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KEEPING IT TOGETHER

Fundamental Fastener Facts - Part 1

By Frank Romano

This article is to review some basic fundamentals of mechanical equipment, and maybe give you something new to munch on.

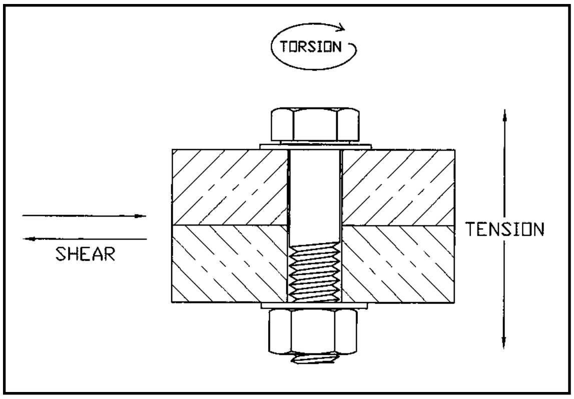


Figure #1

Cars, go-karts, refrigerators, and most everything around us is made up of smaller pieces that are fastened together. Whether rivets, rubber bands, threaded fasteners or zippers are used, one basic requirement is necessary: all the pieces must stay stuck together. You don't have to watch many races to know that it's not uncommon for some sort of fastener to fail. There is no magic to prevent this from happening, just a little bit of knowledge. In this series of articles, we'll go over some of the basics of Threaded Fasteners, and some less-obvious details, so that you might better understand some of the science behind the failures and successes.

Please note this first. Some of the material given here may seem extraordinary or overkill, and because many components of a modern racing kart are probably overdesigned with generous safety factors, some of these stricter guidelines could be ignored. There are, however, situations where this is not the case, where the limits of materials are approached, and these are the times where a little extra bit of knowledge or effort might prevent a catastrophic (or expensive) failure. The hope here is that once you are aware (or reminded) of some of these principles, you might get into the habit of working against the worst case, and, hopefully, everything you do will be better for it. The ultimate decision of how much extra effort is needed in any situation is yours.

The words bolt, capscrew, stud, fastener can generally be interchanged here without incident throughout this article. Definitions of some of the terms used in this article appear at the end, listed as footnotes.

Threaded fasteners are used for two different kinds of basic applications: tension and shear. They must withstand the forces generated by these two types of loads, either singly or in combination, as well as the torsion forces applied during the tightening process. Figure #1 shows the various forces a typical fastener must withstand.

When the bolt is used to clamp parts together, it is under a tension, or tensile, load. This is the most common application. When it is used for mounting another component as in a movable linkage then the bolt is under a shear load. These two applications require different considerations.

TENSION LOADING:

This is the most common purpose of fasteners, so it requires the most discussion. A fastener must apply a clamping force to hold the pieces together that is higher than the load working to separate those parts. If the bolt is undertightened (clamping force less than the joint's load), and the joint doesn't first come apart from the bolt's loosening, the bolt will alternately stretch and contract as it is loaded and unloaded and eventually fail from the effects of fatigue. The clamping force must be sufficiently above this maximum load to resist the effects of fatigue yet be below the yield strength of the bolt's material. If a force is applied to the joint that exceeds the yield strength of the bolt material, it will permanently stretch and the joint will loosen. A proper design will work the bolt between 75 to 90% of its proof load. Threaded fasteners are available in several different grades (load ratings) and are discussed later in this article.

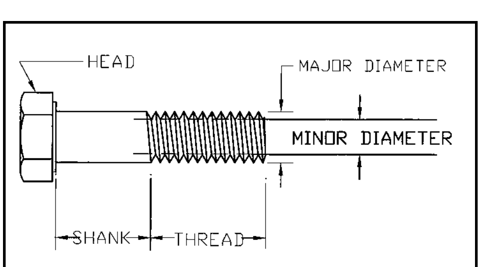


Figure #2

A threaded fastener's joint design is based on the fact that the strength in the threads themselves far exceeds the strength of the bolt's cross section, so ideally, the bolt will break before the threads strip. This means that the clamping force applied by the bolt is concentrated on the minor diameter of the threaded section (the diameter at the root of the thread, the bolt's smallest cross-section). See Fig. #2.

This is the weakest link that controls the maximum load the bolt can carry and this figures into determining the correct bolt length. Since the bolt must stretch in order for a clamping force to be applied to the joint, the majority of the stretch will take place in the threaded portion between the nut and the bolt's shank (the grip area). A bolt length must be chosen to allow as many unengaged threads as possible within the grip area in order to distribute this stretching over as much length as possible. This means to use the shortest length bolt possible that will allow full thread engagement of the nut. If a longer bolt length is chosen that allows few threads in the grip area, the joint is more prone to fail compared to that described above. See Figure #3 above.

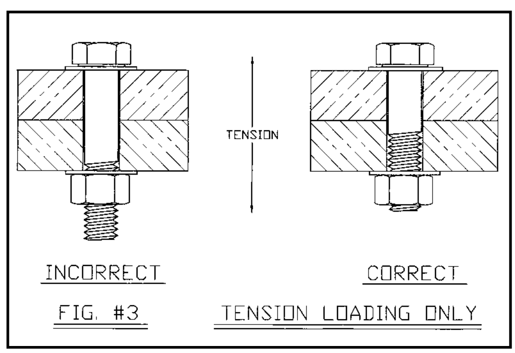


Figure #3

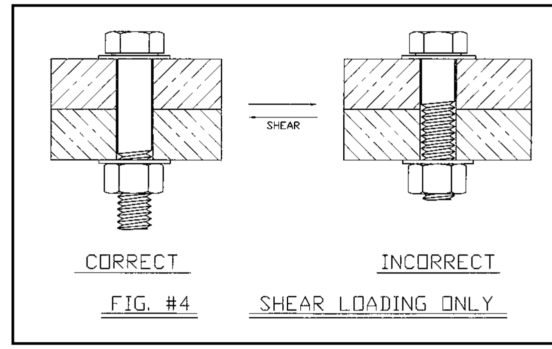


Figure #4

A failure of a bolt in tension due to this kind of misapplication would most likely be at the end of the thread where it meets the shank, due to the stress riser at that point.

In extremely critical applications (engine connecting rod bolts, cylinder head studs), the shank is turned down along all or most of its length to the minor diameter of the thread in order to spread out the elongation (and stress) along the whole bolt.

Bolts correctly tightened to required clamp loads in a properly designed joint will rarely fail in service. In a connection subjected to cyclic loading (on, off, on, off, etc.), this could lead to a fatigue failure, and an inadequate clamping load can be very damaging. In that case, slightly overtightening the bolt over its normal rating and closer to its yield point is necessary for the bolt to better resist the subtle effects of a fatigue failure. Great care obviously, must be taken not to carry this too far.

SHEAR LOADING:

In this situation, the force on the joint is trying to shear (or cut) the bolt. Here, when choosing bolt lengths, you need to have the full diameter of the bolt shank at the point of the shearing action, and keep it away from the threaded portion of the bolt, as shown in Figure #4.

You need to beware that in this situation, there is a trap. Many shear joints rely on the clamping force of the bolt to provide enough friction at the mating surfaces to provide the resistance to shear. In that case the bolt is mainly providing tension load, so care (and compromise) is needed when choosing bolt lengths. In the aircraft field, there are separate classifications of bolts that will only be loaded in shear. They have thinner heads and use special half-height nuts and are used when bolt tension is a smaller issue than weight.

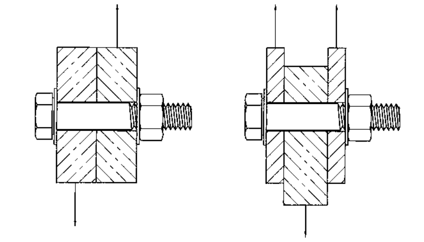
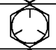


Figure #5

One word about mounting a movable part, as in a linkage, with a fastener: in no way should the fastener be used to directly take any movement onto itself. Some sort of bearing or bushing should be used so that the fastener does not have to deal with the effects of friction and wear.

BOLTHEAD MARKING and INFORMATION CHART

Grade Marking	Description	Specification	Material	Nominal Sizes	Proof Load, psi	Tensile Strength², min. psi
	No lines or markings	SAE Grade 2	Low carbon steel	1/4 thru 3/4 3/4 thru 1 1/2	55.000 33,000	74.000 60,000
	3 lines 120° apart	SAE Grade 5	Medium carbon steel	1/4 thru 1 1 thru 1 1/2	85,000 74,000	120,000 105,000
	6 lines 60° apart	SAE Grade 8	Medium carbon alloy steel	1/4 thru 1 1/2	120,000	150,000
	"X" in center of head	Military "AN" Series	Medium carbon alloy steel	1/4 thru 1 1/4	NA	125,000
	NAS series # indicated	Military "NAS" Series	NA	1/4 thru 1 1/4	NA	160,000

If a shear connection as that in Fig. 4 can be changed to a double shear design, then its shear strength will double due to there now being two points to resist the shearing force. Any trouble needed to accomplish this will be well worth it.

ASSEMBLY INFORMATION:

We've been talking about the stress levels in fasteners, let's talk here about how to measure it. Torque has been relied on as a measurement of tightness because everyone is familiar with it, it's fairly easy to measure, and there is no easy method of measuring it any other way. It is usually adequate for our purposes because most applications tend to have generous safety factors built in. But it is tension, not torque that is the critical consideration when evaluating the tightness of a fastener. Though there is a close relationship between the two under ideal conditions, we must be aware that much torque is lost to friction (up to 90%) and that friction can be greatly affected by a number of things like lubricants, washers, plating, finish, hardness (or lack of any of these), general condition (worn or reused makes a big difference), cleanliness of the components, or anything causing an interference. A small bump or burr on a thread will require considerable torque to overcome the resistance it provides, and this would result in improper tightening of the fastener (the torque that is absorbed by the problem is not being put into tightening the bolt). If you're working with published torque specifications, be sure to note if they are given with or without the use of a lubricant on the threads. And, of course, take extra effort to ensure the threads are undamaged and as absolutely clean as possible.

In the most critical applications where the joint is designed to the limits of the materials, the truest measure of tension is bolt stretch. Though difficult to obtain it is really the only absolute way to gage the stress on the bolt and take full advantage of its size's capability (if you've ever tightened a fastener by counting the number of flats on the nut or bolthead you are really tightening the joint by an indirect stretch measurement). When the stretch is measured either directly or indirectly, the errors mentioned above, which affect torque readings, will not matter. (Trivia - What we call a Torque Wrench, the English and Australians call a Tension Wrench).

If all is designed correctly, the maximum stress level the bolt will see is during tightening. If a bolt should show any signs of yielding during assembly, (it "feels funny") then it should be replaced without fail. All bolts should be inspected before assembly for any necking down or elongation of the threaded section.

STRENGTH RATINGS:

We mentioned earlier that fasteners are available in different grades, and there are many. There are three common grades (the most readily available) and some not-so-common grades that we should all be familiar with.

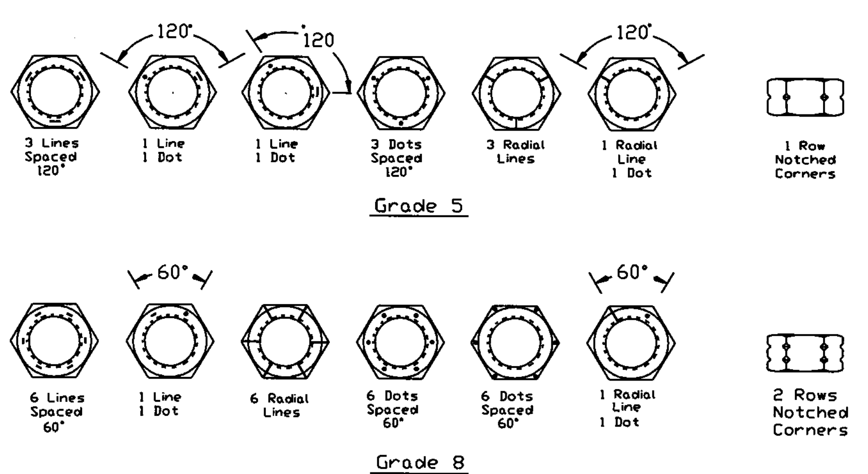
The three common (industrial) grades are: Grade 2 - we should never use them, not even for small paperweights; Grade 5 - the lowest grade we should ever use; and Grade 8 - used on any joint requiring extra strength or insurance. The charts at the end of this article show the identifying marks used on bolts and nuts and their relative strength ratings. Bolts have a fairly standard marking system for grade distinction, but nuts do not. The table shows most, if not all the different markings you might encounter, though there still might be slight variations from those shown. Be aware that some Grade 5 nuts are not marked, and they usually cannot be distinguished from Grade 2 nuts, which are also not marked (Again, NO Grade 2 fasteners should ever be used here, don't even keep any in the shop - you might use them unintentionally). If the need arises for a bolt quality better than those mentioned above, then caution needs to be exercised in certain cases. Some manufacturers have an optional series of bolts that they claim to be better than Grade 8, and here is where to be cautious. High strength steels are heat treated in order to get the higher strength, and this correlates to hardness. Hardness in turn correlates to brittleness, and these "extra-strength" bolts may be extra brittle and for that reason they shouldn't be used where there is a lot of impact loading. The popular opinion regarding bolts that are claimed to be "greater than Grade 8" system is that it is a lot of hype and not a lot of substance.

The not-so-common grades mentioned earlier are the aircraft and military grades, the ones that all the race car building publications insist on using: the "AN" and "NAS" series of fasteners, which utilize the standard SAE thread form, but length designation and quality control are quite different. The material (UTS7) spec of the "AN" series is between grade 5 and 8, and the "NAS" series exceeds that of Grade 8 (truly). They are much better all around when such things as fatigue resistance and shear strength are considered. Though they really are the only ones to use if you are racing a "suspensioned" race car, karting probably does not warrant the extraordinary effort (and expense) it takes to procure these gems, though that decision is completely up to you. Grades 5 and 8 used correctly are more than sufficient for our use. A whole separate article could be written to cover the specifics of using these fasteners - and there are many (almost rocket science).

If a situation involves the use of socket head capscrews, be aware that they are generally equivalent to a Grade 8 rating. Usually not a problem using them anywhere.

Fine threads vs. coarse threads: each has its own advantages and disadvantages, but when all else is equal, fine threads are capable of producing approx. 10% more clamping force than coarse threads. Coarse thread bolts are more popular because

NUT IDENTIFICATION MARKINGS



there are many other advantages to using them. More on this next time.

SPECIAL INFORMATION ABOUT NUTS:

Nuts also come in different grades, and must be closely matched to the corresponding grade of the bolts being used. Various ways are used by different manufacturers to identify the different grades, as mentioned before.

Nuts need to be the slightly softer of the two components in a fastener joint, so they take the most abuse. The threads deform slightly as they are being used, especially the first time. The initial machining of the parts is never a perfect fit with the mating threads, so when the assembly is torqued for the first time, less friction is experienced due to less intimate contact between the parts, then as the threads deform and become more closely matched, subsequent tightenings will experience more friction. This deformation is necessary for proper load distribution and this is why it is very important to have the relative strengths between the two components closely matched. It is also the most dangerous component to reuse in a critical application due to this deformation effect.

Well, there's a lot more on this subject, but this is probably all you can take in one sitting, without getting too bored (too late?). In the next article we'll cover thread engagement lengths, locking devices, the story behind washers, the use of torque wrenches, among other fastener facts.

FOOTNOTES:

1. Safety Factor - any equipment design is a compromise between excess material (read weight and cost) and being able to withstand any unexpected occurrences; its use will determine how much of an issue weight should figure in the design (as in aircraft/race cars vs. boilers/buildings). Issues like these will determine how close a material's working stress will be to its ultimate or yield stress, and the safety factor can numerically relate one to the other.

2. Clamping force is the actual force applied by the bolt to the pieces being held together, calculated by dividing the stress in the bolt (set up by the tightening process) by the cross-sectional area of bolt.

3. Yield strength (or yield point) - steel possesses a certain amount of elasticity, and as long as the loads stay within the "elastic" range, the bolt will return to its original state when unloaded. At a certain load point (the yield point), this range is exceeded, and the bolt will no longer return to its original length when unloaded. This is a function of the bolt's material.

4. Proof load is the bolt's maximum safe load, slightly lower than the yield strength of the bolt's material.

5. Stress riser (or stress raiser) is a point of stress concentration, usually a necked down point on a diameter, or any discontinuity of a surface, as the end of the threads on a bolt at the shank.

6. Fatigue, fatigue failure, fatigue stress has to do with loads being repeatedly applied and relaxed or reversed, as opposed to being continuous. This can greatly reduce the service life of a component even though it's outward appearances are subtle. It can be roughly predicted with calculations that include max stress vs. min stress, number of cycles and properties of the materials. The most significant variable is the properties of the materials when all else is established.

7. Tensile strength (or ultimate tensile strength or UTS) - the actual breaking strength of a material, usually not used in the design of a component (yield strength is most important), but it is used for distinguishing, or rating, one material from another.

- END -