COMPRESSION DIAGNOSTICS

COMPRESSION COMPONENTS

There's a huge difference between understanding compression components and UNDERSTANDING compression components. The distance from one to the other might be comparable to what an air-cooled engine service technician knows and what a top fuel, NASCAR, or Formula One engine builder/designers knows. The technician understands 4-cycle theory but the builder comes close to worshiping it.

These statements are not made to suggest that Briggs & Stratton technicians should become performance engine builders, however, they do form the basis for an argument that the technician can do a better job if better informed. It's the old "knowledge is power" cliché.

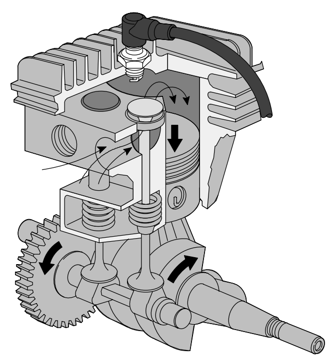
In this session, we'll briefly explore some 4-cycle theory with an emphasis on compression components and "what can go wrong" to set the stage, dive into a few revised service procedures for performing valve work, look at some new valve service/diagnostic aids and finish with a flo-chart for compression component troubleshooting.

4-Cycle Theory

Many of us were taught 4-cycle theory by the "Suck, Squeeze, Bang, Blow" method. Though rather crude, this approach nevertheless makes the 4 strokes unforgettable. We'll take a brief tour through the strokes with an accent on the following areas:

- Engine smokes (blue from exhaust)
- Excessive oil consumption
- Low power

Intake Stroke



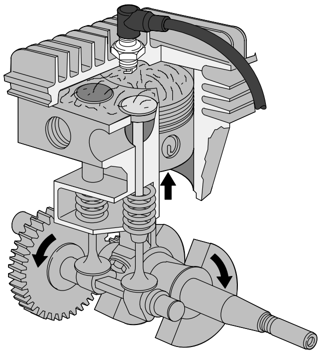
Assuming the fuel and air intake systems are healthy, the intake stroke on most naturally aspirated engines is responsible for delivering the raw material that results in power at the PTO. Functionally, the intake stroke consists of lifting the intake valve off its seat via the tappet and the piston traveling from top dead center to bottom dead center. During the piston travel, an area of low pressure is created in the combustion chamber. Outside ambient pressure is now higher than conditions within the combustion chamber. Since air will always travel from an area of high pressure to low pressure, it is the low pressure "signal" that initiates movement into the combustion chamber.

The term Volumetric Efficiency (VE) is used to describe how effectively the engine functions as an air pump. A looser definition is how efficiently the engine fills the cylinder volume with fuel/air mix. From this point of view, the volumetric efficiency of an engine is described in terms of percentages, where 100% is a completely charged cylinder, 90% is 9/10ths, etc. Automotive engines typically run at 80% to 90% volumetric efficiency. Briggs & Stratton L-head engines attain approximately 70% VE while overhead valve engines are right around 80% VE.

Areas to consider during a diagnostic examination are any obstructions to the smooth passage of the fuel and air charge. If carbon dams or other barricades are present, the cylinder will not be charged to its fullest potential.

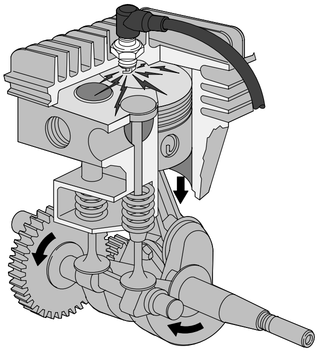
Compression Stroke

The primary accomplishment of the compression stroke is to increase the molecular activity of the fuel/air charge. As the molecules become more excited, energy is released in the form of heat. A rise in temperature coaxes much of the atomized gasoline that is still in a liquid “mist” to alter its state and become a gas. The very root of combustion theory is that only vapors burn - never liquid.



As the compression stroke continues, and molecular activity rises, the temperature continues to rise as already stated. The end goal is to reach a temperature close to the self ignition point of the fuel. Once a spark occurs and a flame kernel develops, gasses begin to rapidly expand resulting in the pressure that forces the piston down as the power stroke. If the fuel/charge is not to a temperature where ignition will occur, energy must be expended to bring it to this point - energy that would be more useful adding power to the power stroke.

Power Stroke



Of the 720 degrees of crankshaft rotation required to fulfill the four strokes required for engine operation, only 180 of these are actually responsible for producing torque. Once the ignition system ignites the fuel/air charge, the flame front spreads across the combustion chamber at nearly 250 feet per second (76 m). Gasses rapidly expand and begin to force the piston downwards. At a speed of 3600 rpm, the piston is accelerated to around 25 mph (40.26 kph) almost instantly. Bearing and component loading can be considerable. Coinciding with the power stroke are also the harshest conditions the engine will see.

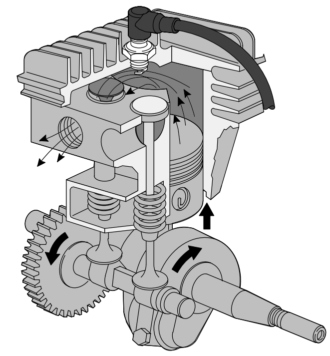
- Pressures from expanding gasses can be over 500 psi (0.0689 bar).
- Temperatures at the flame front may be 3000°F (1648°C).
- Temperatures at the exhaust valve are often 1400°F (760°C).
- Temperatures at the intake valve can climb to 800°F (426.66°C).
- Acids and caustic materials are by-products of combustion.

Any loss of combustion pressure translates directly into a loss of engine power and performance. Specific combustion chamber sealing areas are:

- Spark plug to head
- Head gasket
- Valve face to valve seat
- Piston rings to cylinder wall
- Piston rings to ring land
- Valve guides

During the power stroke, the top ring is forced against the cylinder wall by the rise in pressure. High pressure is directed both downward, forcing the ring onto the bottom of the groove and outward helping to seal the ring against the wall. Piston and ring packages are developed for specific engines through testing.

Exhaust Stroke



This is the clean-up crew of the four strokes and is simply the expulsion of the combustion products. With the piston towards the end of the power stroke, the combustion chamber is still pressurized. On the return stroke, the exhaust valve opens and exhaust gasses move from an area of higher pressure within the cylinder to the lower, outside ambient pressure through the exhaust system. Whatever gasses may be left are mechanically pushed from the chamber by the and rings.

Compression Component Problems

Dynamic service problems that involve compression components will usually fall within three categories:

- Engine smokes (blue) from exhaust
- Excessive oil consumption
- Low power

These are operational problems where the condition occurs while the engine is running. Each situation is an effect of a compression component problem or other engine system problem and must be further defined and isolated.

1. **Engine Smokes**

   More than one engine system malady can result in smoke from the engine's exhaust. Find answers for these questions first:

   - What color is the smoke? Black smoke suggests an overly rich fuel system. Rule out fuel system issues and proceed. Blue smoke is normally oil burning in the combustion chamber or muffler.
   - Is there a cloud of smoke upon cold engine start-up, which dissipates completely after several minutes? If it is determined that the engine has not been tipped, this is most often oil pooling in the combustion chamber and is not necessarily a problem and often easily remedied. Occurrences are usually the result of a vertical crankshaft engine stored on an angle such as a garage floor with a slight slope. If the angle is such that the oil in the sump spills over into the cylinder bore, the lubricant will migrate forwards during storage. The fix, of course, is to store the unit on a level surface.
   - Does the engine emit smoke after it reaches normal operating temperature and continue on, slowly dissipating over time? This symptom may be related to the wear or failure of compression components. To help isolate the problem, try and determine if this is a new condition that has no previous history. Engine wear, which exhibits similar symptoms, generally occurs over time. Has someone performed maintenance just previous to the occurrence? If so, the customer may have overfilled the crankcase with oil.
   - Does the engine emit occasional bursts of smoke and then clear itself? This is usually an issue with the engine's crankcase breather system and is specific to larger, vertical crankshaft engines run at an angle. The angle of operation causes excess oil to collect in the breather chamber. At some point, the oil will be directed into the intake air stream via the breather hose and is consumed in the combustion chamber.
   - Does the engine offer light smoke with no performance problems noted? This may simply be the use of a lubricant with too low a viscosity rating, or oil that's been diluted with gasoline as a result of a sticking carburetor float. Low viscosity or diluted lubricants easily migrate past sealing areas and can end up in the combustion chamber. If encountered, look for other damage as well.

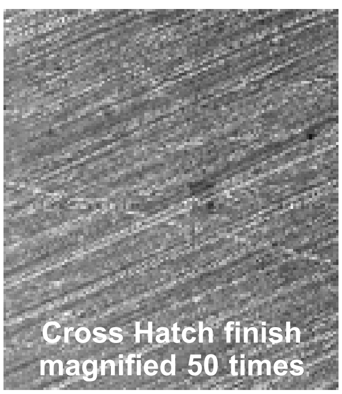
   Although there are more examples that can be brought up, we'll assume the cause of smoke has been isolated to the compression system. Let's also consider that while the engine runs, the crankcase maintains an area of low pressure that can be affected by a problem with components. In addition to compression components, crankcase vacuum will be discussed as it relates to the complaint of Engine Smoking, and later, to Excessive Oil Consumption. The two systems are intertwined and best discussed together.

As a group, compression components consist of the following items:

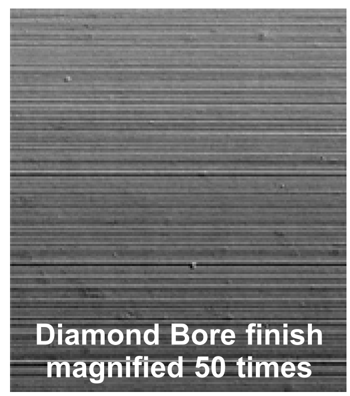
- Cylinder walls
- Piston
- Rings
- Valves
- Valve guides

Smoke as a result of malfunction or wear will usually be associated with the cylinder walls, piston(s) and rings. These components have a dynamic relationship in that their function as an assembly involves some sort of action all the time. We'll examine each, explore their function and define how they may contribute to excess engine exhaust smoke.

Cylinder Walls

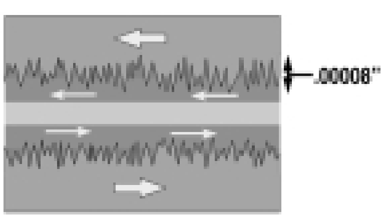

Cross Hatch finish magnified 50 times

The term cylinder wall more closely describes the finish condition of the cylinder bore. The bore itself is nothing more than a round, cylinder shaped structure. The round shape of a cylinder may be more for convenience of machining and sealing than anything else. Oval cylinders have been built with good success but are difficult to machine.

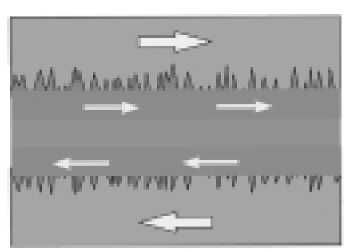

Diamond Bore finish magnified 50 times

As pressure increases from the combustion event, the piston, functioning as a moveable end of the combustion chamber, is forced downward in the bore. To maximize the conversion of this energy into motion, pressure losses must be prevented to whatever degree possible. The piston ring is added as a sealing mechanism between the piston and the cylinder walls.

These parts must be made from materials that can withstand pressure, temperature, wear, and caustic chemicals as well as be lightweight to maximize power and performance. The cylinder bore may be constructed of aluminum or cast iron but will either way be characterized by a surface finish of graduated asperities.



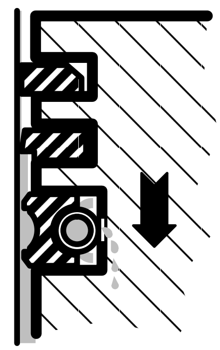
Asperities are high and low peaks, which are comparable to mountains and valleys. The valleys become pockets for lubricant storage that help when the lubricant is released to prevent metal-to-metal contact between the peaks.



During engine operation, the rings are dragged repeatedly up and down the cylinder walls. On a microscopic level, this operation is similar to planing a piece of wood, with the ring acting as the plane blade. The higher peaks on the cylinder walls are shaved down and a “working” surface is formed.

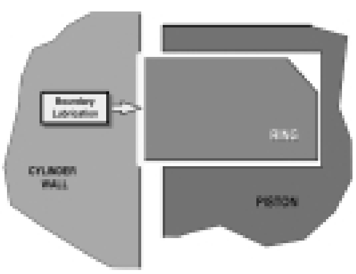
Briggs & Stratton utilizes a break in procedure that applies varying load over a 24-hour period to normalize an engine before power testing. Early on in this process, higher asperities are still present. Without an established, flat working surface, these asperities can and do make metal-to-metal contact with the rings. If there is a particularly high peak, or larger broken peak that gets between the skirt and the wall, light scratching may occur on the wall and/or skirt. This is a normal component of the break-in process and presents no threat to engine life or performance. Scratches are more noticeable on Kool Bore™ and Diamond Bore engines with a softer aluminum surface.

Piston Rings



Briggs & Stratton uses three piston rings on all engine models. The rings are made of cast iron. When they are installed in the cylinder bore, they are in a compressed condition and exhibit a relatively equal force outwards against the cylinder walls. Rings may be designated simply by their location; top, middle and bottom, or by their function; compression, wiper and oil control ring.

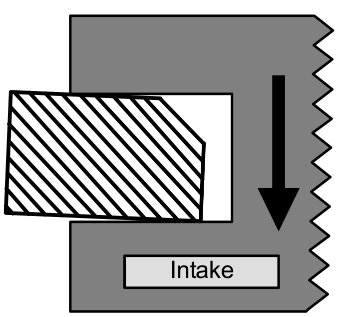
- **Compression ring**



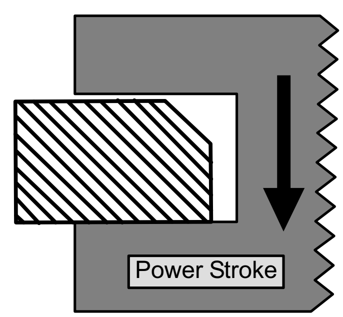
This ring is an extension of the piston and is there to prevent expanding gasses from getting by without doing any work. Not only does it need to seal against the walls, but within the ring groove as well.

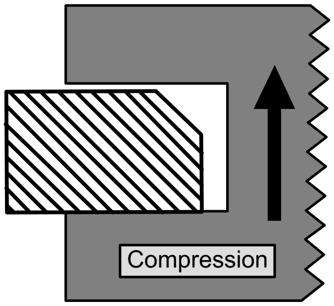
The compression ring, and 4 cycle engine rings in general, are designed to rotate while the engine is running. This causes a constant “wiping” effect within the ring lands. Wiping prevents a buildup of combustion residue and shellacs that can interfere with the ring to ring-land seal as well as cause rings to stick in their grooves. Though important for all three rings, a clean, flat ring land surface is particularly important to the compression ring.

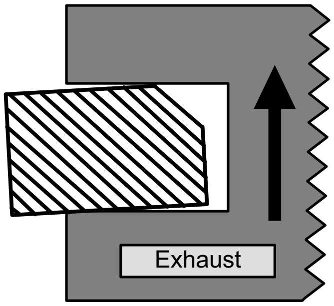
What can go wrong?



Although there are several issues that can cause or increase smoke from the exhaust, engine wear is the most common. Many people believe that wear allows oil to pass by the area of contact between the ring and the wall. This is to some degree true, but it is not the main avenue.







During the power stroke, the ring is sealed against the wall and the ring land by the pressure of expanding gasses. The same applies to the compression stroke though to a lesser degree. A worn ring will not seal as well as one that is within specifications. A poor seal does not directly result in oil transfer into the combustion chamber. It will result in a loss of crankcase vacuum, lower power and hard starting. The pressure that has leaked past is now in the crankcase wreaking havoc with the breather system and doing nothing to help put power to the PTO.

The intake and exhaust strokes are to be blamed for oil that migrates directly into the combustion chamber. Without pressure against the top ring, the ring is more relaxed and the oil mist from the crankcase travels past the ring via the ring groove. To support this, you may have noticed worn engines with a considerable amount of carbon present within the ring groove of the top two rings. This condition means that oil has been present over time and has coked onto the lands and the back of the groove.

Pistons and rings are developed as a system. The sealing point of the ring against the groove face is extremely important. Both ring and cylinder wear move the point of seal. Move it far enough and the engine will blow smoke from the exhaust. From a visual standpoint, one engine may appear to have the same amount of wear over and above reject standard as another, yet not emit smoke from the exhaust. The difference may well be in the piston and ring package.

- **Wiper Ring**

Also called the Scraper, Napier or Secondary Compression Ring, its primary job is to provide a controlled film of oil to lubricate the compression ring. It is also the second line of defense against any blow by that has past the top ring. On modern Briggs & Stratton engines, most wiper rings have a tapered face. The concept is similar to a knife blade carving a piece of wood. As the ring travels from top dead center to bottom dead center, the lower edge of the ring is at a sharper angle and scrapes the oil down the bore to be handled by the oil ring.

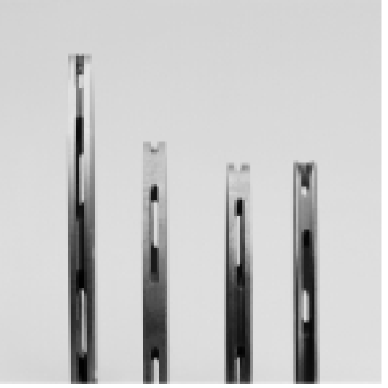
What can go wrong?

Wear of the wiper ring reduces its performance just as wear does to the compression ring. As wear occurs, more lubricant is allowed past by way of a thicker film left on the wall and also by way of the ring groove.

If these rings are ever installed upside down, the ring will scrape oil upwards, towards the compression ring. If enough collects between the top and middle ring, the top ring can be hydraulically lifted off the lower land effectively breaking the seal on all upward strokes.

If the ring end gap is too tight, it can hamper the passage of blow by to the crankcase. Some blow by always occurs. If pressure builds up between the rings, the top ring to lower land seal can be broken similar to what happens if lubricant collects.

- **Oil Control Ring**



This ring has the initial contact with lubricant that is deposited on the cylinder walls by the engines lubricating system. It does most of its work from top dead center to bottom dead center by controlling the amount of oil on the wall. The excess lubricant that is more finely metered by the second ring is also collected and returned to the sump or base by way of ports towards the ring groove wall or by a channel cast in the piston skirt.

What can go wrong?

As a stand-alone component, it has little effect on smoke from the exhaust unless it is stuck or broken and cannot do its job at all.

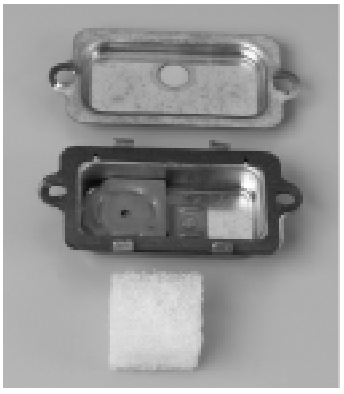
- **Crankcase Vacuum**

The discussion so far has already defined the essence of crankcase vacuum and the breather system but in a sort of “behind the scenes” approach. We’ll bring it out into the open by returning to the intake stroke of a healthy engine for a moment. As the piston drops down in the bore, it creates an area of low pressure in the combustion chamber compared to ambient. At the same time, it creates an area of high pressure in the crankcase.

The breather was added to Briggs & Stratton engines to allow an escape port for pressure. It is set up as a one-way valve that closes when the pressure signal vanishes. As the piston returns up the bore, it leaves behind an area of low pressure compared to ambient.

What can go wrong?

Bear in mind, that when the engine is running, there is a constant cloud of oil mist within the crankcase. If the breather plugs up or the internal reed or flapper valve sticks closed, it’s as if it wasn’t there at all. If the internal pressure has no where to go or can’t escape fast enough, the high crankcase pressure can cause the rings to lift off their lower lands on the return stroke and deliver a burst of oil mist to the combustion chamber.



Say there’s a small air leak at an “O” ring seal. The air enters more readily than it can leave because as soon as it’s inside the engine, it becomes an oil mist. To some degree, it adopts the viscous nature of the lubricant, which has an inherent resistance to flow or movement. The low pressure becomes less and less and the breather is caused to move more and more “air” out of the crankcase. Besides functioning as a valve, the breather is also a separator. It allows oil to settle out of the air and then returns it to the reservoir. When confronted with a higher volume than it is prepared to deal with, it can become overpowered and begins to pass oil into the closed loop system, delivering oil to the carburetor throat or oil soaking the air filter element.

In both of these situations, we have an engine with healthy compression components that act like they’re worn out.

The simplest method of isolating breather malfunctions from engine wear issues is by crankcase vacuum and/or leakdown testing.

2. Excessive Oil Consumption

All engines consume oil. If the lubrication system does its job and applies a film on all bearing surfaces, the very nature of this event determines that losses will occur. Lubricant will be lost from the following areas:

- When the cylinder wall is exposed to the rapidly burning gasses during the power stroke, the lubricant film deposited to prevent metal to metal contact between the rings and the wall will be consumed.
- On the intake stroke, a low pressure area is created in the bore, and a potentially higher pressure is created as the piston displaces volume in the crankcase. If the pressures are significantly different, the oil mist present to lubricate the valve guides may migrate to the combustion chamber.

The discussion on Engine Smokes (blue) From Exhaust also describes the complaint of excessive oil consumption as oil is consumed and therefore the level drops. Abnormal engine wear occurs over time unless there is a catastrophic cause. Due to the time factor, there may be evidence of oil consumption that is more than what the customer considers normal but might not be evident as smoke from the exhaust.

There are two other areas to consider:

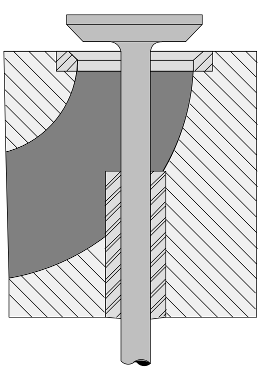
- Anything that alters the area of low pressure in the crankcase. This could be a breather valve that seals poorly or a slight air leak at an “O”-ring or gasket.
- Loss of oil from an external leak such as an oil seal or sump gasket.

3. Low Power

It almost goes without saying that compression system problems nearly always result in low or reduced power. Hard starting may be another reported complaint. Based on an understanding of 4-stroke theory and the discussion of compression system components above, the relationship is not hard to understand.

The final area to investigate is the valve train. Problems in this area are fairly easily repaired in comparison to cylinder components. As mentioned under the Power Stroke, conditions within the engine can be extreme. The valves, in particular the exhaust valve, are forced to contend with some of the worst of these.

Valve Train



The valve train is a subsystem. It is the traffic cop of the engine, directing what enters and leaves as well as when. Not only must these components survive in an unfriendly environment, they are also subjected to considerable mechanical stresses as well.

The gear ratio of the camgear to the crankshaft is 1/2 to 1. This means that the camgear makes one complete revolution for every 2 revolutions of the crankshaft. At 3600 rpm, the valves will open and close 1800 times in a minute, or 30 times per second.

While determining emission limits for small air cooled engines, the California Air Resources Board commissioned a study to established a mean average life expectancy for powered equipment. It was reported that both walk behind lawn mowers and consumer tractors last approximately 7 years. The study established that the average use was about 20 hours per year for a walk behind mower and 38 hours for a tractor. Using these figures, a tractor will run approximately 266 hours over the course of its life span. Assuming a constant speed of 3600 rpm, the valves will open and close 4,104,000 times in one season. Over 7 years, this figure climbs to an astounding 28,728,000 openings and closings for each valve.

Probably the worst condition the valves have to contend with is high heat. Reported temperatures at the intake valve can be 600° to 800°F (316° to 427°C). The exhaust valve encounters 800° to 1400°F (427° to 760°C), and sometimes higher. This may sound bad, but the materials the valves, valve seats and valve guides are constructed of are designed to handle these extremes. However, this doesn't mean there can't be problems.

Since valve timing is a mechanical setting that is unlikely to change unless there is internal engine damage, the most common failure is deterioration of the seal formed by the valve face contact with the valve seat.

What can go wrong?

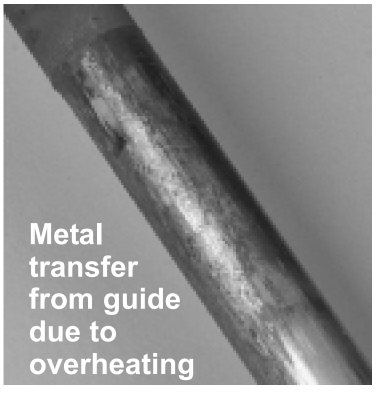
We'll start at the bottom and work our way up.

- Insufficient valve clearance. A certain amount of clearance, or valve lash, is specified between the end of the stem and the tappet on "L"-head engines or between the rocker arm and the valve stem or cap on Overhead Valve engines. As the engine warms up, components grow from expansion. If valve clearances are too tight, and temperatures rise high enough, the valve may not be allowed to return all the back onto the seat. This will obviously cause a loss of power, as an escape route now exists for the expanding gasses. The exhaust valve is cooled by its contact with the seat. If the engine runs long enough, the valve face is superheated, with pitting, erosion and burning soon to follow.
- Valve guide wear. This is pretty much an unavoidable fact of life. The rocking motion caused by the advancing and retreating cam lobe is transmitted to the valve stem via the tappet on "L"-heads. A similar motion occurs as the rocker pushes down against the stem on Overhead Valve engines. The motion should always be parallel with the valve stem but can't be accomplished with traditional components. The stem almost always has a diagonal pressure against it, which accelerates wear. Accelerated, unnatural wear can also occur if the valve spring is not parallel to the valve stem. Check this carefully after installing the retainers.

Fine carbon chips are easily introduced to the exhaust valve guide, as they are commonly present in the form of soot as it exits the engine through the exhaust port.

The guides and valve stem are also considered areas of boundary lubrication where very little lubricant is found. Any excess oil will find its way to the combustion chamber and emissions will increase so it is necessary to create this condition.

The valve guide helps the valve to seat squarely on its seat. When wear occurs, the natural rocking motion is transmitted more dramatically to the stem. The valve will lift off it's seat, move to the side, return to the seat and strike up the face of the valve until the natural angle of the two allows it to nestle back onto the seat. Obvious wear to the seat and valve occur from this action.



- Exhaust valve overheating caused by engine conditions (plugged cooling fins, heavy, long-term load, too lean a mixture, etc.) or valve conditions such as poor contact with the seat. An obvious indentation in the exhaust valve seat indicates the valve has overheated and become soft enough for the seat to leave an impression in the face. If you encounter this condition, check the rest of the engine for additional overheating damage.

- Caustic erosion causes loss of material primarily on the valve face but will affect the seat as well. A variety of corrosive chemicals are formed as a by-product of combustion. Since the removal of lead from gasoline, chemical erosion is not as prevalent as it once was.
- Debris, usually carbon chips, that lodges between the valve and seat presents conditions similar to too little valve clearance already mentioned.

Exhaust valves on Briggs & Stratton engines all have a 45° angle, while some intake valves are 30°. The steeper angle of the exhaust helps to grind up any material present between the face and seat. The tail end of the power stroke then assists its removal through the exhaust port and into the muffler. Although this design is effective, it is still possible to encounter debris that will build up over time and prevent a good seal.

30° intake valves are less fortunate in that the angle is not as extreme as the exhaust, nor is the velocity of gasses moving through the port as high. Particles lodged between the face and seat have more of a tendency to stay put.

- Too great or too little valve rotation will reduce valve life. The winding and unwinding of the valve spring as it is compressed and relaxed and tappet-camgear and rocker-valve stem orientation cause valve rotation. Valve rotation causes a wiping effect, which helps keep the valve and seat free of deposits and debris. It also assists in cooling as the hotter edge of the valve closest to the cylinder rotates to a cooler area periodically.

Excessive rotation causes accelerated wear and too little, overheating and burning. Accelerated wear can be caused by installing rotators where they don't belong and is by far the least common of the two. Burning due to a lack of rotation can occur from deposits in the guide and by improper techniques in adjusting valve clearances on "L"-head engines. When clearances are adjusted, the valve stem must be ground at a 90° angle. Some technicians attempt to make this adjustment by hand against a grinding wheel. If the angle is off or a high point exists, the rotating motion transferred by the camgear and tappet will be affected.

The valve train is one of the most complicated engine subsystems and must function reliably under hostile conditions. A thorough knowledge of its purpose and operation is necessary before a technician can reliably inspect, diagnose and repair its components. Poor workmanship and "patches" will quickly result in returns and unhappy customers just from the nature of its operating characteristics and environment. Not only this, but increased concerns with engine exhaust emissions suggest we pay more attention to this area.

Briggs & Stratton has published well-established and reliable valve service procedures for many years. If properly performed, they are as good today as they were then.

Modern day engines have increased power demands placed on them by applications. Federal and state Governments have regulations in place that address emission outputs over the life of the engine. They also target service procedures to the extent that they are properly performed.

In lieu of these issues, Briggs & Stratton suggests certain modifications to our existing valve service procedures. When properly performed, we have measured horsepower increases of 4% to 6% on the dyno, which is "free" power. These numbers are the result of increased airflow through the intake port and the more efficient burning of the fuel/air charge. This translates into reduced emissions.

Overall, it's a winning combination. The customer has a piece of equipment that has greater power reserves, and we, as service technicians, do our part for the environment. In the next section, we'll explore these simple procedures in detail.