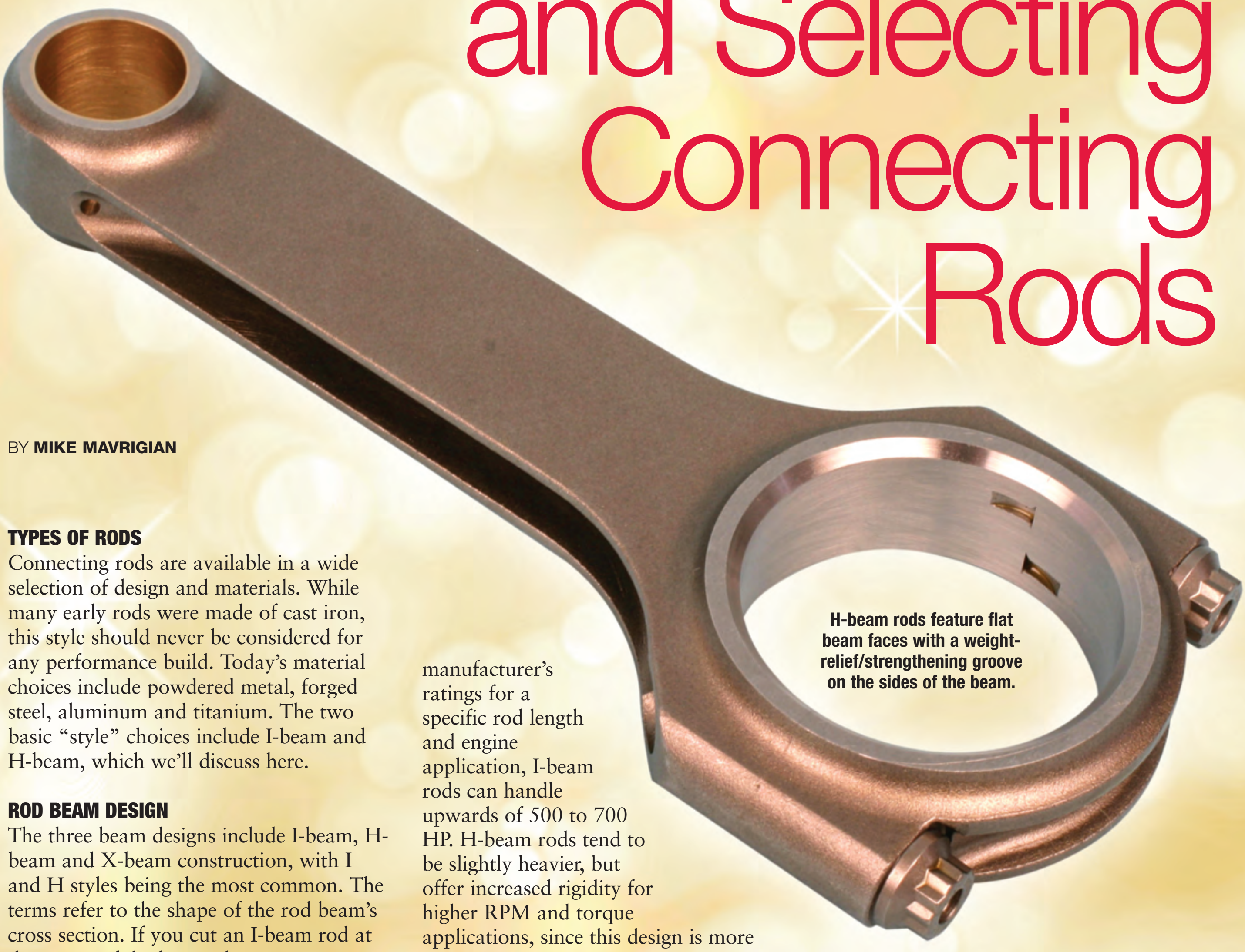
Understanding and Selecting Connecting Rods

BY **MIKE MAVRIGIAN**



H-beam rods feature flat beam faces with a weight-relief/strengthening groove on the sides of the beam.

TYPES OF RODS

Connecting rods are available in a wide selection of design and materials. While many early rods were made of cast iron, this style should never be considered for any performance build. Today's material choices include powdered metal, forged steel, aluminum and titanium. The two basic "style" choices include I-beam and H-beam, which we'll discuss here.

ROD BEAM DESIGN

The three beam designs include I-beam, H-beam and X-beam construction, with I and H styles being the most common. The terms refer to the shape of the rod beam's cross section. If you cut an I-beam rod at the center of the beam, the cross section resembles the capital letter "I." If you cut an H-beam rod, the cross section looks like the letter "H." An I-beam rod features smooth sides, with a big groove running the length of the front and rear beam faces. An H-beam rod features flat, smooth faces, with grooves on each side of the beam. A more "exotic" and less common style is the X-beam rod which features grooves on faces and sides (for weight reduction while retaining strength).

How do you choose between I-beam and H-beam rods? All other variables being equal, I-beam rods tend to be a bit lighter than H-beam rods, and are perfectly adequate for mild to wild street engines. Depending on the rod manufacturer's ratings for a specific rod length and engine application, I-beam rods can handle upwards of 500 to 700 HP. H-beam rods tend to be slightly heavier, but offer increased rigidity for higher RPM and torque applications, since this design is more resilient against higher compressive forces. For mild to wild street powerplants, either style is acceptable. As more stress is imposed (higher compression ratio, forced induction, etc.), a move to H-beam makes sense. We could also consider factors such as windage and parasitic oil cling, but then we're getting into serious racing applications where every ounce of power can be a game changer.

PM RODS

The vast majority of current OE connecting rods are of the powdered-metal (PM) type. For example, all of the factory GM LS-platform engines feature PM rods, with the exception of the LS7 and LS9, which feature forged titanium rods.

Powdered metal rods are "pressure cast," with a specially-formulated metal powder that's placed into a mold, then heated to a melting point and pressurized. Once out of the mold, the small and big ends are honed to size and rod bolt threads are cut. The rod is then secured in a fixture at the parting line area, and the cap is then snapped off, with no loss of material. The result is a fractured parting line on both the rod and cap (PM rods are often referred to as "cracked cap" rods). While this process may at first seem a bit crude, it creates a very precise mating surface interlock. The cap fits to the rod precisely (mirror image surfaces) for perfect cap-to-rod alignment. Because of

The deep groove on the beam sides of an H-beam rod reduce weight and provide extra rigidity for higher horsepower and torque and higher-RPM applications, as compared to I-beam rods.

I-beam rods feature smooth beam sides and face recesses. I-beam rods are typically lighter than H-beam designs. Depending on material, length and application, forged steel I-beam rods are generally viable for 500-700 HP applications.

this mating design, each cap must always remain with its original rod. While a PM rod big-end bore can be slightly oversize honed and mated with oversize-O.D. bearings, these rods cannot be re-sized in the traditional manner (where mating surfaces are ground flat to create a smaller, non-round bore, and then honed round again). Care must be taken when handling PM rods so as not to damage the irregular mating surfaces.

PM rods are surprisingly strong and perfectly acceptable for street use, but if your build is destined to spit out over about 400 HP, I'd recommended an upgrade to stronger rods (forged steel being the most common upgrade). If you do plan to retain original equipment PM rods, I strongly suggest eliminating the OE rod bolts in favor of much stronger performance rod bolts, such as those made by ARP.

OE PM rods, while satisfactory for most street applications, have their limitations in terms of horsepower-related stress, there are a few performance aftermarket PM rods that are now available that feature a much more sophisticated metal alloy mix that is cooked and pressurized to higher levels, that are reportedly capable of handling upwards of 800+ horsepower (sort of a hybrid approach of both PM technology and forging). I've not had a chance to use these new PM rods yet, but what I've heard so far has been very positive.

While PM rods have traditionally been used only at the OE level, we're now also starting to see high performance aftermarket PM rods. Howards Cams, as an example, teamed up with GKN and now offers forged powder metal rod technology with an extremely dense and non-directional grain structure. A high-tech base powder is blended with select alloy elements. Melting, atomizing and annealing are controlled to exacting standards. The metal-mix is compacted (in dies) under tremendous pressure, at over 1500 degrees F. Hot forging with a 750-ton press finalizes the structure of the metal. This new generation of PM rods represents a hybrid of both PM and forging.

While OEM-level PM rods are (as stated earlier) good for around the 400 HP area, and maybe even a max of 500 HP (although that's pushing it). Howard's new PM rods represent a new level in OM technology, and even with 5/16" ARP 2000 rod bolts, their rods are rated for 585 + HP. Reportedly, when fitted with L19 rod bolts, these rods have even survived at 800 + HP levels.

WHY THE OEs ARE USING THESE RODS

The OEs are using powder forgings for a number of reasons. Tighter tolerances can be maintained in both dimension and weight, and the use of a powder forging process makes connecting rods which are easier to machine, require less stock material, and the process eliminates as many as six machining operations. According to MascoTech, a primary manufacturer of these rods for the OEs, the increased machinability of powder forging has reduced tooling per unit cost from about $0.22 to about $0.04.

DESIGN ADVANTAGES OF POWDER METAL FORGING

- Even distribution of stress over the entire side of the I-beam area.
- Increased I-beam rigidity (100% increase in stiffness over conventional forged).
- Improved noise/vibration/harshness level, which improves piston and ring action.
- No bore offset between rod and cap.
- Increased bore stiffness and geometry.
- Increased bearing reliability.
- Reduced weight.
- Crankshaft mass reduction.
- Single weight grade (+- 2g on 400g rod).
- Reduced mass variation for improved balance.
- Full density across entire rod.
- Lower cost carbon steel.
- Proven fracture split method (no crank bore elongation during cracking)
- High machinability.

(continued)

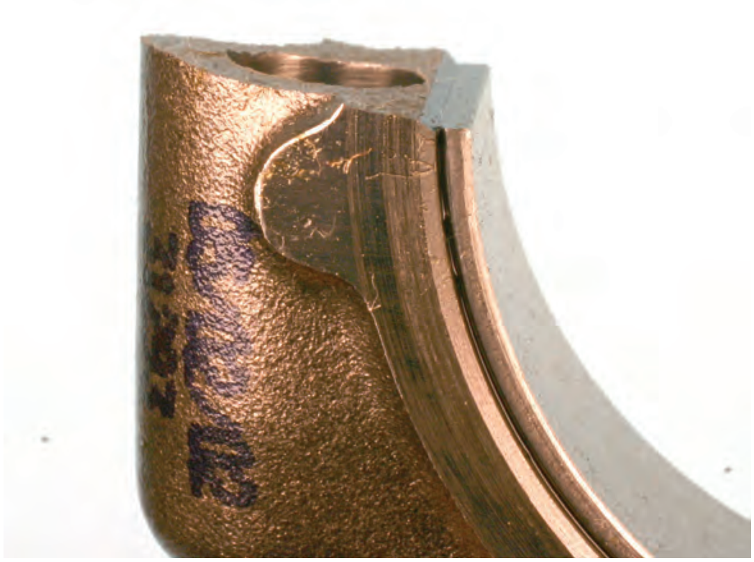
RECONDITIONING PM RODS

A major concern when trying to recondition cracked cap rods in the traditional manner relates to the irregular mating surfaces of the rod and cap. When these rods are manufactured, they are formed as a single piece. The caps are then separated by fracturing the cap from the rod, which leaves an irregular (and unique) mating surface. This irregular surface provides an accurate locating of the cap to the rod, preventing any misalignment of the cap during assembly.

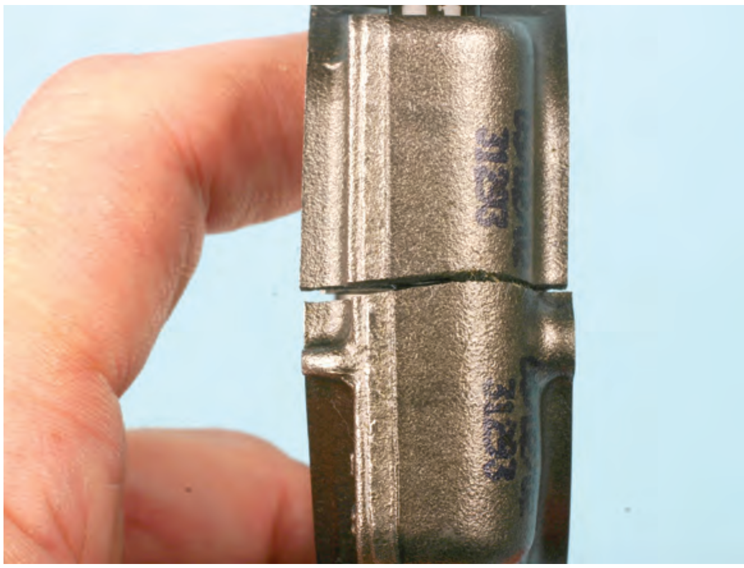
However, if the mating surfaces are machined or ground flat, in order to reduce the rod's large end bore in preparation of re-honing to size, you lose all centering ability. As described earlier, this would destroy the unique cap-to-rod interlock that was created when the cap was broken away from the rest of the rod during manufacturing. Since no interlock mating remains, and since there are no positioning tangs to use, this makes it possible to install the cap slightly off-center, due to the small tolerance range of the bolts to the cap's bolt holes. As a result, the cap might then be installed off-center left-to-right (laterally), or at an angle relative to the axis of the large end bore. If only for this reason, it is not advisable to reface the rod and cap mating surfaces.

The other reason that an attempt to resize these rods can create a problem is due to the relatively thin cap material. Once the mating surfaces are ground flat, the new smaller and non-round large end bore may require so much enlargement in order to create a round hole that the cap material may be reduced enough to create a potential weak area. We need to note that in the process of creating flat mating surfaces, it may be necessary to reduce the mating surfaces by as much as .040" or more, which could result in a combined reduction of the hole by as much as .080" or more. Precious little cap material may be left after resizing in this instance.

The best approach, if resizing is necessary, is to avoid disturbing the irregular cracked mating surfaces altogether. Instead, hone the big end to an oversize that will accommodate the fitting of oversized-O.D. rod bearings. Unfortunately, these oversized bearings are not yet available for all cracked cap applications, so check with your bearing suppliers before committing to this. If available though, bearings may be obtained that feature a standard size I.D. and a .002 + .003" larger O.D.; or in an undersized I.D. (to accommodate an undersized ground crank) and an oversized O.D. to accommodate an enlarged connecting rod big end.



Powder metal rods are pressure molded as one piece. The caps are then separated by a controlled fracturing or "cracking" process where the cap is snapped off of the rod. The resulting irregular mating faces then register back together very precisely.



The irregular mating surfaces at the parting line is unique to each rod's mating area. When the rod bolts are tightened to specification, the parting line disappears. It's critical to always keep each cap with its original rod. PM rods cannot be resized in the traditional manner.

FORGED STEEL RODS

Forged steel rods are constructed starting with an ingot of steel alloy, generally using 5140 or the stronger 4340 chrome moly steel. The steel is heated and hammer-forged under enormous pressure of around 240,000 lbs at around 2200 degrees F. This produces a tight internal grain structure wherein the molecules are more tightly compacted. This is followed by heat-treat hardening, final machining and stress relieving. On some early OE forged rods, you may notice what first appears as a "casting mold seam," which is simply a trace of the outer edge that remained after the initial forging was stamp-trimmed to remove any excess material that squeezed out of the stamping pattern. Today's aftermarket performance forged steel rods rarely feature this, as forging techniques and finish machining have become much more advanced.

Individual manufacturers often employ their own proprietary formulas, but generally speaking, during conventional steel forging, a steel ingot is heated in an oven to about 2,200 degrees F (at which point the steel very formable…not yet a liquid, but very easy to move around and shape). The ingot is then placed in a forging die and squeezed into the approximate shape of the desired profile. This "squeezing" is performed either by a hammering or pressing process. Either

Aluminum connecting rods, although made of high-density aluminum forgings or cut from billet stock, are beefier and command more room. Extra attention to clearances between the rod big end and the block and camshaft is critical.

way, the goal is to compress the alloy mix not only to precisely fill the die, but also to increase the strength of the alloy by compacting the molecules and aligning and strengthening the grain structure. Basically, the size of the ingot is much larger than the volume required in the die (generally, this will start with an ingot that weighs about twice as much as the desired final product). During the forging/compacting process, the excess material is forced out of the die at its mating lines. This excess is later sheared off in a trimming die.

The trimmed, rough-shape forging is then quenched and tempered. Heat treating is best done before machining, since the heat treating/tempering process can deform the part's shape by as much as 0.060". Manufacturer methods may vary, but this might involve quenching the part in a glycol solution. The part is then machined to its final shape. Once machining is completed, the rod is stress relieved to remove any stresses that might have been induced by the machining process. This may be done in an oven, heating the rods to within 400-600 degrees F. Both the heating and cool-down times are carefully controlled. The rod is then final-machined for small and big-end bore size. The final step involves achieving the desired surface hardness.

ALUMINUM RODS

The benefit of aluminum rods (whether forged or cut from extruded billet stock) involves weight reduction. However, even though aluminum rods are generally fabricated using 7075 or 7075-T6 aluminum alloy, in order to perform at high stress levels, aluminum rods are thicker and beefier, requiring more clearancing with regard to block and camshaft clearances. Due to the higher cost of aluminum rods, it really doesn't make sense for a street engine.

BILLET RODS

Billet rods, as the term implies, are machined from dense material blank stock (forged and or extruded). Billet rods, as compared to forged rods, may be lighter, but are more expensive due to the cost of the high-grade stock and the CNC machining. For even an ultra-strong street engine, this is slight overkill, unless budgeting isn't a concern.

TITANIUM RODS

If you want the lightest rods with the best strength-to-weight ratio, titanium is the choice. However, it's pricey. Since you'll only realize the weight benefit from the 5,000 rpm and up range, you really don't need titanium rods for any street engine.

Titanium rods are billet-machined from Ti6AL4V stock, and are about 33% lighter as compared to a same-application forged steel rod. However, titanium rods are much more expensive. Since you're really only going to see/feel the advantage at engine speeds over around 5,000 rpm or so, it's really a waste of money for a street engine. Also, titanium, for all of its strength-to-weight features, is a fragile material that is sensitive to scratches. Small scratches in the surface can lead to stress cracks, which leads to rod failure. Also, titanium (from a friction/machining standpoint, is rather "gummy" and likes to gall when rubbed (in the case of connecting rods, this concern exists at the rod big-end sides), so titanium rods must be polished and/or coated with a hard-surface coating (such as chromium nitride).

WHICH ROD MATERIAL?

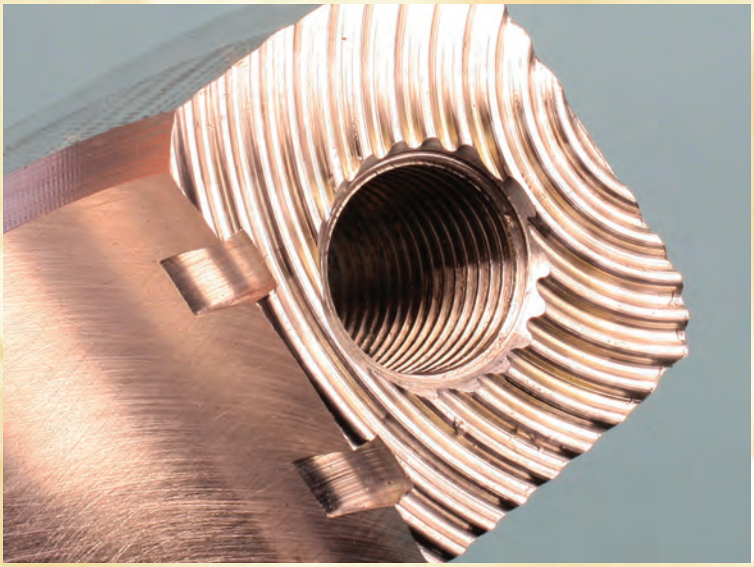
Forged or billet steel is suited for the vast majority of street and race applications. Where further weight reduction is desired, forged/billet aluminum rods are available, but at a higher cost. For high-RPM engines where weight savings are really critical, titanium rods are an option, but they tend to fatigue over time, as compared to steel. When used in racing applications they will likely need to be replaced more often, as compared to steel rods. Titanium rods are also very expensive, which is a major factor when you're on a real-world budget. Aluminum rods are lighter than steel but cost less than titanium and more than steel. Aluminum rods tend to be more on the chunky side and generally require more attention to block clearance.

CENTER-TO-CENTER LENGTH

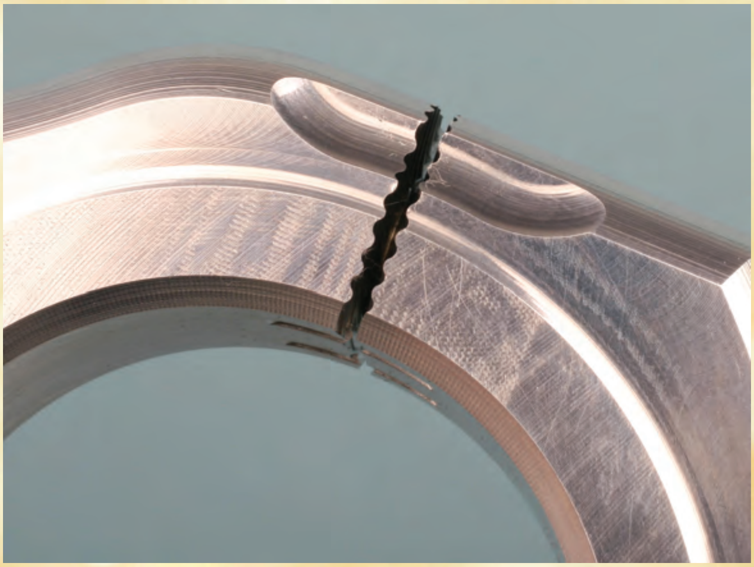
Rod length refers to the distance between the centerlines of the small end (piston pin) bore to the big end (rod pin) bore. Rod length is a factor in determining the combination required to achieve a specific stroke, relative to the block deck height.

For example, let's say that you want to achieve a zero-deck clearance (where the piston top is flush with the block deck). The crank stroke, rod length and piston CD (compression distance) all stack up to compare to the block deck height.

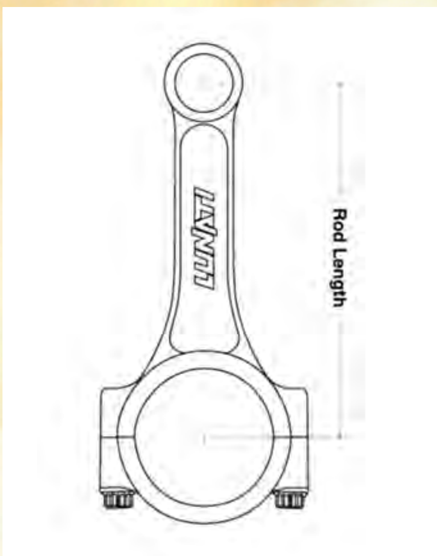
- The block deck height is the distance from the crank main bore centerline to the block's cylinder head deck.
- When considering stroke, we only need to factor half of the crank's total stroke, since we need to consider the distance from the centerline of the crank's rod journal at top-dead-center position. If your crank has a 4.00" stroke, we only need to factor-in half of total stroke, which in this example is 2.00".
- Piston CD is measured from the centerline of the piston's pin bore to the



Some high-dollar racing aluminum rods feature very precise cap mating surfaces such as the broach cuts seen here.



The radius groove broach cuts register the caps to the rods with extremely high precision, eliminating any chance for the cap to move in relation to the rod.



Connecting rod length always refers to the distance from the centerline of the small end bore to the centerline of the big end bore. (Illustration courtesy Lunati.)

Today's high performance aftermarket connecting rods are made with very high standards and close tolerances. Typically, a set from a leading manufacturer will be less than 2 grams in terms of weight variation. Typically there is no need to machine these rods for weight matching prior to crank balancing.

top deck of the piston.

If you know the block deck height and the crank stroke, you can choose the combination of rod length and piston CD that will place the piston deck at the block's deck (or to determine where the piston will be at TDC relative to the block deck).

EXAMPLE: If the block deck height is 9.980" and you plan to use a 4.150" stroke crank, a 6.760" rod and a piston CD of 1.113", the top of the piston will be 0.032" below deck. If you want the piston flush with the block deck, the piston CD would need to be 0.032" higher, or 1.145".

If you desire that the piston is flush with the block deck:
BLOCK DECK HEIGHT = ½ stroke + rod length + piston CD

One half of the crank stroke, length of the rod and the piston's compression distance are added together and compared to the block's deck height.

ROD CLEARANCES

There are six basic areas to consider relative to connecting rod clearance to other components:

- Big end of the rod to the block (when stroke is increased, check clearance at the pan rails and at the bottom of the cylinders). With main bearings, crank, rod bearings, rods and pistons test-installed, slowly rotate the crank and observe how close rod big ends are to the lower areas of the block. A minimum of about 0.080" is recommended.
- Big end of the rod to the camshaft (when using increased stroke). About 0.070" clearance is the minimum. With the cam and timing system installed, slowly rotate the crank and observe clearance at all rod big end areas.
- Small end of the rod to the underside of the piston (only a concern if using rods that have weight pads at the small end). Minimum is about 0.060".
- Small end of the rod between the piston pin bosses. Minimum is about 0.080". Especially if using thick aluminum rods, checking this is more critical.

(continued)

BY **MIKE MAVRIGIAN**

• Rod bearing clearance (this will likely be in the 0.0025 to 0.0035” range, but always refer to your engine’s specs. Be aware that forced induction applications may require greater bearing clearance as opposed to naturally-aspirated applications)

• Rod side clearance. This is the clearance between the big ends of a pair of rods on a common journal. With rods and bearings installed, spread the rod big ends apart and insert a feeler gauge between the big ends. Clearance for steel rods should be in the 0.014 – 0.020” range. Aluminum rods may require slightly greater clearance (refer to the rod maker’s specs)

• Small end of the rod bushing (assuming you’re using floating pins) to the wrist pins and piston pin bores. Refer to the rod and piston makers’ specs.

A note regarding rod to cam clearance: If clearance is required, you have two choices: remove material from the rod or change to a camshaft that features a smaller base circle. If you swap out to a smaller base circle cam, you’ll need longer pushrods. Considering today’s CNC

A rod bolt stretch gauge allows you to monitor each rod bolt’s length from free-state to fully tensioned. With the rod bolt placed onto the gauge, the dial gauge is zeroed to establish a reference point…

Without disturbing the gauge setting, the gauge is then used to check the bolt length during the tightening phase. The rod bolt and/or rod maker will provide a recommended bolt stretch specification. This provides more precise awareness of the bolt's elastic state as compared to using only a torque wrench. If undertightened, the bolt won't enter its elastic state required for proper clamping force. If overtightened beyond the bolt's elastic range, the bolt is weakened and can easily fail. The stretch method allows you to measure how much stretch has been induced.

capabilities, most cam makers can produce whatever you need, in anywhere from a week to a month, depending on their workload.

If you decide to relieve the rods, do this carefully at the upper big end shoulder to avoid weakening the rod bolt female threaded areas. Also, the grinding needs to be free of sharp edges and grind/scratch marks. Once the rod shoulder has been relieved, re-assemble and re-check the clearance. Once you're satisfied with clearance, carefully polish to remove any potential stress risers. Many of today's performance rods are designed with radiused/sloped shoulders to address increased stroke issues, but nonetheless, you should always check for clearance, especially when using an increased-stroke crank. BE AWARE: If any material is removed from the rods, this must be done prior to crank balancing!

NUMBERING YOUR RODS AND CAPS

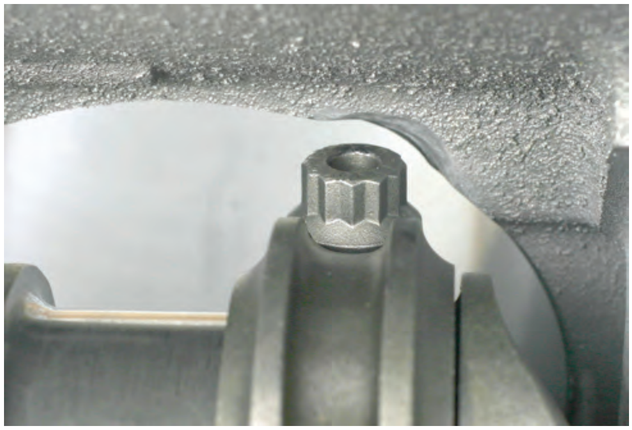
During initial assembly and during disassembly, it's critical to keep each rod organized with its original cap due to alignment and bearing clearance concerns. Each rod and cap should be identified (adjacent to the parting line). This might involve numbering by cylinder location, or in the case of quality aftermarket performance rods, matching serial numbers may be laser-etched onto a common side of each rod and cap. If your rods are not number-labeled, be sure to label them prior to disassembly. While an old-school commonly involved the use of a number punch, try to avoid this method, since (depending on the type of material and material thickness) this may distort the big end. A preferable method is to use a simple and inexpensive electric engraving pen.

ROD BOLTS

If you're running stock OE rods in any engine that's going to spit out around 350 or more HP, upgrade the rod bolts to high tensile strength performance aftermarket rod bolts. If you purchase quality performance aftermarket connecting rods, they'll commonly already include these higher quality bolts.

The critical aspect that you need to understand involves the handling of your rod bolts. PAY ATTENTION to the rod bolt or connecting rod manufacturer's

Rod bolts must be lubricated according to the rod bolt maker's instructions. Lubrication will allow more accuracy and consistency when tightening. Be aware that a different torque specification will apply depending on the use of engine oil versus a moly lube. Because a moly lube greatly reduces friction, the torque-tightening spec will be lower as compared to the use of engine oil. It's critical to follow the product's instructions! When applying any lubricant to rod bolts, lube both the threads as well as the bolt's under-head area.



Whenever you use a longer stroke crankshaft for a given engine, always perform a test pre-assembly to check for possible clearance issues. In this example, the bottom of a cylinder bore was slightly relieved to provide added clearance between the rod bolt and block.

instructions and specifications for lubricating and tightening the rod bolts.

Depending on the specific engine application, the tightening method may involve tightening by torque, tightening by bolt stretch monitoring, or (with some late model applications) a torque-plus-angle method. Generally speaking, a torque/angle procedure will only apply when using OE rod bolts. Most performance aftermarket rod bolt and rod makers will provide both a torque specification and a stretch range (giving you a choice of tightening methods).

If you intend to use the torque spec, bolt makers will usually provide two different torque values: one with the use of engine oil as a lubricant and one with the use of a specific moly lube. Torque value will always be a bit lower with moly, because moly decreases thread and underhead friction (if you use moly but tighten to the oil spec, you run the risk of over-tightening). The use of moly is preferred, since it greatly reduces friction and provides a more accurate (and consistent) torque value. When you lubricate the rod bolt prior to installation, be sure to apply lube both on the bolt threads and to the underside of the rod bolt head.

Tightening by monitoring stretch is more time-consuming but more accurate. This involves using a dedicated rod bolt stretch gauge to first obtain a relaxed, free length of the bolt. The dial gage is then set to zero. During initial tightening, the gauge is placed onto the rod bolt to monitor how much the bolt is stretched. For instance, if the torque spec is 70 ft-lb, the rod bolt could be initially torqued to, say, 60 ft-lb. Check length with the gauge. Tighten a bit more, re-check with the gauge, etc. until the recommended amount of stretch has been achieved. Note: this must be done with each bolt (the gauge must be zero'd to each bolt's free length). If you don't want to bother with monitoring stretch, simply follow the torque spec provided by the rod bolt or rod maker, and you should be fine for a street application. The stretch method is simply more precise and is commonly used by pro race engine builders, but it's also a good way to create a record of rod bolt installation for future reference. I prefer using two rod bolt stretch gauges, with one dedicated to each rod on a common journal. This allows me to verify bolt stretch as I tighten both of the rod's bolts.

Remember that bolts are designed to stretch when they enter their elastic state (you want this "alive" elastic state in order to provide sufficient clamping force). However, if the rod bolt is overtightened and exceeds its designed elastic state, the bolt immediately weakens. If a rod bolt has been

BY **MIKE MAVRIGIAN**

If you service engines on a frequent basis, a dedicated rod vise is essential. A composite-lined vise will prevent nicking damaged to the rod, holding the big end securely during either bolt removal or tightening during test fittings.

stretched beyond its elastic range, it must be replaced.

Regardless of which tightening method you choose, it's a good idea to take advantage of a stretch gauge (even if you intend to tighten with torque only). Regardless of what type of rod bolts you have (OE or aftermarket), using a stretch gauge, first measure each rod bolt's overall free-length (when new and uninstalled) and record this length. Be sure to record which rod each bolt will be installed to (cyl. 1, cyl. 2, etc.). During any future engine teardowns (or when the opportunity arises), re-measure each bolt's free length and compare it to the original (new) free-length that you recorded. If the bolt has elongated (stretched) by more than 0.0005" (one-half-thousandths), replace the bolt, since it has begun to lose its elastic properties. Never just assume that a used rod bolt is still serviceable.

ROD BOLT FRICTION FACTOR

If a bolt is tightened by addressing only torque value, you may not necessarily achieve the desired pre-load due to the variable of friction. Since we can't predict the frictional loss, measuring rod bolt stretch provides the most accurate method of ensuring that the clamping loads will be both sufficient for the task and that each pair of rod bolts will achieve EQUAL: loads.

Bolt stretch is generated by a number of factors, including tensile strength and mass, including the length/diameter of the bolt being stretched. For example, let's consider two 3/8" x 1" bolts. One features a 1"long shank, with threads on the full 1" of the shank length. The other bolt features ¾" of shank length that is full-diameter and smooth, and only ¼" of thread length at the tip. The bolt with partial thread will stretch less, because the shank area between the head and nut engagement area has a thicker cross-section. The partial-thread bolt will have a .375" diameter shank, while the all-thread bolt will have only a .324" shank (due to the smaller root diameter inside the thread path).

According to ARP as an example, they calculate stretch number for every bolt shank diameter and material grade.

A rod cap splitter tool is another handy device. The big end is placed on a 2-piece anvil. With the rod bolts backed off, as the tool handle is turned, the anvil gently and controllably separates the cap from the rod without the need to bang the bolt heads with a hammer and potentially dropping the rod in the process.

Shown here is a view of a block's camshaft bore. Notice how close the proximity of the rod bolt shoulder to the cam tunnel. If you're using a high-lift cam, and/or you're overstroking, and/or using thicker-than-stock rods, always check rod to cam lobe clearance.

On the spec sheet that is included with every bolt set, the maximum allowable amount of stretch is listed, in addition to a torque value, but the torque value should be used as a guide only. The maker does not want the installer to use a torque value as the final indication of bolt stretch. Rather, the bolts should be individually measured for stretch during tightening, to assure that each bolt is installed at its optimum elastic clamping load.■

Mike Mavrigian has written thousands of technical articles over the past 30 years for a variety of automotive publications. In addition, Mike has written many books for HP Books. Contact him at Birchwood Automotive Group, Creston, OH. Call (330) 435-6347 or e-mail: mike@birchwoodautomotive.com. Website: www.birchwoodautomotive.com