A Study of Anti-Loosening Ability of 5/8 BSW Fasteners under Vibration with High Tension Steel and Stainless Steel Bolts

Bikash Panja
Department of Mechanical Engineering
Kalyani Government Engineering College
Kalyani, India
e-mail: b.panja_86@yahoo.co.in

Santanu Das
Department of Mechanical Engineering
Kalyani Government Engineering College
Kalyani, India
e-mail: sdas.me@gmail.com

***Abstract*— Threaded fasteners have been popularly utilized for temporary joining of machine elements due to the feature that they provide high clamping force and torque using a simple tool. However, they have the problem of loosening under vibrating conditions which leads to loss of clamping force, and finally failure of the system. In the present experimental work, anti-loosening ability of various fastening elements, such as conventional nut, nylock nut, flat washer, spring washer, inside and outside serrated washer, are tested with conventional 5/8″ BSW High Tension Steel (HTS) and Stainless Steel (SS) bolts. The concept of hybrid double nut using a conventional nut and one nylock nut at the outside, and adhesive bonded nut with conventional 5/8″ BSW (both HTS and SS) bolt is also tested to obtain enough resistance to loosening. On the basis of the experimental results, hybrid double nut and adhesive bonded nut can be recommended for both HTS and SS 5/8″ BSW bolts to apply under vibration conditions, as they resist loss of clamping force effectively.**

Keywords*— bolt; nut; washer; BSW fasteners; loosening; anti-looseners, accelerated test, vibration.

I. INTRODUCTION

Invention of threaded fasteners is a great innovation in the progress of human civilization. These are used for temporary joining of machine elements for manufacturing assembly, servicing, repair and replacement, etc. due to their operational simplicity and their ability to provide high clamping force with a simple tool. However, screw fasteners have an inherent limitation of loosening under vibration [1] [2].

Screw fasteners were first used for lifting water at Hanging Garden of Babylon promoted by the King of Assyria in 3rd century B.C. The screw was later described by the Greek mathematician Archytas of Tarentum (428-350 B.C.). Archimedes applied the principles of threaded fasteners and developed a screw pump which was used for irrigation [3] [4]. By 1493, people started applying screw to press olives in ancient Greece. Leonardo da Vinci is credited for innovating and introducing usage of different screw threads by making different sketches of threaded components which were later engineered to apply to different fields of applications [3].

The use of metallic screws as fasteners began in Europe in the late 15th century. The screw was used in furniture but did not become a common wood working fastener until efficient machineries were developed for its productive manufacture near the end of 18th century [5]. In 1770, an Englishman, Jesse Ramsden (1735-1800), invented the first satisfactory screw cutting lathe. The British engineer Henry Maudslay patented a screw cutting lathe in 1797. A similar device was patented by David Wilkinson in the US in 1798. In 1908, square drive screw were invented by P.L. Robertson in Canada that was considered a standard machine tool in North America. In the early 1930, head screw was invented by Henry F. Phillips. A team of researchers lead by Fujii investigated in detail the performance of threaded fasteners under vibratory condition related to loosening tendency. They invented ‘step lock bolt’ [3] showing good anti-loosening characteristics.

Prevention of loosening of threaded fasteners under vibratory condition is a challenging task to engineers, and engineers all over world have tried to develop some anti-loosening fasteners with new ideas.

K. Hongo conducted [2] some experiments on variable axial loading of threaded fasteners with respective to their loosening tendency. He proposed causes of loosening as reduction in axial tensile force of bolt and plastic elongation of the bolt thread.

Gerhard H. Junker described [6] the theory of self loosening of preloaded bolted joint subjected to vibratory condition, and introduced a testing machine for evaluating locking properties. According to him, the theory of mechanism of self loosening of nut and bolt is based on the effect of friction between interacting solid bodies and direction of external force, and movement.

Paland [7] tested various types of threaded fasteners for axial loading, and gave the rule of loosening arithmetically, and by measuring the tangential strain on the surface of the nut. He came to a conclusion that a loaded nut widens elastically in a radial direction at the area near the bearing surfaces and contracts in upper part.

Another group lead by Fujii tested the effectiveness of screw threads, spring washers, serrated washers, nylon inserted nuts, metal inserted nut, cover ring nut, double nuts and eccentric nuts of few sizes to resist loosening. Test results showed that the popularly known anti-loosening fasteners did not possess much resistance to loosening [8].

Sase et al. [8] and Fujii and Sase [3] proposed a new shape of screw fasteners, manufactured it and evaluated its performance in their decade long project. This shape was named "Step-Lock Bolt" (SLB) that had eight steps with zero lead angle at the circumference of the thread within one revolution of it. The efficacy in preventing the initiation and progress of loosening was examined by applying a force cyclically at right angles to the centre line of a bolt. The SLB was found to have loosened the least among various combinations of conventional bolt and so-called anti loosening nuts available. They also found certain combinations of hardness of SLB and nut giving desirable performance of the SLB [3] [8] [9]. In another work, Pai and Hess [10] experimentally observed the tendency of loosening of fasteners under dynamic shear loads, and proposed few strategies to avoid the loosening. Croccolo et al. [11] carried out experiments and validated experimental results through finite element analysis relating the coefficient of friction in bolted joints to the preloading force and tightening torque requirement to avoid failures of aluminium components of a motor bike.

Saha et al. [12] developed a set up to test loosening of threaded fasteners. The testing machine was developed following a device used by Fujii and Sase [3]. As loosening in screws occurs only when repetitive forces are applied at right angle to the longitudinal axis of bolt, the testing machine was designed with this consideration. Using the same testing rig, Bhattacharya et al. [13] made detailed experimental investigation on the loosening tendency of different combinations of fastening elements (bolts, nuts and washers) with different clamping forces under repeated oscillatory motion. With the same set up, Mahato and Das [4], Panja and Das [14] and Samanta et al. [15] [16] carried out experiments on anti-loosening characteristics of various threaded fasteners.

Different groups through out the world worked on loosening nature of threaded fasteners. Izumi et al. [17] [18], Sanclemente and Hess [19], Cheatham et al. [20], Eccles et al. [21], Dinger and Friedrich [22] carried out experimental or analytical studies on the loosening behaviour of different threaded objects. Three dimensional finite element analysis (FEA) was performed by Izumi et al. [17] to understand the effect of friction and the loosening tendency between fastening elements. Later on, Izumi et al. [18] performed similar analysis using double nut and spring washer and validated the FEA results with that of the experimental findings. Sanclemente and Hess [19] did loosening tests of threaded fasteners under cyclic transverse loads, while Cheatham et al. [20] performed tests and finite element analysis of secondary locking features in threaded inserts, Eccles et al. [21] made a detailed overview and analysis of anti-loosening threaded fasteners, and prevailing torque nuts in particular, with respective to mechanisms of loosening and arresting it. Woo et al. [23] proposed a relationship to explain loosening of bolts of plate heat exchangers, and through FEA, suggested minimum number of bolts required related to the force applied to suppress its loosening. Dinger and Friedrich [22] recently numerically assessed contact stresses, and tried to find out their effect on fastener loosening. Basava and Hess [24] studied experimentally the loss of clamping force in a bolted joint under axial vibration condition, and explored its reasons behind the same.

Although lot of works were done by different research groups worldwide to understand the reasons of loosening, and to develop fasteners with anti-loosening or locking features, scope for finding out threaded fasteners with enhanced anti-loosening characteristics still exists. Lot of works were done by Bhattacharya et al. [13] to explore loosening tendency of M10, M16, 3/8″ BSW and 5/8″ BSW fasteners with different bolt-nut-washer combinations applying repetitive loads at 3 Hz. However, the present work is done at 5 Hz frequency of repetitive loading. Anti-loosening characteristics of hybrid double nut and adhesive bonded nut (with araldite adhesive) fitted with 3/8″ BSW bolt is explored, and compared with some other threaded fasteners available.

II. LOOSENING MECHANISM AND ITS PREVENTION

Two or more parts fastened using threaded fasteners are held together by the tensile force generated by the elongated bolt and by compression generated on to the objects being tightened. These forces (tensile on bolt and compression on object fastened) are called pretension force. Spontaneous decrease in pretension force indicates screw loosening, as reported by Bhattacharya et al. [13]. Loosening mainly occurs in threaded fasteners either without relative rotation between bolt and nut or by relative rotation of the bolt and nut. These are described in detail by Hongo [2], Fujii and Sase [3] and Bhattacharya et al. [13].

Loosening can be minimized by change of thread design, or by use of various locking nuts as stated in the following.

A. Prevention of Loosening by Change in Thread Design

Loosening caused by relative rotation can be minimized by reducing lead angle and flank angle, and reducing relative slip between the bearing surface of nut and fastened material by introducing a taper, etc. as detailed by Fujii and Sase [3] and Bhattacharya et al. [13].

B. Prevention of Loosening by Use of Various Locking Nuts

A variety of locking fasteners are used nowadays by major companies. Through the efforts of the American National Standards Subcommittee B18:20 on locking fasteners, three basic categories of locking fasteners have been established. They are free spinning, friction locking and chemical locking [9] [25].

‘Step lock bolt’ has been reported by Sase and others [8] to show anti-loosening property by putting ‘step parts’ having no lead angle at certain positions on to the bolt. In 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. Nylock nuts are also used to increase friction between nut and bolt threads thereby reducing loosening tendency [3] [13]. Variations of the techniques discussed above have been proposed and are being used in different threaded joints [25].

III. Details of Experimentation

A. *Experimental Setup*

An indigenously developed Test Rig, as reported in Bhattacharya et al. [13], is used with some modifications for carrying out experiments to judge anti-loosening ability of threaded fasteners. There are a load cell and a load indicator (compression type, Make– Sushma, Bengaluru, India, Model SLC-302) to observe clamping force. The testing rig provides a repeated oscillatory motion to achieve vibration of fixed frequency and amplitude for desired number of oscillations. Rotational speed of the cam shaft is measured with a tachometer, and it comes to be 300 RPM and motor speed is 1480 RPM. In this way, the rocking plate strikes 300 times a minute on the clamped plate with an amplitude of 0.2 mm.

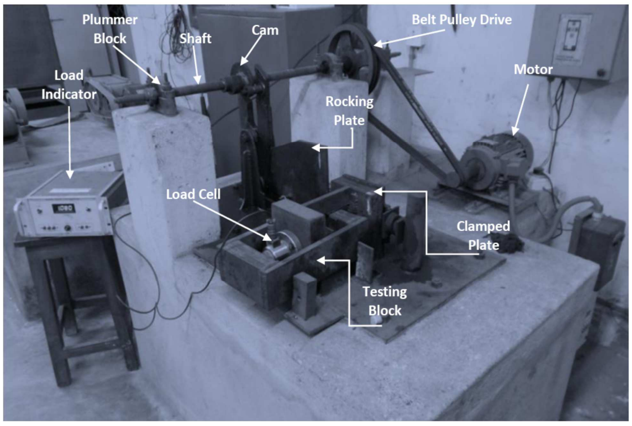

Fig. 1. Pictorial view of the test rig.

The rocking plate transmits vibration to the plate clamped to a fixed structure using the nut and bolt assembly under test. Setup of the testing device is shown in Fig.1. The vibration provided is of repeated hammering in nature. Due to this vibration, fasteners begin to loosen, decreasing the corresponding clamping force. All the tests are repeated once, and average readings are used for data presentation and analysis.

B. *Details of Fasteners Tested*

Different available known-to-be anti-loosening fasteners have been used for loosening tests. The clamping conditions and number of oscillations allowed for the experiments are shown in Table 1 and Table 2. Photographic view of a nylock nut is shown in Fig. 2, and Fig. 3(a-d) depicts the photograph of different washers tested such as flat, spring, inside and outside washers.

In this work, adhesive is used in one set of experiments. Adhesive bonded nut is locking of chemical category which fills the gap between the male and female threads and bond them together; epoxy based high strength ‘Araldite’ adhesive (grade: Mechanik) is used in this case. Thickness of adhesive is not more than 1mm, as the gap available between nut and bolt threads are less than 1 mm. The adhesive covered joint is kept for 24 hours within which it gets secured. The araldite is a standard epoxy adhesive made by Huntsman Advanced Materials (India) Pvt. Ltd. While loosening the nut, application of somewhat high torque is found to be sufficient, and this does not damage the fastening element.

TABLE I. Details of clamping conditions for 5/8″ BSW × 8″ HTS conventional bolt

Sl. No.	Nut used	Washer used	Initial clamping force (ton)	Clamping force after 11000 oscillations (ton)
1	Conventional nut	---	1.271	1.190
2	Conventional nut	Flat washer	1.264	1.191
3	Conventional nut	Spring washer	1.276	1.234
4	Conventional nut	Inside serrated washer	1.266	1.229
5	Conventional nut	Outside serrated washer	1.267	1.232
6	Nylock nut	---	1.267	1.246
7	Hybrid double nut	---	1.276	1.264
	Adhesive bonded nut	---	1.269	1.257

Hybrid Double Nut is used in another set of experiments. It is a combination of one conventional nut and one nylock nut. In this case, first a conventional nut and then a nylock nut are used for clamping.

Fig. 2. Photographic view of a nylock nut

Fig. 3. Photographs of washers used [Top from left: flat, spring washer, bottom from left: outside serrated and inside serrated washer]

IV. Results and Discussions

Fig. 4 shows the tendency of loosening clamping force with the increase in the number of oscillations of different kinds of high tension steel (HTS) fastening elements as detailed in Table 1. From this plot, it is observed that initially up to about 1000 oscillations the rate of loosening is quite high. After certain number of oscillations, the loss of clamping force becomes less. In most of the test cases other than that of conventional fasteners with or without flat washers, rate of loosening reduces significantly after few thousand of oscillations. The plot shows that the use of spring washer, or inside or outside, serrated washer can reduce the loss of clamping force to a noticeable extent. However, flat washer does not at all give any effect to arrest loosening under vibration, and shows similar loosening tendency as that of a conventional threaded fasteners. Spring and serrated washers are expected to impart some anti-loosening tendency as they tend to indent on the bearing surface of the nut or the clamped plate. However, this is experienced not to show the desired performance. The same was also experienced by Fujii and Sase [3].

TABLE II. Details of clamping conditions for 5/8″ BSW × 8″ SS conventional bolt

Sl. No.	Nut used	Washer used	Initial clamping force (ton)	Clamping force after 11000 oscillations (ton)
1	Conventional nut	---	1.273	1.212
2	Conventional nut	Flat washer	1.275	1.222
3	Conventional nut	Spring washer	1.272	1.229
4	Conventional nut	Inside serrated washer	1.271	1.233
5	Conventional nut	Outside serrated washer	1.269	1.234
6	Nylock nut	---	1.277	1.249
7	Hybrid double nut	---	1.275	1.259
8	Adhesive bonded nut	---	1.282	1.268

A nylock nut has a nylon ring inside the nut to raise friction between threads. It is seen that use of nylock nut gives some resistance to loosening for the HTS bolt. Adhesive bonded nut is found to have comparatively good anti-loosening fasteners under vibration with that of nylock nut. Adhesive bonded nut is locking of chemical categories which fill the gaps between the male and female threads and bond them together. In this way, it tries to resist rotation of the nut relative to the bolt, and hence, causes good anti-loosening ability of the threaded fastener. Hybrid double nut shows quite high ability to resist loosening under vibration. Dual effect of double nut and friction raising nylock nut may be the main reason behind the anti-loosening characteristics of the hybrid double nut having one simple nut and one nylock nut fitted on the HTS bolt. Higher friction between nut and bolt along with the pre-loaded force and torque existing additionally between two nuts may have promoted the anti-loosening characteristics of this hybrid double nut.

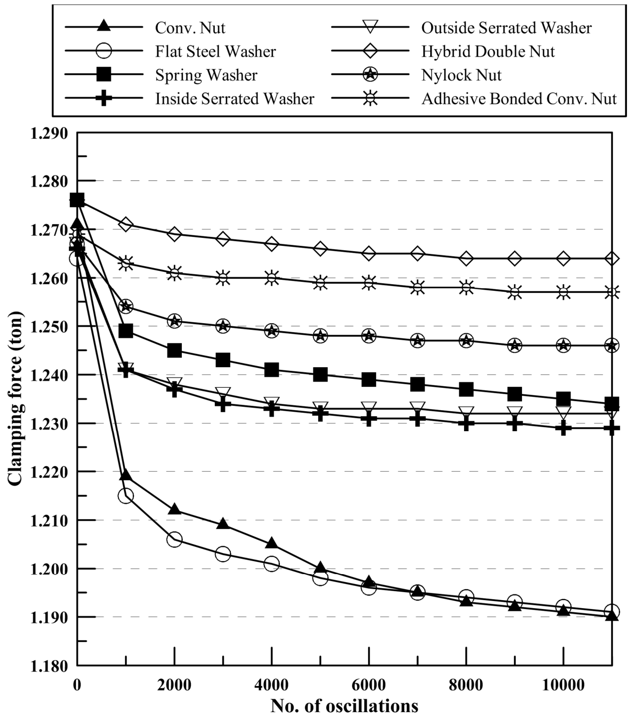

Fig. 4. Comparison of loosening for 5/8″ BSW HTS bolt with different nut and washer under vibration.

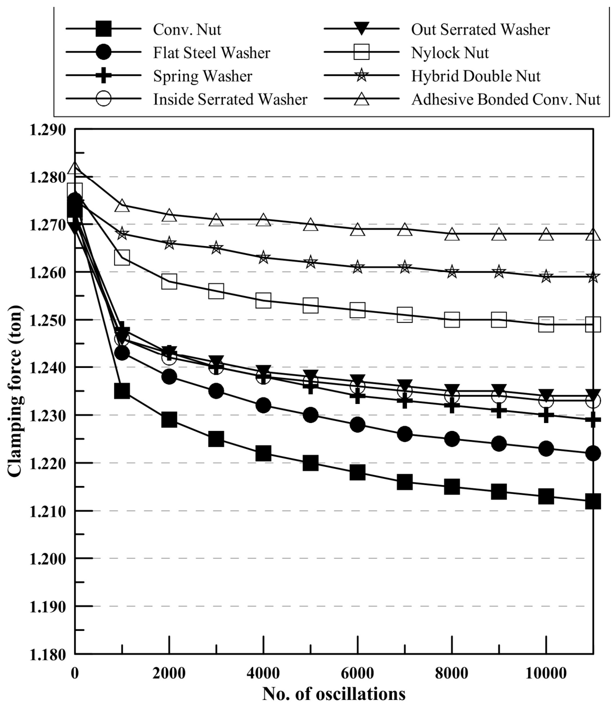

Fig. 5. Comparison of loosening for 5/8″ BSW SS bolt with different nuts and washers under vibration

Similar to HTS bolts, plots shown in Fig. 5 depict initial high rate of loosening in most of the tests, followed by slow loosening rate after certain number of oscillations for 5/8″ BSW stainless steel (SS) bolts. From these experimental plots, it is seen that flat washer does not give remarkable effect to arrest loosening under vibration, and shows almost similar loosening tendency as that of conventional threaded fasteners. Use of spring washer, or inside, or outside, serrated washer shows only marginal improvement of anti-loosening nature of these. Hybrid double nut and adhesive bonded nut are found to be comparatively good anti-loosening fasteners under vibration, followed by nylock nut. In this test on stainless steel (SS) bolt, adhesive bonded nut shows minimum loss of clamping force under vibration. High strength bonding between the nut and bolt with the application of adhesive is likely to be raising the resistance against relative rotation between nut and bolt. In this way, good anti-loosening ability of adhesive bonded threaded fasteners can be obtained.

For both HTS and SS bolt materials, hybrid double nut and adhesive bonded conventional nut render large resistance to loosening under vibration, and hence, these techniques can be recommended for applying in temporary joining of components using threaded fasteners.

V. CONCLUSIONS

From the experimental results and discussions made with different combinations of fastening elements, following conclusions may be drawn.

1. It is found that flat washer do not prevent loosening considerably in contrast to the common perception. Even the use of spring washer, inside serrated washer, or outside serrated washer, gives marginal anti-loosening characteristics for both high tension bolt (HTS) and stainless steel (SS) 5/8″ BSW bolts tested.
2. Nylock nut shows good anti-loosening ability and less possibility to loosen for both HTS and SS 5/8″ BSW bolts in vibrating environment. The nylock nut provides an extra friction grip on the bolt thread to resist loosening.
3. Hybrid double nut using one inside conventional nut and one nylock nut on the outside is found to prevent the loosening quite effectively compared to a single nylock nut. Use of the adhesive bonded nut also provides enough resistance to loosening in comparison with the nylock nut, and it shows similar locking characteristics as that of hybrid double nut for both HTS and SS bolts, and hence may be recommended.

ACKNOWLEDGMENT

Authors wish to express their acknowledgement to All India Council for Technical Education, New Delhi, India for providing the R&D grant (vide its sanction letter Ref. 8018/RDII/BOR/R&D(244)/99-2000 dated March 24, 2000) with which the test rig was set up. The help and support extended by Shri Goutam Chakraborty and Shri Sushanta Barik of Mechanical Workshop are gratefully mentioned.

REFERENCES

[1] N. Sase, K. Nishioka, S. Koga, and H. Fujii, "An anti loosening screw fastener innovation and its evaluation," Journal of Material Processing Technology, vol. 77, pp. 209-215, 1998.

[2] K. Hongo, "Loosening of bolt and nut fasteners," Transaction of Japan Society of Mechanical Engineering, vol.30, No. 215, pp. 934-939, 1964 (In Japanese).

[3] H. Fujii, and N. Sase, SLB concept for screw fastening and its anti loosening performance, Souvenir of the 18th All India Manufacturing Technology, Design and Research Conference, Kharagpur, India, pp.25-34, 1998.

[4] K.N. Mahato, and S. Das, A study on antiloosening characteristics of different 3/8 BSW threaded fasteners, Proceedings of the 14th National Conference on Machines and Mechanisms, Durgapur, India, pp. 409-415, 2009.

[5] W. Christopher, "Observation on development of woods screws in North America", Museum of Fine Arts, Boston, http://www.cool.conservation-us.org/coolaic/sg/wag/Am_Wood_Screws.pdf, 2005.

[6] G.H. Junker, "New criteria for self-loosening of fasteners under vibration," SAE International Automotive Engineering Congress, Paper No. 690055, pp. 934-939, 1969.

[7] E.G. Paland, Investigation of the locking features of dynamically loaded bolted connections, Dissertation Submitted to Hannover University, Germany, 1966.

[8] N. Sase, S. Koga, K. Nishioka, and H. Fujii, Evaluation of anti loosening nuts for screw fasteners, Journal of Material Processing Technology, vol. 56, pp. 321-332, 1996.

[9] N. Sase, and H. Fujii, "Optimizing study of SLBs for higher anti-loosening performance," Journal of Materials processing Technology, vol. 119, pp. 174-179, 2001.

[10] N.G. Pai, and D.P. Hess, "Experimental study of loosening of threaded fasteners due to dynamic shear loads," Journal of Sound and Vibration, vol. 253, No.3, pp.585-602, 2002.

[11] D. Croccolo, M.D. Agostinis, and N. Vincenzi, "Failure analysis of bolted joints: effect of friction coefficients in torque-preloading relationship," Engineering Failure Analysis, vol. 18, No.1, pp. 364-373, 2011.

[12] S.K. Saha, S. Srimani, S. Hajra, A. Bhattacharya, and S. Das, On the anti-loosening property of different fasteners, Proceedings of the 13th National Conference on Machines and Mechanisms, Bengaluru, India, pp. 229-232, 2007.

[13] A. Bhattacharya, A. Sen, and S. Das, "An investigation on anti loosening characteristics of threaded fasteners under vibratory condition," Mechanism and Machine Theory, vol. 45, pp. 1215-1225, 2010.

[14] B. Panja, and S. Das, On the anti-loosening characteristics of M16 threaded fasteners under vibratory conditions, Proceedings of the 15th National Conference on Machines and Mechanisms, Chennai, India, pp. 273-282, 2011.

[15] Samanta, S., Das, S., Roy, R., Bhukta, K. Pal, A. and Das, S., "Comparison of anti-loosening characteristics of various M14 threaded fasteners", Indian Science Cruiser, vol.26, No. 6, pp. 22-27, 2012.

[16] S. Samanta, S. Das, R. Roy, K. Bhukta, A. Pal, and S. Das, [2012b], Comparison of loosening characteristics of 3/8 BSW threaded fasteners under accelerated vibratory condition, Journal of the Association of Engineers, India, vol.82, No. 3&4, pp.34-43.

[17] S. Izumi, T. Yokoyama, A. Iwasaki, and S. Sakai, "Three dimensional finite element analysis of tightening and loosening mechanism of threaded fastener," Engineering Failure Analysis, vol. 12, pp. 604-615, 2005.

[18] S. Izumi, T. Yokoyama, M. Kimura, and S. Sakai, "Loosening-resistance evaluation of double-nut tightening method and spring washer by three-dimensional finite element analysis," Engineering Failure Analysis, vol. 16, pp. 1510-1519, 2005.

[19] J.A. Sanclemente, and D.P. Hess, "Parametric study of threaded fasteners loosening due to cyclic transverse loads," Journal of Engineering Failure Analysis, vol. 14, pp. 239-249, 2007.

[20] C.A. Cheatham, C.F. Acosta, and D.P. Hess, "Tests and analysis of secondary locking features in threaded inserts," Engineering Failure Analysis, vol. 16, pp. 39-57, 2009.

[21] W. Eccles, I. Sherrington, and R.D. Arnell, "Towards an understanding of the loosening characteristics of prevailing torque nuts", Proceedings of the Institute of Mechanical Engineers, Part

C: Journal of Mechanical Engineering Science, vol. 224, pp. 483-495, 2010.

[22] G. Dinger, and C. Friedrich, "Avoiding self-loosening failure of bolted joints with numerical assessment of local contact state," Engineering Failure Analysis, vol. 18, No.8, pp. 2188-2200, 2011.

[23] T.K. Woo, B.C. Hwang, Y.J. Jang, and C. Kim, Preventing loose bolts and reducing the number of bolts required in plate heat exchangers, International Journal of Precision Engineering and Manufacture, vol. 10, No.1, pp.29-34, 2009.

[24] S. Basava, and D.P. Hess, "Bolted joint clamping force variation due to axial vibration," Journal of Sound and Vibration, vol. 210, No.2, pp. 255-265, 1998.

[25] Boltscience, http://www.boltscience.com/pages/ vibloose.html accessed on 12.3.2013.