Self-loosening of threaded fasteners

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Here Bill Eccles, Bolt Science, looks into the causes of self-loosening of threaded fasteners and what steps can be taken to help prevent loosening.

Introduction

Practically every engineering product with any degree of complexity uses threaded fasteners. A key advantage of threaded fasteners over the majority of other joining methods is that they can be dis-assembled and re-used. This feature is often the reason why threaded fasteners are used in preference to other joining methods and they often play a vital role in maintaining a product's structural integrity. However, they are also a significant source of problems in machinery and other assemblies. The reasons for such problems are due, in part, to them unintentionally self-loosening.

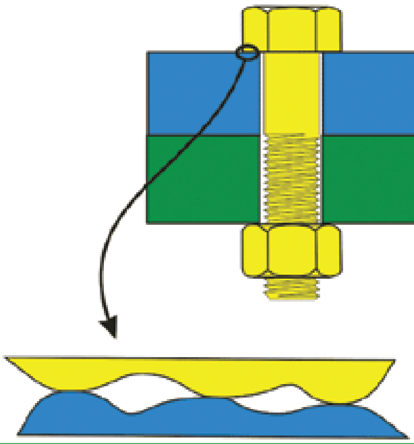
Such self-loosening has been a problem since the start of the industrial revolution and for the last 150 years inventors have been devising ways in which it can be prevented. Many of the common types of locking methods for threaded fasteners were invented over 100 years ago, however it is only relatively recently that the main mechanism that is considered to cause self loosening has become understood. There are a number of mechanisms that can result in a threaded fastener coming loose; these can be classified as rotational and non-rotational loosening.

Rotational and non-rotational loosening

In the vast majority of applications, threaded fasteners are tightened so that a preload is imparted into a joint. Loosening can be defined as a subsequent loss of preload following the completion of the tightening process. This can occur by one of two means. Rotational loosening, more commonly referred to as self-loosening, is when the fastener rotates under the action of external loading. Non-rotational loosening is when no relative movement occurs between the internal and external threads but a preload loss occurs.

Fasteners coming loose due to non-rotational loosening

Non-rotational loosening can occur as a result of deformation of the fastener itself, or the joint, following assembly. This can occur as a result of a partial plastic collapse of these interfaces. When two surfaces come into contact with each other, asperities on each surface sustain the bearing load. Because the actual contact area can be substantially less than the apparent area, very high localised stresses are sustained by the asperities that, even under moderate loading, are greater than the yield strength of the material.



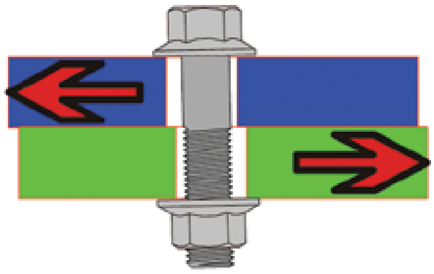
Magnified surface showing asperity contact

This leads to the surface partially collapsing following the completion of the tightening operation. This collapse is typically referred to as embedding. The amount of the clamp force that is lost due to embedding depends upon the bolt and joint stiffness, the number of interfaces present within the joint, the surface roughness and the bearing stress being applied. Under moderate surface stress conditions, the initial collapse results in typically around 1% to 5% of the clamp force being lost within the first couple of seconds of the joint being tightened. When the joint is subsequently dynamically loaded by applied forces, a further reduction occurs due the pressure changes that take place on the joint interfaces.

Loosening as a result of embedding loss is problematic on joints that comprise several thin joint surfaces and a small bolt grip length. If the surface bearing stress is kept below the compressive yield strength of the joint material, the amount of embedding loss is calculable and the joint can be designed so as to compensate for this loss.

Junker's theory of self-loosening of fasteners

Gerhard Junker in 1969 published a technical paper ('New criteria for self-loosening of fasteners under vibration' SAE Paper 690055, 1969) giving results of test work that he had completed to support his theory as to why threaded fasteners self loosen. His key finding was that preloaded fasteners loosen as a result of rotation as soon as relative motion occurs between the mating threads and between the bearing surfaces of the fastener and the clamped material. Junker found that transverse dynamic loads generate a far more severe condition for self-loosening than dynamic axial loads. The reason for this is that radial movement under axial loads is significantly smaller than that which is sustained under transverse loading.

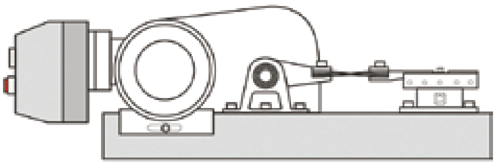


Transverse movement of a bolted joint

Junker showed that preloaded fasteners self-loosen when relative movement occurs between the mating threads and the fastener bearing surface. Such relative movement will occur when the transverse force acting on the joint is larger than the frictional resisting force generated by the bolt's preload. For small transverse displacements, relative motion can occur between the thread flanks and the bearing area contact surface. Once the thread clearances are overcome the bolt will be subject to bending forces, and if the transverse slippage continues slippage of the bolt head bearing surface will occur. Once this is initiated the thread and the bolt head will be momentarily free from friction. The internal off torque, present as a result of the preload acting on the thread helix angle, generates a relate rotation between the nut and the bolt.

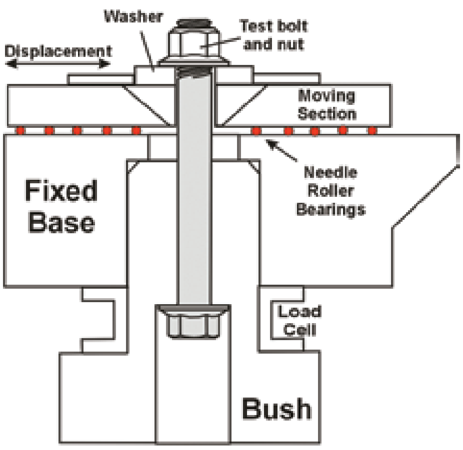
Under repeated transverse movements this mechanism can completely loosen fasteners.

To investigate the causes of loosening, Junker developed a test machine, the so-called 'Junker machine' that will quantify the effectiveness of the loosening resistance of a fastener design.



Junker fastener test machine

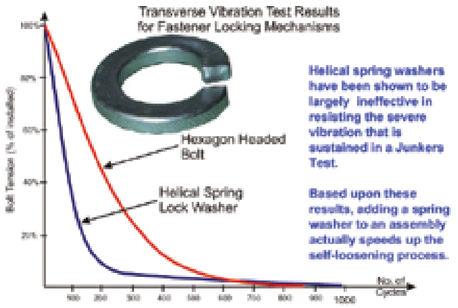
Roller bearings are used to eliminate the effects of friction between moving and fixed plates. A load cell allows continuous monitoring of the bolt load as transverse motion is applied from a moving plate that the nut is clamped onto. This is a major advantage over the shock test standard in that the loss of preload can be measured during the test and a graph of preload verses cycles plotted. The idea behind the Junker machine is that a transverse displacement generated by a cam results in a rocking action in the fastener. Overcoming the friction grip of the fastener creates a self-loosening action.



Section through Junker test machine

Junker vibration test loosening curves

A test like the Junker test (test details in the specification DIN 65151), allows the performance of various fastener designs to be compared in terms of their resistance to self-loosening. Over the last twenty years a significant amount of work has been completed investigating existing fastener designs to allow comparisons to be made as to their resistance to vibration loosening. To make a valid comparison it is vital that the same vibration amplitude is used, since this has a major influence on the results. A typical test result is shown here for helical spring washers.

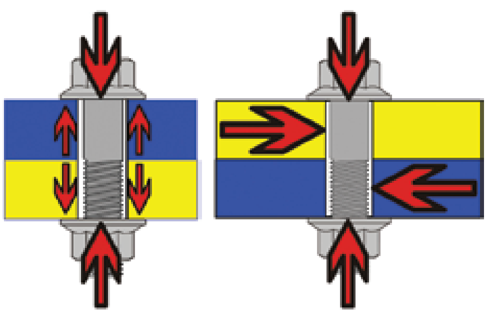


Placing a helical spring washer under the bolt head has been shown on some tests to speed up the loosening, others show that the use of such washers give a similar performance to using a bolt without any locking device. Many large OEM manufacturers are aware of these findings and no longer specify such washers in their internal standards. However, judging by the continued use of these washers, many organisations do not seem to be aware of these findings.

Many of the locking devices used on threaded fasteners are either based upon preventing relative thread movement between the bolt and nut threads (such as with nylon insert nuts) or relative movement of the nut to the joint (such as with the various types of 'lock' washers). However, Junker and other later researchers all point to the importance of preventing transverse joint movement. A bolted joint, properly designed so that the clamp force from the bolts is sufficient to prevent transverse movement by friction grip between the joint plates, will not come loose. At the design stage this can be achieved by selecting the fastener size and strength so that the preload can create sufficient friction grip to prevent the external loads causing the joint to move.

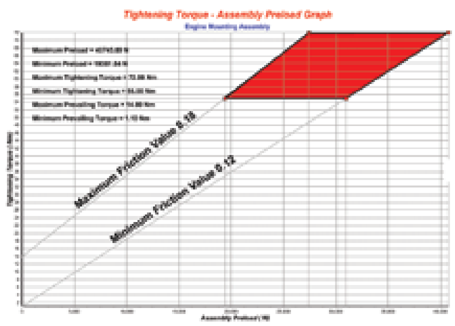
Conclusions from the research

The most widely accepted cause of threaded fasteners self loosening is not so much vibration but joint movement, in particular, transverse slip of the bolt threads and bearing surfaces. If sufficient preload can be achieved from the bolts to prevent joint movement, no locking device will be required, as friction will hold the parts together. The major problem of designing with threaded fasteners is ensuring that the preload is sufficient to hold the parts securely together when variations in frictional conditions are included. The diagram shows the effect that frictional variations will have on bolt preload.



The key to preventing self loosening is to provide sufficient bolt load

Typically, the tightening specification includes a torque range so that the joint can be economically assembled. When account is taken of this and also that a prevailing torque (with maximum and minimum limits) may be present, a graph can be produced which shows the variation in preload that results from the assembly specification.



The effect of friction on bolt preload

Designing the joint on the basis of the minimum anticipated preload generated by the bolt would eliminate any risk of loosening, designing using the mean value of preload would result in the potential of a number of bolts loosening if no 'safety factor' was applied. Allowance also needs be made for the loss of preload from embedding, this occurs in the threads and under the bolt head and nut face as the contact surfaces settle. To maintain a limit on the amount of embedding it needs to be ensured that the bearing stress under the nut face, bolt head and within the joint, are kept within the maximum permissible bearing stress for the material being clamped.

In cases when joint movement cannot be prevented, in cases of thermal expansion for example, then a locking device of proven ability should be specified.

Prior to forming his company, Bolt Science in 1992, Bill's original background was in design engineering. The company is a provider of independent technical expertise in bolted joint technology. He is a chartered engineer and has a Doctorate in Engineering on the self-loosening of threaded fasteners. Bill has delivered training courses around the world on the analysis of bolted joints and bolting technology.