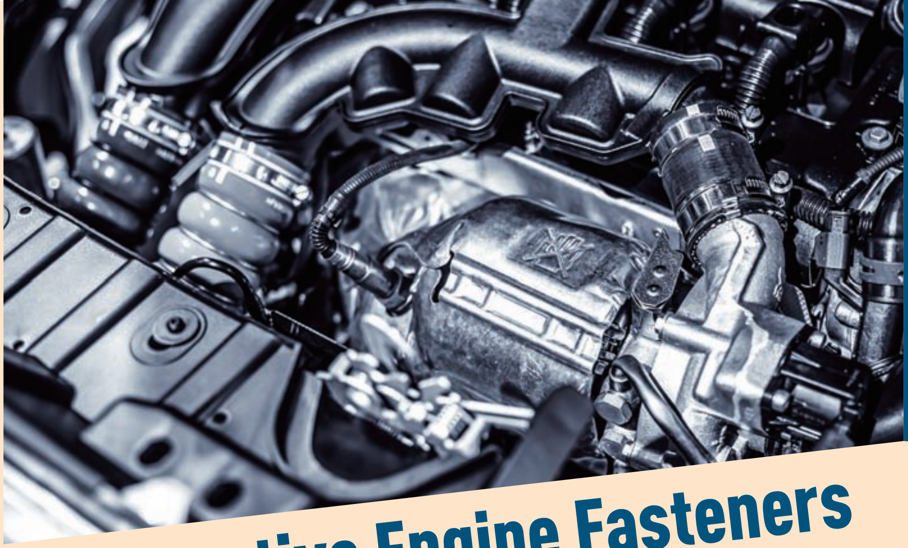


Automotive Engine Fasteners

by Laurence Claus

Every automobile is full of fasteners silently doing their job. Although some only perform minor functions, others are very important. Perhaps none, however, are more critical to the essence of the automobile than the fasteners used in the engine. In the typical automobile, internal engine components cycle many, many times a minute. It is even more extreme in racing engines. Racing engines operate at higher rpms so that they see cycles many times greater than the average automobile. For example, a racing engine operating at 7500rpm will see as many as 25 piston directional changes every second. Obviously an automobile engine operating at 2600rpms is less demanding, but still places it amongst the most critical of all the automobile systems.

Growing up my father had a 1963 Studebaker which came from the factory equipped with a Chevrolet 350 short block V8 engine. Compared with the vehicles I own today, where there is barely any open space in the engine compartment, the Studebaker was just an engine with a battery and a couple of other ancillary items. You could access almost any item on the engine without much effort. Not so today's engines, which are complicated power plants with all sorts of ancillary items sprouting from them, so tightly wedged in that there is little open space. Inside the engine, though, they haven't changed very much.

Although there are many different sizes, styles, and makers, the four stroke, internal combustion engine operates pretty much the same way that it has since inception. Every engine has a cylinder block that encases a fixed number of moving parts that generate the power put out by the engine. Automotive engines generally have an even number of pistons (4, 6, or 8) although there are exceptions to this rule. The piston is attached to the Connecting Rod, which, in turn, is connected to the Crank Shaft. As the piston starts to move up from the bottom of its stroke, a fuel and air mixture is introduced into the open space above the piston. As the piston continues to move upwards, it begins to compress this mixture until it reaches near the top, when a spark ignites the compressed fuel and air mixture, resulting in a controlled "explosion". Since the "explosion" is contained by the Cylinder Head, the explosive force is turned back on the piston, thrusting it downward. With all the cylinders acting in unison, they perform an intricate dance with some moving up to start the cycle and some thrusting down to end their cycle. Each piston is attached by way of a Connecting Rod to the Crankshaft, which turns to provide the engine's source of output power.

There are a number of very important threaded fasteners which hold the important components described above together. These include:

- Connecting Rod Bolts
- Main Bearing Bolts or Studs
- Cylinder Head Bolts or Studs

Additionally, other important engine fasteners include:

- Valve Adjustment Bolts
- Flywheel Bolts
- Pulley Bolts
- Valve Cover Bolts
- Cam Tower Bolts or Studs
- Intake Manifold Bolts
- Harmonic Balancer Bolts
- Fuel Pump Bolts
- Water Pump Bolts
- Exhaust Manifold Studs

Before we look at a couple of these important fasteners in closer detail, let us first consider the challenges that these fasteners face and the properties that they must possess.

The two primary challenges of internal engine fasteners are the magnitudes and types of loads that they experience in operation. This is true for all engines but increases as engines slide up the high performance scale. Higher revving engines place greater loads on the internal components, which, in turn, mean higher performing fasteners are required.

The first thing that engineers are taught about fasteners is that they must act like a stiff spring. In other words, they must stretch so that they can pull together the items that they are joining. In fact, fastener materials are quite stiff, producing a steep slope in this elastic portion of the stress strain curve. What that means in layman's terms is that as long as the fastener is in this elastic zone, small changes in elongation produce large tension loads. This is a fortunate development for fastener users because they can take advantage of these tension loads to combat the forces trying to pull the joints apart.

The elastic behavior of fasteners, however, is not infinite. It is, in fact, a function of the material used for the fastener. Eventually these materials reach a point where they become limited by the stress applied upon them and this elastic behavior changes to plastic behavior. Once again in layman's terms, that means that fasteners which once acted as a spring cease doing so and stretch permanently until they break. To increase the point where this transition occurs, designers utilize stronger versions of the same material or choose other, stronger materials.

In the case of these internal engine components there are significant forces acting on the system. Even though the average person rarely has the opportunity to really push their engine's limits, designers must design for operations over the entire effective range. As engine speeds increase so do the loads. Therefore, designers must utilize strong fasteners that allow them to produce even higher compressive loads in the joints they are holding together.

The second important consideration is the type of loading that the engine components experience. Internal engine components are experiencing fluctuating loads. This means that the load is applied and reversed multiple times. In fact, the rate of load reversals while the engine is operating on some of these components can be thousands per minute. This type of loading, however, exposes parts to a potential failure known as fatigue. If a part is exposed to this on-again, off-again loading, and the magnitude of the loading is high enough, a small flaw can be compelled to form a small crack which will progressively get larger until the part fails. Fatigue failure is normally catastrophic because it is unforeseen and unpredictable, and if it happens to a fastener during a period where the engine is revving at high rpms, it is likely to destroy the entire engine.

Considering these two requirements, engine designers and fastener engineers must work together to design some of the most highly engineered fasteners out there. So, what are some of the characteristics that make engine fasteners special?

Materials:

Many automotive and almost all racing engine internal fasteners utilize materials that provide performance advantages which exceed materials used for standard Grade 8 (PC 10.9) fasteners. In fact, it is customary for alloy steels such as 8740 and 4340 to be used for engine components. These materials can easily achieve strengths in the 180ksi minimum range. For racing engines, however, this strength range is likely insufficient. A racing or high performance engine may require strengths well into the 200+ ksi range. To achieve this, it is not uncommon for fastener manufacturers of specialty engine parts to utilize materials like H11 (a tool steel) or MP35N (a nickel-cobalt super alloy). These materials will be far more expensive than standard fastener materials but are well worth the investment in the properties they possess for these most challenging applications.

Geometry:

When a threaded fastener stretches, it will almost always do so in the threads. This makes sense as the minor diameter of the bolt or stud is the smallest cross section. Unfortunately, this also sets-up a case where a fastener with a full bodied shoulder above the threads will stretch non-uniformly. Therefore, it is common on engine fasteners (as well as other critical fasteners that may be stretched through most of their elastic range) to have a reduced diameter shank. These are often referred to as "wasted shank" or "reduced shank" variations. By designing this necked down section of the body, the part is more consistent and predictable in the way it stretches. This is advantageous as it provides better overall joint quality.

Fatigue:

The best defense against a fatigue failure is to maintain greater tension in the joint than the magnitude of the fluctuating load. However, other steps can be taken in manufacturing to further lessen the risk of a part failing by fatigue. To understand the advantage of these practices, however, one should first understand two basic concepts about fatigue. First, a fatigue failure starts with a crack. The crack must initiate from some point. This point is usually the location of a localized stress riser, such as a small manufacturing imperfection or from a sharp transition in geometry. Secondly, fatigue cracks always initiate in tension. Therefore, if you can place the part surface in compression, the compression stresses must be first overcome before a crack can start in tension. It is similar to water being retained in a reservoir. It cannot spill out until it has first risen above the level of the dike holding it within.

Manufacturers are able to do some things in their manufacturing processes to take advantage of these two principles. To address the first principle, engine parts subject to fatigue loading will require excellent surface finishes. This means that common surface discontinuities such as small cracks, voids, folds, and laps are not allowed. In some cases, parts may be precision ground to achieve a smooth surface with a consistent and low surface roughness. Threads will be manufactured to the "J" thread style. J-threads possess the maximum root radius allowed by standard on clearance fit threaded products. Designers will maximize radii at geometry transitions, such as the fillet (where the head and body come together.) The second principle, of instituting a compressive stress, is addressed by rolling threads after heat treatment , rolling the fillet radius after heat treatment, and, in some cases, providing the parts with a controlled shot peening operation.

Cylinder Head Bolts and Studs:

To allow for engine assembly, the engine block is open at the top of each cylinder bore. Therefore, the completed engine requires a top to seal off each piston chamber. This "lid" is known as the Cylinder Head and, in addition to providing the top surface of the piston bore, it also houses the valves which let fuel and air into the cylinder and exhaust out of it. Now imagine the engine operating at full capacity, there are explosions happening many times a second. The Cylinder Head retards the forces from these explosions causing them to push backwards and thrust the piston downwards. The forces that push against the head would like to blow it right off the top of the engine, however, the cylinder head bolts or studs hold it there and prevent this from happening. The forces, however are pretty extreme and, thus, require a critical fastener.

Cylinder Head Bolts and studs are often fastened to the yield point (where the fastener transitions from elastic behavior to plastic behavior.) Because of the severe loading conditions these parts experience this makes sense because this will be the point where the fastener is able to achieve its highest, safe tension. The ramification of this, however, is that these are one-time use parts and should be replaced with new hardware if an engine rebuild or maintenance takes place. Additionally, it is not uncommon for these fasteners to have "wasted shanks" to provide more consistent elastic stretching.

This application is sometimes designed with bolts and sometimes with studs. A stud is essentially an interrupted threaded rod (there is usually a small body or shank between the threaded ends). It can be hand tightened into the receiving tapped hole, the Cylinder Head fit into place, and tightened with a nut. There are two potential advantages to using studs over bolts. First, it is likely easier for the mechanic or engine builder to align the Head Gasket before fitting the Cylinder Head into place. Secondly, when using a bolt, the bolt is being exposed to dual forces. As desired, it generates axial tension forces, but also it is being exposed to a twisting force from the wrench or socket driving it. This second force is not exerted on a stud, only the axial tension force from the tightening of the nut. This has the advantage of eliminating some losses and complications that are the result of this twisting action.

Connecting Rod Bolts:

Attached to the piston is a rod which extends down and is connected to the Crankshaft. This is essentially a clamshell type of connection. The Connecting Rod end fits over a bearing on the Crankshaft and is attached on the other side by the Connecting Rod Cap. This joint is then held together by two Connecting Rod Bolts, one on either side of the Crankshaft. During high intensity operation the forces are severe enough to push on the seam of this joint, trying to open it up. The only things preventing this from happening are the Connecting Rod Bolts.

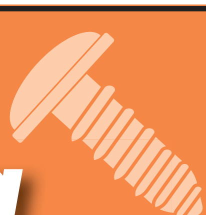
Connecting Rod Bolts come in a wide variety of styles and types. Because of the high chance of fatigue loading, many are precision ground or contain features to press fit or tightly secure them in the joint. Some may have "wasted shanks" to provide better elastic stretch consistency and drive systems are almost always a style that allows high transfer of torque.

Main Cap Bolts or Studs:

The Crankshaft is fixed into the engine block in a number of locations via the Main Journal Bearings. These are held in-place with a "cap" very similar to the Connecting Rod Cap. There are two bolts on either side of the Crankshaft that hold this "cap" to the engine block. Although not as extremely loaded as the Connecting Rod Bolts, these fasteners are highly loaded all the same. Therefore, many of the same principles that apply for the Connecting Rod Bolts and Cylinder Head Bolts apply to these as well.

Summary:

This was a simple introduction to some challenging and critical fastener applications. An automobile engine has many fasteners performing critical functions, even if they are not all as highly loaded or complicated in design as those highlighted in this article are. The bottom line is that any failure has the potential of wrecking the entire system. Therefore, all engine fasteners should be appreciated for the level of engineering and know-how that goes into each one.



Locking Fasteners -Part 1-

by Guy Avellon

There are many reasons why a fastener may become loose, all of which involve loss of preload, such as: not initially achieving a desired preload during assembly, tightening the bolt head instead of the nut, embedment into softer materials, extreme temperature variations, severe vibration, nonparallel joint surfaces, inconsistent application of torque, shear forces, heavy load impacting, or a host of other reasons. It is for these reasons that supplemental locking devices have been developed and used: to keep the parts together.

Using the term 'lock' or 'locking' in our present litigious society can present some legal problems if the product fails to perform as expected. This is because 'lock' implies some type of permanency and we literally hang on that word to feel that the connection is going to be safe forever. As with any connection, performance includes the selection of the correct product for the application and the proper installation technique.

Basically, we have two choices: lock the nut or lock the bolt.

While there have been a multitude of designs for the locking feature of the nut, the bolt is limited to having its threads distorted, using a nylon insert or by applying an anaerobic or cyanoacrylate chemical to the threads. These methods are used to help prevent the bolt from backing out of a tapped hole.

Nylon:

Nylon is a favorite material to use with any type of fastener to provide some prevailing off torque resistance. Used with bolts, the nylon is applied either as a round plug in the threads towards the end of the threads or as longitudinal patch. Nylon is relatively soft and will not damage the internal threads of softer materials. The nylon patch and plug have been found on bolts of all different strength levels, except it would not be as effective on a higher strength Grade 8, 10.9 or socket head cap screw.

There is a minimal amount of metal removal that neither method would affect the performance of the bolt. It may be argued that the patch would provide more surface area and hence more drag than the plug but again, it would depend upon the application needs and mating materials. Both would be suitable for use