A Review on Preload Decay in Threaded Fasteners Application

Mr. Tejas Nesarikar[1] Prof. U. M. Rawat[2]
[1]M. Tech Student [2]Principle & Head of Department
[1]Department of Mechanical Design Engineering
[1,2]V. V. P. Institute of Engineering and Technology, Solapur-413004, Dr. Babasaheb Ambedkar Technological University, Lonere, Maharashtra, India

Abstract— The Nut and bolt assembly used in various mechanical applications are to be studied to find out decay happening due to vibrations applied to it. In this project I aim to study various combinations of threaded fasteners used in particular application such that decay due to vibrations could be explored. A significant advantage of a bolted joint over other joint types, such as welded and riveted joints, is that they are capable of being dismantled. This feature however, can cause problems if it unintentionally occurs as a result of operational conditions. Such unintentional loosening, frequently called vibrational loosening. It is important for the Designer to be aware of the bolt loosening mechanisms which can operate in order to design reliable joints. This research describes the dissertation work of studying the behavior of loosening mechanism considering the bolt preload decay. After review of literature it was concluded in this review that the most occurring root cause of loosening is side sliding of the nut or bolt head relative to the fastened joint, resulting in the relative motion occurring within the threads. If this does not occur or can be prevented, then the loosening of bolts can be reduced.

Keywords: Bolt, Bolted Joints, Vibration, Loosening of Bolts, Junker Test, Fasteners

I. INTRODUCTION

A significant advantage of a bolted joint over other joint types, such as welded and riveted joints, is that they are capable of being dismantled. This feature however, can cause problems if it unintentionally occurs as a result of operational conditions. Such unintentional loosening, frequently called vibrational loosening in much of the published literature, is an important phenomenon and is widely misunderstood by Engineers. It is important for the Designer to be aware of the bolt loosening mechanisms which can operate in order to design reliable joints. The information presented below is key information for the Designer on the theory of vibration loosening of threaded fasteners and how such loosening can be prevented.

It is widely believed that vibration causes bolt loosening. By far the most frequent cause of loosening is side sliding of the nut or bolt head relative to the joint, resulting in relative motion occurring in the threads. If this does not occur, then the bolts will not loosen, even if the joint is subjected to severe vibration. By a detailed analysis of the joint it is possible to determine the clamp force required to be provided by the bolts to prevent joint slip.

Often fatigue failure is a result of the bolt self-loosening which reduces the clamp force acting on the joint. Joint slip then occurs which leads the bolt being subjected to bending loads and subsequently failing by fatigue.

Pre-loaded bolts (or nuts) rotate loose, as soon as relative motion between the male and female threads takes place. This motion cancels the friction grip and originates an off torque which is proportional to the thread pitch and to the preload. The off torque rotates the screw loose, if the friction under the nut or bolt head bearing surface is overcome, by this torque.

There are three common causes of the relative motion 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 difference in clamp material.
3) Applied forces on the joint can lead to shifting of the joint surfaces leading to bolt loosening.

Work completed during the 1960's in Germany indicated that transversely applied alternating forces generate the most severe conditions for self-loosening. The result of these studies led to the design of a testing machine which allowed quantitative information to be obtained on the locking performance of self-locking fasteners. Such machines, often called Junkers machines in the literature - after it's inventor, have been used over the last twenty years by the major automotive and aerospace manufacturers to assess the performance of proprietary self-locking fasteners. As a result, a rationalization of the variety of locking devices used by such major companies has occurred. 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.

A Junker test is a mechanical test to determine the point at which a bolted joint loses its preload when subjected to shear loading caused by transverse vibration. Design engineers apply the Junker Test to determine the point at which fastener securing elements – such as lock nuts, wedges and lock washers – fail when subjected to vibration. The data collected by the test enables design engineers to specify fasteners that will perform under a wide range of conditions without loosening. Research into the causes of vibration induced self-loosening of threaded fasteners spans six decades and the causes of self-loosening are now well understood. It was pioneering experimental research into the behavior of bolted joints under transverse loads, conducted by German engineer Gerhard Junker in the late 1960s which underpins modern theories on self-loosening behavior.

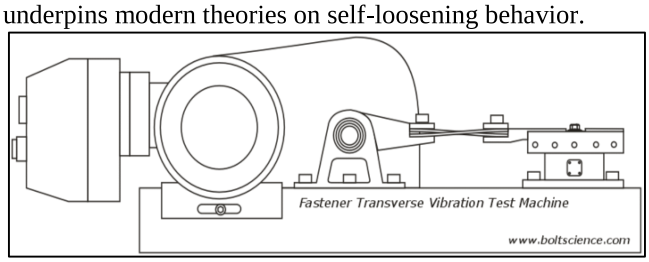

Fig. 1.1: Junker's Transverse Vibration Test Machine.

A. Terms and Nomenclature of Screw Threads.

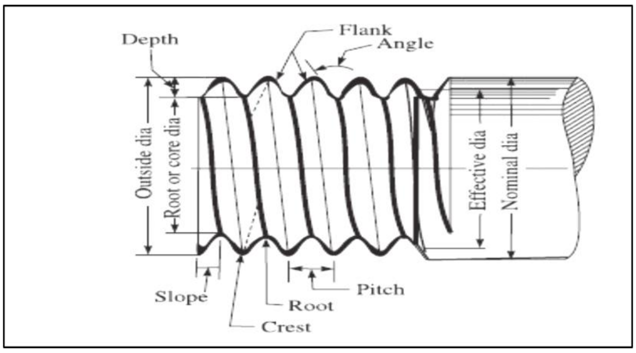

Fig. 1.2: Thread terminology.

1) Pitch: The distance measured parallel to the axis from a point on a screw thread to a corresponding point on the next thread is called pitch or in other words the distance from crest to crest or root to root is called pitch of the thread.
2) Lead: The distance moved by a nut or a bolt in axial direction in one complete revolution called lead.
3) Crest: The outer-most part of the thread is called crest.
4) Root: The inner most part of the thread is called root.
5) Flank: The surface between the crest and the root is known as flank of the thread.
6) Angle of thread: The angle between the flanks measured on an axial plane is called angle of thread.
7) Depth: It is the distance between crest and root measured at right angle to the axis.
8) Nominal diameter: The diameter of the cylindrical piece on which threads are cut is called nominal diameter.
9) Major diameter: Diameter at the crest of the thread measured at right angle to the axis is called major diameter and is also known as outside diameter.
10) Minor diameter: The diameter at the core or root of the thread is called minor diameter. It is also called as core diameter.

B. Profile of Threads

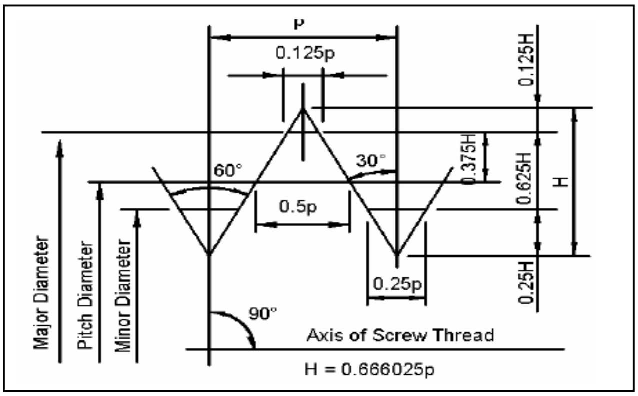

Fig. 1.3: ISO metric threads profile.

The basic profile of ISO metric screw thread is shown in Figure1.2. BIS (Bureau of Indian Standard) has adopted the same thread form as in the practice in several other countries. The thread is characterized by angle of 60^o between the flanks and pitch, denoted by p. The theoretical depth, H is related to p as H = 0.866025 p. certain practical changes are introduced in manufactured threads according to design profiles of threads. Figure 1.3 shows design profile for external and internal threads.

II. LITERATURE REVIEW

N. G. Pai and D. P. Hess [1] presents results of a study on failure of threaded fasteners by vibration induced loosening caused due to dynamic shear loads. A three-dimensional finite element (FE) model is used to study details of four different loosening processes that are characterized by either complete or localized slip at the head and thread contacts.The results show that loosening can occur at relatively low shear loads due to the process of localized slip.

N. G. Pai and D. P. Hess [2] presents the experimental method in which they have developed the cantilever beam and nut bolt arrangement as a model to study the behavior of the loosening effect under the action of the vibration by studying the effect of loosening in connection with the position of the fastener placement.

C. A. Cheatham, C. F. Acosta, D. P. Hess [3] presents results from an experimental investigation of loosening of threaded inserts. The tests are performed on a transverse test machine which provides transverse shear.Both secondary locking features are found to provide improved resistance to loosening. The improvement with inserts with prevailing torque locking feature is found to be minimal at first, then increase with decreasing preload and eventually level out with a fraction of initial preload retained.

R. I. Zadoks and D. P. R. Kokatam [4] shows the axial stiffness of a bolt plays a critical role in the prediction of the self-loosening process of threaded connections subject to oscillatory excitation.The model is loaded by pulling the nodes around the outside of the bolt head in the axial direction while holding the bottom of the plate fixed. Several analyses are performed to investigate the axial stiffness of the bolt.

N. G. Pai and D. P. Hess [5] present a study on loosening of threaded fasteners subjected to dynamic shear loads. A fundamental analysis of loosening reveals that a fastener can loosen at lower loads than previously expected due to localized slip at the contact surfaces. Four different loosening processes of a screw under different conditions of slip at the head and thread contact regions are identified. Experimental results illustrating these loosening processes are presented. In addition, the minimum dynamics hear force required to initiate loosening is determined experimentally.

F. M. Leon, N. G. Pai, D. P. Hess [6] presents the results from tests that investigate the effect of thread dimensional conformance of fasteners on yield and tensile strength.Variations in bolt pitch diameter were found to affect the yield and tensile strength by about an order of magnitude more than variations in bolt major diameter or nut pitch and minor diameters. The mean tensile strength for conforming product was found to be as much as 20% greater than the tensile strength for nonconforming product.

Ingrid A. Rashquinha and Daniel P. Hess [7] shows the dynamics of threaded fastened assemblies represent a highly nonlinear constrained vibration problem that is nontrivial, but of considerable practical importance. In this paper, a dynamic model of a fastened assembly is developed which incorporates a dynamic fastener model with dynamic structural component models.

Satoshi Izumi, Takashi Yokoyama, Atsushi Iwasaki, Shinsuke Sakai [8] investigated the mechanisms of the tightening process and the loosening process due to shear loading using the framework of the three-dimensional finite element method (FEM). Results are compared with those of conventional theories based on material mechanics and with experimental results. We found some new aspects of threaded fastener theory. Previous theory overestimates the tightening torque in the relation between preload and tightening torque.

Abhay Kakirde, Dr. Shriram Dravid [9] "A review on loosening of bolted joints" Authors have reviewed the various studies carried out by previous researchers in this area of research. Main reasons of loosening are cyclic loading and unloading of threaded components. Many researchers have developed machines for their experimental work. Loosening i.e. unlocking rotation of threaded assembly is caused by the restoring action of an elastic torsion of a bolt shank because of the relative motion at mating surface on threads.

Bikash Panja and Santanu Das [10] "Development of anti loosening fasteners and comparing its performance with different other threaded fasteners" In the present experimental investigation, anti-loosening ability of various fastening elements, such as conventional nut, nylock nut, flat washer, spring washer, inside and outside serrated washer, is tested with a conventional M16 high-tension steel bolt. All these fasteners are tested in terms of their loosening characteristics. Accelerated vibrating conditions are used for the test on an indigenously made test rig.

III. Design of Experimental Set Up

As the objective of the project is to study the bolt preload decay, we need to predict the clamp load practically with the help of measuring instruments for various combinations of fasteners. The experimental set up is designed with the help of the strain gauges and strain indicators.

Fig. 3.1: Experimental set up of Transverse Vibration Test Rig.

The design of experimental set up is discussed in the following points

A. *Selection of Strain Gauges*

The strain gauge has a wide application in the measurement field. In an Electrical resistance strain gauge the displacement or strain is measured as a function of resistance change produced by the displacement in the gauge circuit. Here foil type strain gauge is selected for measurement of preload in terms of strain. The width of foil type strain gauge is very large as compared to the thickness. The following table 3.1 shows the properties and specification of the strain gauge.

Sr. No.	Properties	Specification
1	Gauge Resistance	350+0.5 Ohm
2	Gauge Length	5 mm
3	Backing Material	Epoxy
4	Gauge Factor	1.9 to 2.2
5	Maximum Excitation Voltage	12 Volts
6	Temperature ranges	5 to 100 ^{0}C

Table 3.1: Specification of Foil Strain gauge

The following images show the foil of strain gauge with its size. This strain gauge foil is mounted on MS plate where the value of preload is to be measured after tightening the screws for various combinations.

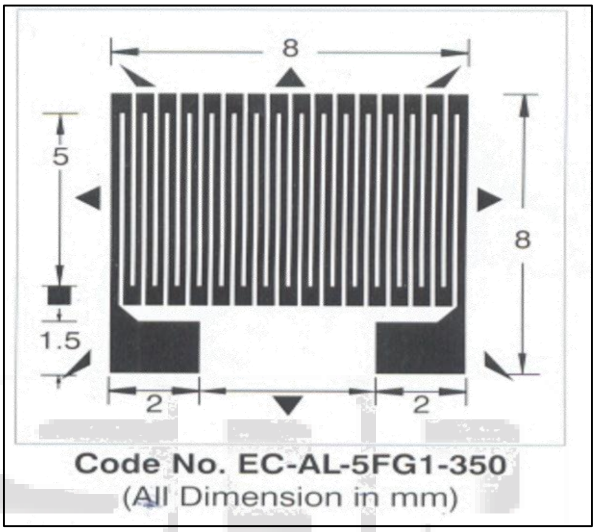

Fig. 3.2: The Dimensions of Strain Gauge Foil

The orientation of strain gauge plays an important role as the displacement is the key factor. The orientation of strain gauge 1 is at a distance of 6 mm and 9 mm distance in order to measure both the strain approximately near to the screws. The following picture shows the actual positions of the strain gauge.

Fig. 3.3: Image of Mounting of Strain Gauge

The Strain gauges are arranged in such a way that they will a form of two gauge of rectangular rosette.

B. *Strain Indicator*

The strain indicator is a digital Data Acquisition System which gives the strain values on the indicator. For determination of preload values we have two channel strain indicator which is as shown in the following image.

Fig. 3.4: Image of Strain Indicator

The following table shows the specification of the strain indicator.

Sr.No. No.	Parameters	Specifications
1	Input	Quarter/Half/Full bridge configuration. Built in bridge completion resistors
2	Bridge resistance:-	1000 Ohms.(Optional for 350 Ohms)
3	Bridge excitation :-	5VDC @ 30mAmps Temperature compensated
4	Channels	2
5	Tare	Null facility for each individual channel course & fine adjustment by potmeter
6	Range	0 to +/-1999 micro strains
7	Resolution	1microstrain
8	Access time	300milli sec per reading
9	Gage factor	2.1
10	Accuracy	Accuracy :- 0.5% FS +/- 2 counts
11	Power	230VAC 50 Hz +/- 10%

Table 3.2: Specification of Strain Indicator

In this way the design of experimental is carried out by mounting the strain gauge by selecting the strain gauge foils and the strain indicator.

IV. Experimental Investigation of Bolt Preload Decay

This chapter deals with the experimental approach carried out for the bolt preload decay. It contains the detailed experimental procedure along with procedure and the observations which are found for decaying in the bolt preload with our designed test rig. The preload values for the screw and its composition were taken from the FEM results, as we proceed for the unknown torque tightening values for corresponding bolt preload. That can be calculated numerically by using the empirical relations.

A. Prerequisites of the Experiments.

The experiment requires some of the theory related to vibration, frequency, and basics of experimental stress analysis. The purpose is to deal with the numerical calculation part for the bolt preload. As we are conducting a dynamic investigation we need a Tachometer and vibration meter in order to find out the frequency for the corresponding bolt preload decay. In order to measure the frequency the vibration meters are available with different specification. For this experimental work we have selected the SKF vibration meter CMS 100-SL.

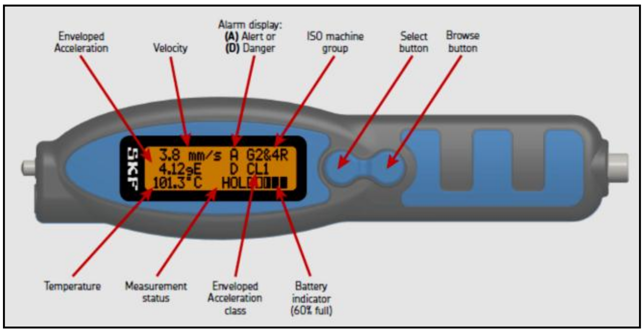

Fig. 4.1: SKF machine Condition adviser

The specifications of this meter are as follows,

- Velocity: Range: 0.7 to 65.0 mm/s (RMS), 0.04to 3.60 in/s (equivalent Peak), meets ISO 10816.
- Frequency: 10 to 1000 Hz, meets ISO 2954.

B. Experimental Procedure

1) The strain indicator should be set to zero before tightening the screw. (same is followed to subsequent combination trials.)
2) Tight the screw for desired combination.
3) Note down the strain indicator reading. This reading is at static condition and gives the bolt preload value in terms of strain.
4) Switch ON the motor which is coupled with pulley and shaft. Measure its RPM with the help of tachometer.
5) Observe the changes on strain indicator and note it. Also note the time with the help of stopwatch.
6) With the help of SKF vibration meter note the velocity of guide plate along with the frequency in Hz given by the vibration meter for corresponding change observed on strain indicator.

The experiment conducted for different combinations of socket head cap screw for a selelcted RPM as the pulley is provided for the change in RPM speed.For indivisual size of head cap screw there is a set of three combination namely with no washer, with plain washer and spring washer.

V. Results and Discussion

In this chapter the results obtained from the experiment and their significance with the bolt preload decay is discussed. The results are founded with the help of FEM method and Experimental method is compared. Also the discussion is carried out in consideration of bolt preload decay with the effect of vibration, also in tightening torque and how the loosening mechanism are correlated with the experimental value.

The comparison of bolt preload with the ANSYS and with the Strain indicator reading is compared and errors in results are found.

The experimental results were discussed in order to find how effect of the vibration leads to the loosening of the fastener system and it is also tries to establish the relation between tightening torque and preload values and the frequency at which the loosening occurs.

VI. Conclusion

The work carried out in this dissertation is mainly concerned with the analyzing the loosening characteristics i.e. bolt preload decay. The study is carried out to find out the significant effect of vibration on the fastener system. The experimental study shows that in dynamic condition fasteners loosening effect caused due to the increase in frequency which results in the reduction in the tightening torque as the tightening torque is directly proportional to the bolt preload. The stability of fastener system under vibration is totally dependent upon the tightening torque. Hence it is necessary to design the fastener system when it is subjected to transverse vibration. The concluding remarks of the experimental study are as follows.

- The loosening effect is not immediately occurs. It is a cyclic process for a fastener system which is subjected to the vibration.
- The loosening effect is more in the transverse vibration than longitudinal vibration.
- Loosening effect and bolt preload decay is a non-linear one as it does not occurs immediately.
- The experimental study shows that the loosening phenomenon is not a subsequent characteristic.

References

[1] N. G. Pai and D.P. Hess, "Three dimensional finite element analysis of threaded fastener loosening due to dynamic shear load", Engineering Failure Analysis, Volume 9(2002), Page no.383-402.

[2] N. G. Pai and D.P. Hess, "Influence on fastener placement on vibration induced loosening", Journal of Sound and Vibration, Volume 268(2003), Page no.617-626.

[3] C. A. Cheatham, C. F. Acosta, D. P. Hess "Test and analysis of secondary locking features in threaded inserts " Engineering Failure Analysis, Volume 16 (2009),Page no.39-57.

[4] R. I. Zadokas and D. P. R. Kokatam, "Investigation of axial stiffness of bolt using a three dimensional finite element model" Journal of Sound and Vibration, Volume 246(2) (2001), Page no.349-373.

[5] N. G. Pai and D.P. Hess, "Experimental study of loosening of threaded fasteners due to dynamic shear load", Journal of Sound and Vibration, Volume 253(3) (2002) Page no.585-602.

[6] F. M. Leon, N. G. Pai and D.P. Hess, "Three dimensional finite element analysis of threaded fastener loosening due to dynamic shear load", Engineering Failure Analysis, Volume 8(2001), Page no.49-56.

[7] I. A. Rashquinha and D.P. Hess, "Modelling nonlinear dynamics of bolted assemblies", Applied Mathematical Modelling, Volume 21(1997), Page no.801-809.

[8] Satoshi Izumi, Takashi Yokoyama, Atsushi Iwasaki, Shinsuke Sakai "Three dimensional analysis of tightening and loosening mechanism of threaded fastener", Engineering Failure Analysis, Volume 12(2005) Page no.604-615.

[9] S. D. Borawake, Prof. Dr. S. B. Desai, "An investigation of loosening behavior of Lube filter Head and shell connection under transverse loading by Finite element analysis", International Engineering Research Journal (IERJ) Volume 1 Issue 5, Page no.262-268, 2015.

[10] Pradip D. Jamadar, Hemant K. Waugh, Dr. Girish R. Desale, Dr. Kartikeya Tripathi, "Finite element based Pretension analysis of threaded Fasteners with Experimental Investigation" International Journal of Innovations in Engineering and Technology (IJIET) Volume 6 Issue 4 April 2016, Page no. 586-592.

[11] V. B. Bhandari, "Design Of machine elements", Tata McGraw Hill, 2005. Volume 7, issue 2007, 2nd edition page no- 272.

[12] S. S. Rao "Mechanical Vibrations" Pearson, 2011.

[13] K. Mahadevan, K. Balveera Reddy, "Design Data Hand Book", CBS Publishers, and Distributors Pvt. Ltd., 2011.

[14] Dr. Sadhu Singh, "Experimental Stress Analysis", Khanna Publishers, Delhi, 2004. Volume 5, issued 3 April 2015, page no 327.

