2.4 to 3.0 percent titanium. Inconel 751 is classified as an HEV3 alloy by SAE.

Stainless steel valves are typically chrome-plated to improve lubricity and reduce stem wear, and the valve head is often swirl polished to improve airflow and reduce stress that could cause valve failure. On chrome-plated valves, the coating may be .0002˝ to .0007˝ thick up to a hard plating of as much as .001˝.

Chrome has microscopic pores that retain oil, but actually creates a slightly rougher surface finish on the valve stem. Other alternatives include various thin film coatings for wear resistance and lubricity. Dry film coatings may also be applied to the head and valve stem to reduce the build up of carbon deposits on the valves, and ceramic thermal barrier coatings may be used on the valve face to reflect heat back into the combustion chamber.

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Titanium valves are the lightest valves available, and typically weigh about 40 percent less than stainless steel valves of the same size (with solid stems). Titanium valves are great for high revving engines and allow more aggressive cam profiles that open and close the valves more quickly. But titanium valves are not for everybody because rising material costs continue to push up their price. Titanium valves may cost more than $85 each, and a set of custom-made titanium valves may be in excess of $100 for each one.

Because titanium valves are so expensive, they are often custom machined rather than produced to stock dimensions for specific heads. The head diameter, stem length and diameter, and tip are all machined to the engine builders' specifications.

A common alloy used for titanium valves is 6242, an alloy that contains 6 percent aluminum, 2 percent moly, 4 percent zirconium and 2 percent tin. Different heat treatments are typically used for the intake valves and exhaust valves. The heat treatment is very important because it determines the ultimate strength and hardness of the metal.

Titanium valve tips and stems are often coated, especially on street applications, to improve lubricity and reduce the risk of stem galling. A steel insert may also be welded or pressed into the tip of the valve to reduce wear, or a hardened steel cap may be used on the end of the valve. Stem coatings may be plasma spray moly or a similar friction-reducing material, or a thin film coating such as diamond-like carbon (DLC), titanium nitride (TiN), or chromium nitride (CrN) applied by a physical or chemical vapor deposition process. Thin film coatings are lighter than sprayed coatings by up to 4 grams, and do not change tolerances as much. Hard thin film coatings such as diamond-like carbon are only 20 microns thick, yet are extremely durable.

Valve Seats

One of the drawbacks of using titanium valves is that titanium does not conduct heat as well as steel. Consequently, the valve seats must have good thermal conductivity to pull heat away from the valves. If the exhaust valves get too hot, they can cause preignition and detonation that can destroy an engine. Excessive temperature can also cause the valves to burn, and the seats to pit and erode, either of which can cause compression loss in a cylinder.

When titanium valves first became popular, tool steel alloy valve seats were often used. The seats were durable enough but proved to be too hard for the titanium valves, and they didn't pull heat away from the valves fast enough to provide adequate cooling at high rpm. Cast iron seats were tried and worked well enough on street engines, but they lacked the durability required for NASCAR and other high rpm, high horsepower engines. The seat material that proved to work best with titanium valves turned out to be beryllium copper (Be-Cu).

Beryllium is a rare metallic element that is lighter than any other metal, but it also has a high melting point, is very strong, stiff and hard. Beryllium is used in many aerospace applications including rocket nozzles and nose cones. It is also used in the construction of nuclear weapons. More peaceful applications include contacts for spot-welding machines, electrical switches and high performance valve seats.

When alloyed in small amounts with other metals such as copper, beryllium improves hardness, strength, corrosion and fatigue resistance. The amount of beryllium, copper and other ingredients in the alloy also affect the thermal conductivity of the seat and how quickly it can transfer heat from the valve to the cylinder head. Some 2 percent beryllium alloys have a thermal conductivity rating of up to 140 BTUs per foot per hour per degrees F, while others that contain less beryllium are in the 60 to 68 BTUs per foot per hour per degrees F.

Most tool steel and iron alloy valve seats, by comparison, are rated much lower at 20 to 22 BTUs per foot per hour per degrees F. This is good enough to provide adequate cooling for stainless steel valves in an aluminum or cast iron cylinder head, but not for titanium valves in a high horsepower (over 600 hp) performance engine.

Many racers have been using a softer beryllium copper alloy for the intake valve seats, and a harder, more thermally conductive alloy for the exhaust seats. Intake valves run much cooler than the exhaust valves, but also tend to have more radical lift profiles and slam shut harder than the exhaust valves. Consequently, a softer seat material has more of a dampening effect when the valve closes to reduce the risk of valve bounce when the valve closes. It's also kinder to the valve face and helps extend valve life.

Though beryllium copper seats have been the alloy of choice for racers using titanium valves, one of the drawbacks to using seats made of this material is that beryllium is a toxic metal.

There's no risk in handling the seats, but the dust that's given off when cutting or grinding the seats can be dangerous because of the beryllium it contains. The danger is in inhaling dust that contains particles smaller than 10 microns in size. Beryllium may cause a lung disease called berylliosis or other allergic reactions. Dust can be minimized by using a liquid coolant while machining the seats. Wearing a dust mask that meets HEPA standards is also a good idea.

Occupational Safety and Health Administration (OSHA) regulations say workers should be exposed to no more than 2.0 micrograms of beryllium dust per cubic meter of air during an 8 hour shift. But these regulations are over 50 years old, and some are calling for much more stringent regulations that would reduce exposure to 0.2 micrograms per cubic meter. Because of these concerns, other valve seat alloys are now being used in place of beryllium copper.

The 2007 rule change in NASCAR that finally did away with leaded gasoline forced many teams to take a second look at the valve seat alloys they were using in their engines. Tetraethyl lead is an excellent octane booster for high compression racing engines, and it also forms a protective coating on the valve seats that acts like a lubricant to extend valve and seat life. But lead is a toxic heavy metal. Because of this and the fact that lead poisons catalytic converters and oxygen sensors, tetraethyl lead was phased out of most motor fuels back in the 1970s.

Even so, NASCAR continued to use leaded fuels because there were no rule requirements for emission controls, and electronic engine controls were forbidden. NASCAR engine technology was essentially frozen in the pre-fuel injection era, so leaded racing gas lived on. When NASCAR finally succumbed to environmental pressure to get the lead out, some teams found the seats they were using didn't provide enough cooling for the titanium valves in their engines. Other alloys were tried, and some new beryllium-free copper-nickel based alloys were found to provide even better cooling and durability. The new valve seat materials enabled the engines to make more horsepower by allowing seats with a larger inside diameter and different seat angles to increased airflow. Some tests have shown as much as a 10 percent gain in horsepower is possible over beryllium copper seats!

Powder Metal Seats

Most late model aluminum heads are fitted with either cast iron or iron alloy seats, or powder metal (PM) seats. PM seats have become very popular with the vehicle manufacturers for a variety of reasons. PM seats are less expensive than iron seats, and they are proving to be very durable. PM seats often show little wear at high mileage. Consequently, if you are rebuilding a head with PM seats, the seats may only need a light touch-up.

However, PM seats tend to work harden as they age, and can be be very hard (up to Rockwell 40 to 50) making them difficult to machine. As long as you have equipment that can cut hard powder metal seats, remachining the seats should be no problem. But if you don't have equipment that is designed for this kind of work, you may be better off replacing the seats with new ones to get restore the seats. New powder metal seats are much softer (typically around Rockwell C 25) when they are initially installed, and easier to machine than aged seats. They also require less force to press into the cylinder head than iron or steel valve seat inserts.

One difference between cast alloy seats and powder metal seats is the way the seats are manufactured. Cast alloy seats are made by melting and mixing different metals together so they combine chemically. This molten soup is then poured into a mold and cast to shape. The rate of cooling and subsequent heat treatment of the metal determines its microstructure, hardness, strength and other physical properties.

Powder metal seats are made by mixing together various dry metal powders such as iron, tungsten carbide, molybdenum, chromium, vanadium, nickel, manganese, silicon, copper, etc.), then pressed into a die mold, and subjected to high heat and pressure (a process called “sintering”). This bonds together the metals and forms a solid composite matrix with very uniform and consistent properties.

Materials that are difficult or impossible to mix together in a molten state can be blended together and bonded to create totally unique materials. Another advantage of the powder metal process is that parts can be manufactured very close to final tolerances, reducing the amount of machining that’s needed to finish the part to size. This lowers production costs and boosts manufacturing productivity.

The main reason why vehicle manufacturers have switched from cast alloy seats to powder metal seat inserts, however, is to extend engine durability. Most late model engines have to be emissions-certified to 150,000 miles or higher depending on the application and model year. If the valve seats can’t go the distance during durability testing, the vehicle manufacturer can’t certify the engine.

Powder metal seats are very good at handling thermal stress as well as impact stress, and typically show minimal wear after tens of thousands of miles of use. The homogeneous consistency of a powder metal seat also improves heat transfer, which is good for the valves, too. Powder metal seats also tend to experience less micro-welding between the seat and valve even at high combustion temperatures, which helps extend the life of both components.

Reconditioning The Valve Seats

In cast iron heads with integral seats, the sealing surface on the seats is restored by cutting or grinding. How the seats are cut also affects valve height. Changes in valve height can be compensated for by grinding the tip of the valve stem to reduce its overall length. But there are limits as to how much you can grind off the hardened tip of a valve stem before you grind away the case hardened layer. Replacing the stock valves with ones that have thicker heads is one alternative.

In situations where an integral valve seat is damaged, the head can often be salvaged by cutting out the old seat and installing a seat insert – provided the casting is thick enough to accept a seat.

With aluminum heads, badly worn or damaged seats can be removed and replaced with new seats. But as one supplier said, the demand for replacement seats has been declining because of the longevity of the original equipment powder metal seats that are used in many late model engines.

When seats are replaced, the amount of interference fit is critical for proper seat retention and heat transfer. The seats in some OEM heads may have as little as .002″ of interference fit – but keep in mind these seats were installed in brand new heads.

Engine rebuilders tend to use more interference fit to compensate for any distortion in the seat recess that occurs when the old seat is removed. Some use as much as .005″ of interference in cast iron heads, and up to .007″ of interference fit in aluminum heads. Additional peening or staking of the seats should not be necessary if the correct amount of interference fit is used.

There are a few different kinds of seat and guide machines available today to fit most budgets, from not much more complex than a drill press to the floating powerhead system that has become the industry-standard for many engine builders today to the “live pilot” design. Whereas a “dead pilot” design remains stationary in the guide as the tooling rotates, a live pilot spins with the tooling in the guide.

What type of machine your shop needs is dependent on the type of work you do, but the simple fact remains: in order for a valve to seat correctly, for efficiency and power, engine builders must replace or bring back to spec all valve seats and guides. **MEPG**