Engine Assembly

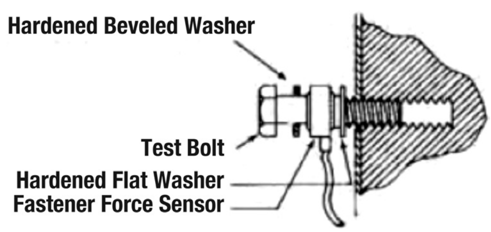
Understanding Torque vs. Clamping Force

BY **CHUCK LYNCH**

The principles that are going to be covered in this article are instrumental in the correct and successful assembly of any component. We are going to take a high altitude viewpoint of this subject to keep it simple and manageable as there is easily enough science and study on this subject to produce a 50 page article.

What is torque? By definition, torque is a measure of how much force acting on an object causes that object to rotate. In the world of component assembly and more specifically to our industry, of engine assembly, we use a torque wrench as the measuring device. To the component you are assembling, that is like using a tape measure to measure the temperature. What we would ideally like to measure is the amount of clamping force that is being generated on the assembled joint. To have a 100% measure of clamping force is not practical or cost effective at nearly any scale outside of R&D.

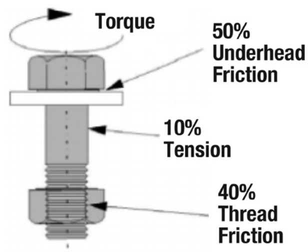
Clamping force, as critical as it is to the performance and longevity of a joint, is very difficult to measure outside of a lab type environment. A device that measures assembled joint clamping force is really no different than a bolt dyno for the sake of simplicity. The device looks like a steel donut that has an encapsulated strain gauge with an I/O and display. You employ a series of shims/washers and spacers to create the assembled length of the joint that the subject fastener will be engaged as illustrated. An example would be to create the thickness of the cylinder heads, washers and head gasket to ensure that the same amount of the fastener is being engaged into the bolt hole.



From this point, you can start to analyze the effectiveness of the tightening procedure that you will use to assemble your component. You will be able to visually see the affects of the itmes listed below. We will follow up with some descriptions for each checkpoint.

✓ Bolt hole condition
✓ Threaded Fastener Condition
✓ Alignment
✓ Lubrication as it pertains to the coefficient of friction
✓ Gasket Reaction, if applicable
✓ Over-coming static friction or a term a friend introduced me too as "stiction"
✓ Tightening speed as it pertains to rotation and stopping speeds"inertial forces"
✓ The effect of fastener grade changes or design
✓ Point at which a TTY fastener goes into yield
✓ Point at which plastic deformation happens relevant the yield zone

Before we explain the items on the above checklist, let's briefly discuss our primary struggle associated with bolted joints and that is overcoming friction. This illustration helps to explain why it is so important to effectively prepare for assembly of your products. The opportunity to utilize the full tension potential of your fastener is slim at best.

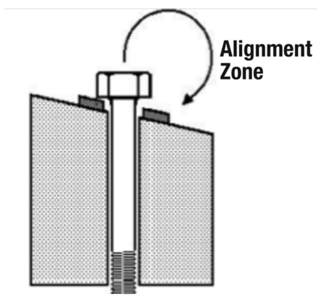


Let's get to explaining that checklist…

The condition of the bolthole: In the rebuild industry, you can see many variants of bolt hole condition from as good as new to having different materials in the threaded hole from welding to installing thread repairs. The threaded holes may have been wire brushed, processed with a thread chaser, re-tapped or even used with cracks present. These conditions may still perform well, just be consistant.

Threaded Fasteners are expensive and we want to re-use what we can.That is why we are in this industry of service and repair or recycling. As with the bolthole, you need to be aware of the thread condition as well as corrosion of the bolt shank and the underhead bearing strength zone. Again, consistency is the rule, set a standard and stick to it.

The **alignment** of fasteners to the mating parts adds another dimension to friction losses. There is now opportunity for side loading/bending and as well as changes in underhead friction and potential for a new friction zone on the shank.



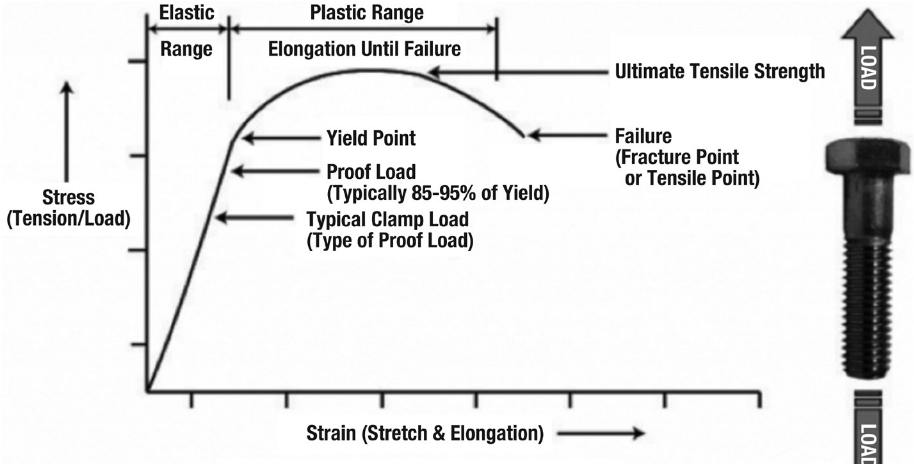
Lubrication is a factor that can have huge impacts on a joint with very little effort. You have to be very cautious of deviating from what is recommended from the supplier of the fastener of the service manual. There are many high quality, high performance lubricants. A lubricant that is too slippery can result in broken or cracked castings and/or fastener failure.

Likewise, a friction factor that does not reduce friction enough can result in too little force which can result in leaks or fasteners backing out, etc.

Gasket Reaction plays a key role in the tightening sequence and the amount of steps. Many gaskets will compress to a point, then relax or need to have the load re-distributed for balance. This is why you sometimes see steps like tighten bolt to X spec, then loosen bolt 180 degrees then tighten to X. Gasket compression rates can vary greatly do to material, thickness, relative hardness, coatings, surface finish and the list continues to grow and change.

"Stiction" can become an issue when you are doing a series of tightening steps. Once a fastener is under pre-load, it can take a significant amount of force to get the rotation started again. If proper tightening practices are not followed, the result can be a false indication of a tight joint which can later reveal itself as a loose fastener. A good example would be jerk torqueing which is very common with "click" type torque wrenches. This leads into the next checkpoint…

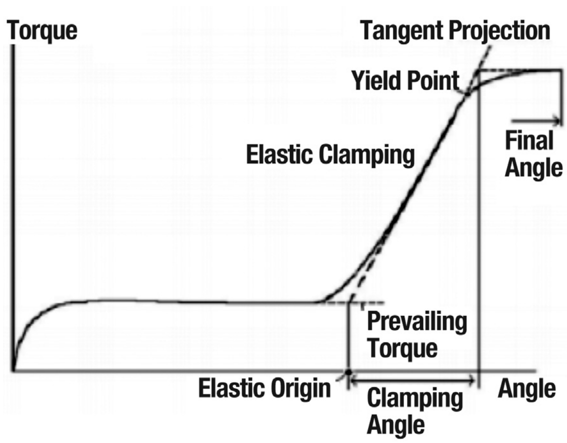
Tightening Speed is probably the most common contributor to improperly tightened fasteners. The popularity of click type torque wrenches is well deserved. It provides an audible notification and a feel to tightening a joint that Beam or Dial Torque wrenches do not offer. That being said, a lot of bad habits are born of relying on the click. The most common issue that comes with the click wrenches is torque scatter. Torque scatter is the result of under or over rotating the fastener during the tightening process. A slow, steady and even rotation yields the best results but we tend to get hurried and start to jerk on the wrench. In many instances the bolt did not have the opportunity to properly overcome "Stiction" or there is so much inertia that the bolt will over-rotate. This can have a huge impact on clamping force that can easily be in the thousands of pounds of clamping forces. Keep in mind that most 11.5 mm head bolts are producing clamping forces of more than 12,000 ft./lbs. per fastener when tightened properly. It does not take very many degrees of rotation to change that force by 2,000 lbs. too tight or too loose. Therefore, it is not improbable to have a 4,000 lbs. spread on one cylinder head. Again as stated above, be consistent in all of your processes.



Tensile Stress-Strain Diagram

Fastener Grade is an area that problematic to assembly performance if you are not careful to properly identify what fasteners are correct for the application. Torque-to-Yield fasteners are very common today but you must be cautious about substituting bolts. These bolts will have a specific operating range in which the transition from being elastic in the yield zone and transitioning to the plastic deformation zone can be very specific.

Yield Point is critical to identify. This is the point at which the fastener transitions to the point of being elastic. That is the characteristic that is so desirable for dynamic assemblies such as head bolt that are trying to react to cylinder pressure trying to blow the head off. The illustration at the left gives a brief description of the dynamics between the rotation and clamping force.



Plastic Deformation is not what we want to see but a phenomenon that we must understand. If the fastener is stressed beyond the effective elastic zone, it will move to a point in which it can longer maintain desired tension on the joint. In layman's terms, the fasteners just turned into taffy. It will continue to stretch and possibly not snap but it will no longer show an increase in tension.

Again, as stated when we opened this article, this information is really just an overview of a much more in-depth study but hopefully it will help to trigger some thoughts about the true reasoning behind the use of that torque wrench and how we use that wrench.

A good tool for understanding and teaching what is happening when you are tightening fasteners is a load cell. For about the cost of a profilometer, you can see the effect of each factor covered in this article. With that information, you can better understand the forces that make us need to torque plate hone, to machine with main caps installed or why a valve seat leaks on an assembled engine but not at head assembly. You can create safe resolutions to leaks and distortion with supporting data instead of the costly field experiment.■

AERA Technical Specialist Chuck Lynch spent 20 years of his career at Jasper Engines in many roles, including process engineer. He has also worked as a quality auditor, analyzed tooling needs, coordinated procurement and training for equipment and tooling, incorporated the use of super abrasives, coordinated failure analysis of components, and more. For more information, email: chuck@aera.org.