A STUDY ON LOOSENING CHARACTERISTICS OF THREADED FASTENERS

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1. Introduction

Screw fasteners are undoubtedly one of the greatest innovations, which human beings have ever developed. The outstanding feature of the screw fastener is that, they have been the best method for temporary joining of machine elements due to their simple design and they provide a high clamping force using a very simple tool. So they provide to be the best assembly method in industry despite the advances in welding, riveting, adhesive, etc [1]. However, they have an inherent and inevitable fault: they loosen eventually by vibration.

To overcome this problem engineers all over the world have worked hard to impart some anti-loosening resistance to this fasteners and have eventually come up with some ideas that nowadays in use.

2.1 Definition of Screw Loosening

Materials fastened using screws are held together by the force of tension generated by the elongation of the bolt shaft (the bolt axis force) and by the force of compression generated in the objects being tightened (the tightening force) [2]. These two forces remain in balance as long as no external forces are applied to the objects being fastened by the screws. The general term for the forces involved in pulling or fastening the two materials together is the pretension force.

In some situations, such as in the course of using machinery, the pretension force applied at the time that the materials forming the machinery were originally fastened may decrease for a variety of reasons. This spontaneous decrease in the pretension force is what is described in general terms as screw loosening.

2.2 Loosening without relative rotation between bolt and nut

In this case, some residual plastic deformation, such as stretching of bolt, shrinking of an intermediate piece, or smoothening of the contact surface like the sides of the thread ridges and the bearing surface of the nut, invariably exists [3]. Those problems can be solving by selection proper material for bolt and nut.

2.3 Loosening caused by relative motion of the bolt and nut

There are two types of relative motion occurs in threaded fasteners. One is the relative motion between the nut and the bolt. And the other is the relative motion between the nut/bolt and clamping surfaces [4].

There are three common causes of the relative motion [5] occurring in the threads:

1. Bending of parts, which results in forces being induced at the friction surface. If slip occurs, the head and threads will slip which can lead to loosening.
2. Differential thermal effects caused as a result of either differences in temperature or differences in clamped materials.

3. Applied forces on the joint can lead to shifting of the joint surfaces leading to bolt loosening.

2.4 Vibration loosening of nut and bolt

When nut is subjected to vibrating force, a cycle of alternative tensile and compressive forces starts acting on mating surface between nut and bolt [6]. But since the mating surface has two angles namely, the lead angle and flank angle, the forces get split into three mutually perpendicular components. One of these components acts along the axis of the bolt, the other acts in a radial direction and the remaining one acts tangentially to mating surface **(Fig-1).**

So the force that acts along the axis tries to stretch the bolt and deforms it. The radial force acts to deform the thread profile and tangential force generates a moment in the reverse direction that favours loosening.

If relative motion occurs between the threaded surfaces and/or other contact surfaces of the clamped and clamping parts because of an external force, the direction of which is either tangential or radial, the bolted connection will become free of friction in the circumferential direction [7]. This means that the preload acting on the thread creates a force in a circumferential direction and results in the rotational loosening of the bolt or nut.

For **axially** loaded joint [8], pulsating tension of a clamped bolted connection creates radial sliding motions between the thread flanks of the bolt and nut or the interface of the clamped bearing surfaces. The reasons for this are the contraction of the bolt according to Poisson ratio and dilation of the nut walls caused by axial tension. Thus axially loaded nut widens elastically in radial direction at the area near the bearing surfaces and contracts in upper part [9]. These create a relative motion between the nut and bolt which favours loosening of the fastener.

For **dynamically** loaded joints, the relative motion between thread flanks and other contact surfaces of the bearing areas can occur in magnitudes up to the maximum allowance of the thread. These large effects appear when transverse loading, which has to be transmitted by grip friction, exceed the friction force between the clamped parts. The resultant transverse slippage between the clamped parts forces the bolt to assume a pendulum movement, which leads to relative motion in the thread hole and thus in the thread flanks [7].

If the amplitude of such transverse slippage of the bolt is large enough, slippage of nut or bolt head bearing surface will finally occur and make the joint totally free of friction in a circumferential direction. It can be easily realized too that, contrary to the conditions to the axial loading, relative motion between the flanks will occur in all parts of the nut threads when the joint slips under transverse force. Thus, the internal off-torque force becomes sufficient to turn the bolt or nut completely loose as soon as the friction is eliminated from the bearing area as well as from the thread area [7]. Such transverse slippages are more common in practice than usually accepted. Experience shows that these joints most frequently fail by self-loosening.

2.5 Prevention of loosening by means of design

From the above discussion it can be declared that loosening caused by relative rotation can be minimized if [4],

- *The lead angle is reduced:*
  Relative slip depends on lead angle. With the increase of lead angle relative slip also increases and vice versa. If helix angle becomes **(Fig: 2.a)** greater than friction angle then thread becomes overhaul. If lead angle reduces to zero then thread can not transfer torque.

- *The flank angle is made as small as possible - almost zero:*

A very small flank angle increases fastening torque as well as torque due to vibration when it tries to rotate in loosening direction it needs more torque. So very small flank angle **(Fig.2.b)** increases the anti loosening property of thread.

- *Reducing relative slip between bearing surface nut and the fastened material by introducing a taper between these two surfaces:*
  In this case **(Fig.2.c)** contact area as well as friction force increases. But assembly becomes difficult. Inter mediate part must have proper counter profile.

3.1 Locking Fasteners

A variety of locking fasteners are used now-a-days offered by major companies. For example, conventional spring lock washers are no longer specified, because it has been shown that they actually aid self loosening rather than prevent it. There are a multitude of thread locking devices available. Through the efforts of the American National Standards Subcommittee B18:20 on locking fasteners, three basic locking fastener categories have been established. They are: **1. Free spinning, 2.Friction locking**, and 3.**Chemical locking** [6].

a. Free Spinning Type: The free spinning type is plain bolts with a circumferential row of teeth under the washer head. These are ramped, allowing the bolt to rotate in the clamping direction, but lock into the bearing surface when rotated in the loosening direction. The "Whizlock" is in this category.

b. Friction Locking: Friction locking categories can be sub-divided into two groupings, metallic and non-metallic. The metallic friction locking fastener usually has a distorted thread which provides a prevailing torque; an example of this category is the "Philidas" nut. Non-metallic friction locking devices have plastic inserts which provides a thread locking function; an example being the "Nyloc" nut.

c. Chemical Locking: The chemical locking category is adhesives which fill the gaps between the male and female threads and bond them together; "Loctite" is an example. Such adhesives are now available in micro-encapsulated form and can be pre-applied to the thread **(Fig-3)**.

In general terms [6], the key to preventing self loosening of fasteners is to ensure that:

1. There is sufficient clamp force present on the joint interface to prevent relative motion between the bolt head or nut and the joint.

2. The joint is designed to allow for the effects of embedding and stress relaxation.

3. Proven thread locking devices are specified. Specifically, thread locking compounds - such as "Loctite", flanged fasteners such as "Whizlok" or torque prevailing fasteners such as "Nyloc". In general, loose washers, of the plain or spring variety, are not generally advisable.

The self loosening of fasteners is just one aspect of bolted joint design [6] the Designer must consider during the design process. Even if threads are completely locked together by adhesive, problems cannot be prevented if the bolt preload is insufficient to prevent joint movement.

3.2 Some anti-loosening Fasteners

a. Spiralock Bolt: Spiralock Internal Thread Form Systems [10] is one of the newest approaches to prevent loosening. It has a unique 30° wedge ramp for unsurpassed locking performance. Spiralock Internal Thread Form Systems is simple and superior to that of conventional 60° thread forms. As a result, Spiralock threaded holes and nuts provide a reliable solution to high vibration applications where thread re-tightening is impossible.

When clamp load is applied during assembly, the Spiralock thread form locks any standard male fastener in place by drawing the crests of the male thread tightly against the 30° wedge ramp. As a result Spiralock prevents transverse movement of the male thread in respect to the female thread virtually "wedge-locking" the threaded joint. This unique wedge ramp design also eliminates the transverse motion that causes loosening under vibration **(Fig-4)**.

b. Step Lock Bolt: The screw has some steps on the helix and named as "Step Lock Bolt" (SLB). The part which has no lead angle is called 'step part', and the part which has a lead angle is called the 'inclined part'. This type of bolt can be made by rolling process [11].

If the SLB is combined with an ordinary nut and fastened by a certain fastening force, the shape of the step part will be indented to the surface of the inclined thread surface. Eventually the clamping force of SLB will be supported by the step parts. This is contrasted with a conventional screw, which always has a tendency to push out a nut along the inclined thread when friction becomes less. It may be expected that a SLB screw thread hardly slips in the direction of the thread, in other words, along the circumference. It is also anticipated that a SLB will not loosen even though the bottom surface of bolt or nut slips, because a SLB is able to prevent the torsion by itself **(Fig-5)**.

c. Tine Lock: The unique "Tine Lock" concept [12] utilizes a threaded bolt notched (channel) at preset intervals. The tined-nut, when rotated, locks in along the bolt thread to eliminate the possibility of vibration. The fasteners are manufactured with metal or injection moulded materials. The Tine Lock are available in U-Shape, J-Shape and S-Shape that can be placed on or into a panel to form a lock-nut sub assembly **(Fig-6)**.

Lightweight and non-corrosive, "Tine Lock" fasteners have a wide range of uses including automotive, aerospace, marine, defence, road, bridge and highway construction, steel structure construction, railways, machinery and medical instruments. The Tine Lock has one or more tines, which in conjunction with the longitudinal bolt thread channels, prevent counter rotation and loosening. The number of tines and the number of bolt channels are equal.

d. Hard Lock Nut: This is a combination of two nuts to play the roles of the hammer and wedge respectively. A small eccentricity in the sliding part of the convex top of the lower nut acts as the wedge [13]. When the concave upper nut is tightened, the effect produced is exactly the same as that produced by a hammer driving in a wedge. Moreover, it is much more effective to use of a screw as this makes it very easy to force the wedge into place. Tightening the upper nut 2 with a wrench generates torque, which allows the self-locking effect to be felt by hand. Make use of this feedback to set the torque value as required. At this time, the powerful self-locking effect is intrinsic, regardless of whether or not there are any gaps between the upper and lower nuts, so we can rest assured that the nut is securely tightened **(Fig-7)**.

e. Aero-tight Nut: A torque prevailing nut of all metal construction. The nut is slotted in two places which, after the nut has been tapped, are bent slightly inwards and downwards. When the nut is screwed onto the bolt thread the two slotted parts are forced back to their original position. Their stiffness causes the nut threads to bind onto the bolt threads and thus provides a prevailing torque [14] **(Fig-8)**.

f. Cleveloc Nut: A torque prevailing nut of all metal construction. The collar of the nut is elliptical in cross section and it is this that provides the flexible locking element [14]. The nut is pre-lubricated to reduce the tightening torque **(Fig-9)**.

4.1 Development of Testing Machine

To understand the loosening characteristics of nut and bolt, a testing machine is designed under an AICTE sponsored project in our college. From previous works it has been seen that the loosening mechanism becomes most pronounced when the direction of vibration is perpendicular to the longitudinal axis of the bolt [15]. The testing rig has thus been designed to obtain the following:

i. A repeated oscillatory motion to achieve vibration of fixed frequency and amplitude.

ii. Measurement of clamping force at any instant.

iii. Any desired number of oscillations.

To obtain the above requirements the following machines and/or mechanisms have been made use if:

a. A motor provides the basic rotary motion.

b. A cam incorporates the oscillatory motion onto a rocking plate at a fixed frequency.

c. A load cell measures the clamping force at any instant.

d. A proximity switch measures the number of oscillations **(Fig-10)**.

The rocking plate transmits this vibration to another plate clamped to a fixed structure using the nut and bolt assembly under test. The vibration provided is of constant hammering nature. Due to this vibration the fasteners will begin to loosen and the corresponding clamping force will decrease. This decrement after a specific number of revolutions will be a measure of loosening. The above proposition is the key behind the designing and fabrication of the test rig.

4.2 Results and observations

With this testing machine, various types of nuts and bolts, e.g. Conventional BSW and metric nut with spring and serrated washer, nyloc nut, double nut, BSW nut with metric bolt etc are tested. The results are plotted in No. of oscillation Vs Clamping force graph as shown in **Fig- 11** and **Fig-12**.

It is observed from the graph that [16], every fastener loosens initially at higher rate. After a certain no of oscillations, the loosening rate become slower and then stopped when the clamping force become about 90 to 92 % of the initial clamping force.

5. Conclusions

From the Fig.11 & Fig.12 it may be concluded that

1. Nylock nut have the best anti loosening property. So the use of Nylock nut has less possibility of loosening in vibrating atmosphere.
2. Here it is seen that the use of BSW nut with metric bolt also able to prevent loosening considerably. But it may not be suggested for practical use due to the permanent deformation in the thread.
3. Double nut have also considerable anti loosening characteristics. But it needs much space to use.
4. Serrated washer can also be used but it deforms the intermediate part.
5. It may also be concluded that conventional BSW nut-bolt is preferable than conventional metric nut-bolt.

Here, the loosening of threaded fasteners, types of anti-loosening fasteners and testing method of screw loosening with testing results are discussed. The self loosening of fasteners cannot be totally prevented. But it can be minimized by using newly designed locking fasteners. Researches are going on to develop new kind of anti loosening fasteners. Till now chemical locking fasteners have been proved most suitable to prevent loosening and hugely used in industry.

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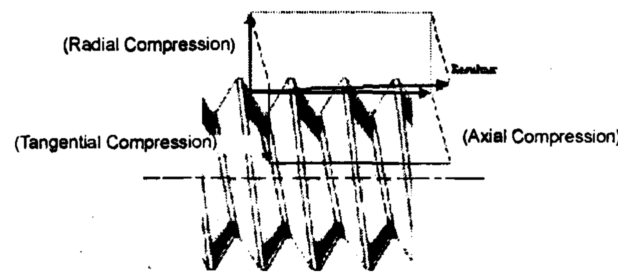
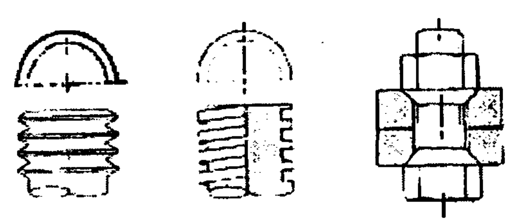


Fig-1.Force distribution in three perpendicular directions



(a) (b) (c)

Fig-2: Ideas to stop loosening

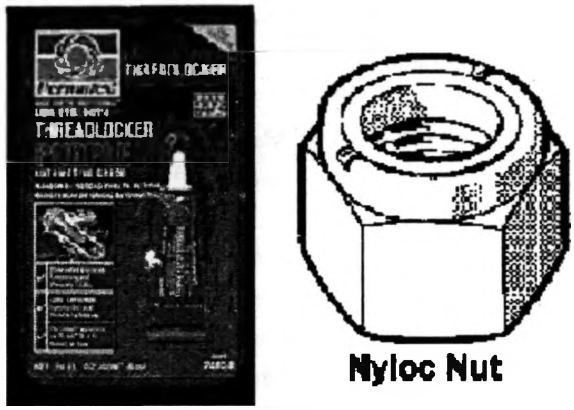


Fig-3: Chemical Locking & Friction Locking

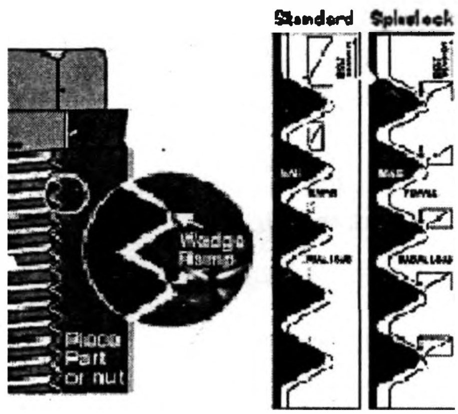


Fig-4: Spiralock Bolt

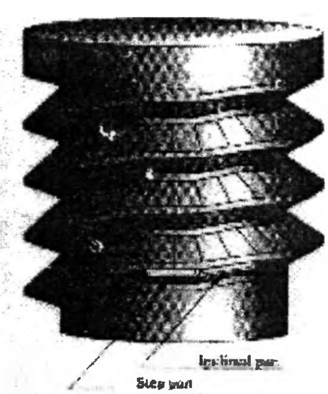


Fig-5: Step Lock Bolt

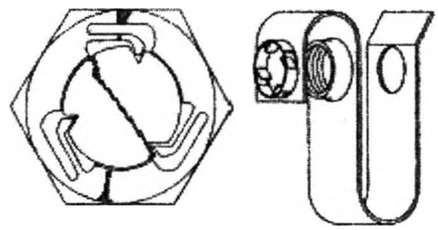


Fig-6: Tine Lock.

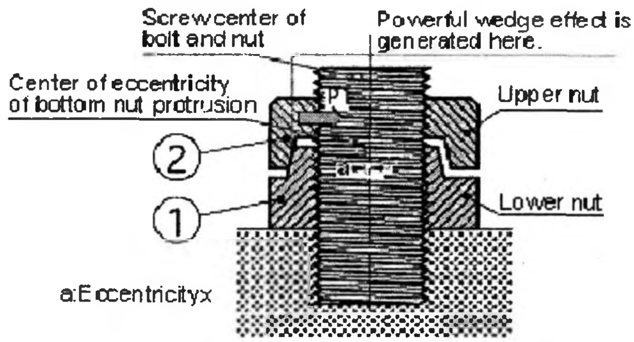


Fig-7: Hard Lock Nut

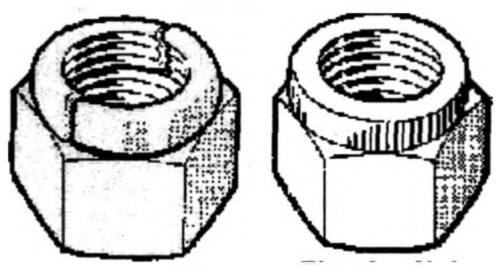


Fig-8: Aerotight & Fig-9:Cleveloc Nut

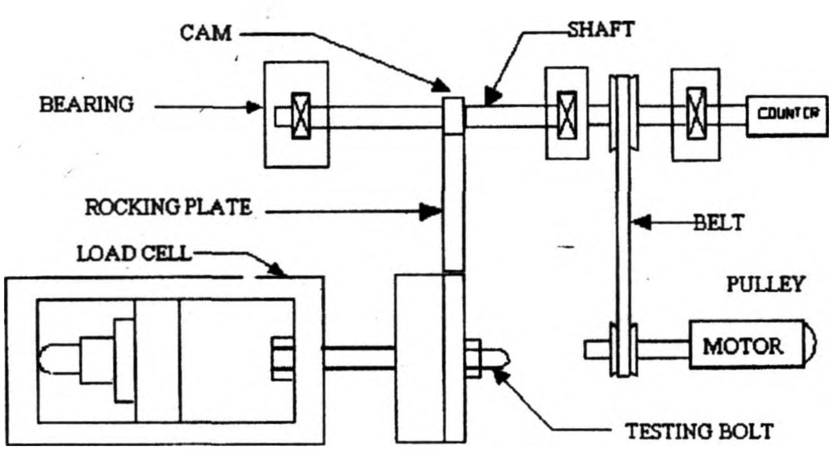


Fig-10: Schematic diagram of Testing Machine

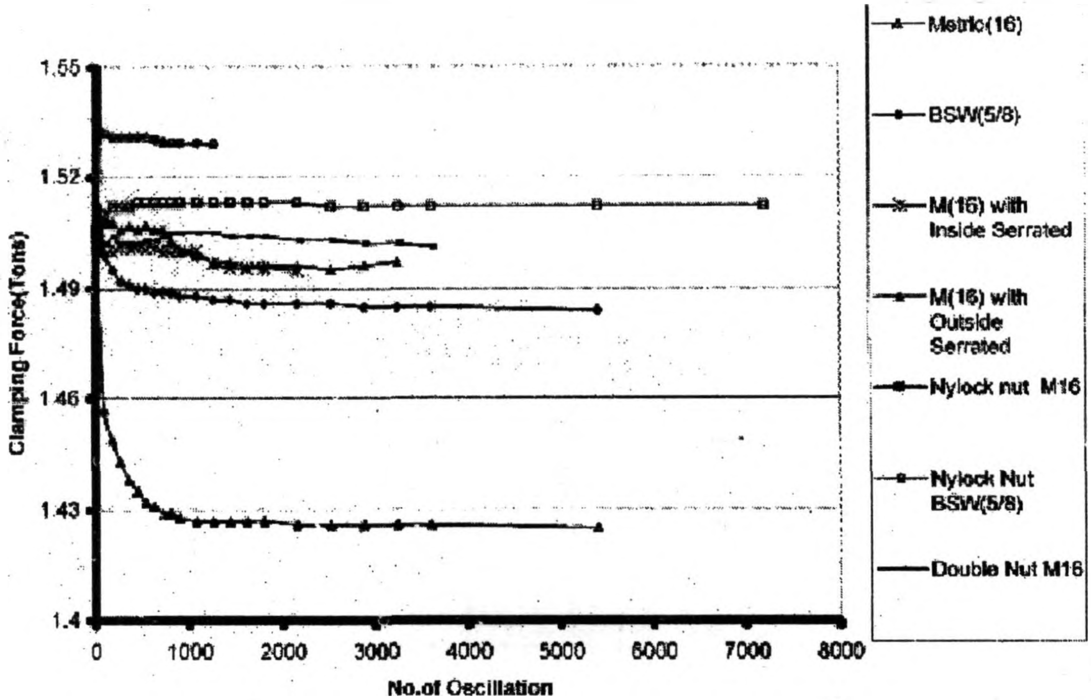


Fig-11: No. of Oscillation vs Clamping Force for Comparison when initial Clamping Force is about 1.5 tons

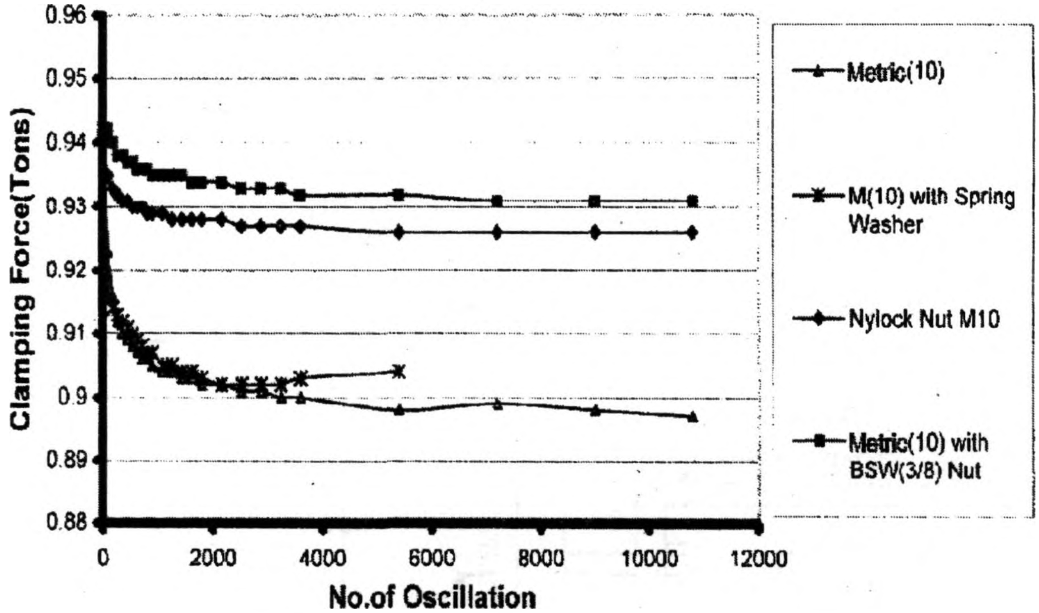


Fig-12: No. of Oscillation vs Clamping Force for Comparison when initial clamping force is about 0.94 tons