On the Anti-Loosening Characteristics of M16 Threaded Fasteners under Vibratory Conditions

Bikash Panja and Santanu Das

Abstract

There have been wide applications of threaded fasteners since its inception few centuries back. However, under hostile vibrating condition, threaded fasteners loosen clamping force leading to failure of the system. Many researchers investigated the mechanism of loosening, and found out the factors behind the loosening. With this understanding, many investigators tried to develop threaded fasteners having locking characteristics. In the present work, loosening characteristics of M16 high tension steel bolt (HTS) with conventional nut, nylock nut, hybrid double nut (one conventional nut and one nylock nut), flat washer, spring washer, inside serrated washer and outside serrated washer are tested under accelerated vibrating conditions using an indigenously made test rig for 11000 oscillations. The loss of clamping force from the initial one indicates the extent of loosening. Hybrid double nut using one conventional nut and one nylock nut has been found out to show remarkably good anti-loosening characteristics over the others tested. On the other hand, the nylock nut applied on a conventional bolt shows better anti-loosening ability than the other nuts and washers tested apart from hybrid double nuts.

Keywords: Metric thread, Washer, Loosening, Accelerated test, Vibration

1 Introduction

1.1 Preamble

A threaded fastener is needed for the purpose of holding, adjustment, servicing, inspection, replacement, etc., and it continues to be a basic assembly method of industry despite advantages of welding, adhesives and other joining techniques. Screw fasteners were first used in lifting water at the famous Hanging Garden of Babylon that was promoted by the king of Assyria in the third century B.C. Initially, the cross section of screw thread was plate-like, and they were used for irrigation purposes [1][2]. Working of screw was described by the Greek mathematician Archytas of Tarentum in fourth and fifth century B.C. The screw pump invented by Archimedes was used for water supply for irrigation in the first century B.C.

Leonardo da Vinci implemented screw threads in many important areas. Besides his works, he left many ideas about screws. During his time, the profile of screw thread was square [1]. Drastic change came afterwards in the shape of thread profile from square to triangular increasing its reliability. Gradually, different other thread profiles were developed to suite its applications due to its distinct advantages, such as easy to assemble and disassemble, cheap, availability, ability to generate high fastening torque by simple means, and its retention for quite a long time [1][3]. However, hostile vibration conditions tend to cause loosening of screwed fasteners, and that is the major drawback of screw fasteners.

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1.2 Cause of loosening and its prevention

Two or more parts joined using threaded fasteners are held together by tensile force generated by elongation of the bolt shaft and by force of compression generated in objects being tightened. These two forces remain in balance as long as no external forces are applied to objects being fastened by the nut and bolt. These forces (tensile on bolt and compression on objects fastened) are called pretension force. Spontaneous decrease in pretension force indicates screw loosening [1][4][5][6]. Two types of loosening mainly occur in threaded fasteners, such as loosening without relative rotation between bolt and nut and loosening caused by relative rotation of bolt and nut.

Three strategies may be adopted to resist loosening of threaded parts as discussed in the following [1][4][5][6].

a) **By reducing lead angle:** With a decrease in lead angle, relative slip decreases. Hence, if lead angle is reduced to a very small value, loosening will be quite less.

b) **Making flank angle as small as possible:** Small flank angle results in increased fastening torque as well as locking of fasteners under vibration. When it tries to rotate in the loosening direction, it needs more torque. Hence, small flank angle increases the anti-loosening property of thread.

c) **Reducing relative slip between bearing surface of nut and fastened material:** By introducing a taper between bearing surfaces, or by other means, contact area, and hence, friction force can be increased causing locking tendency of fastened elements to avoid loosening under vibration. However, assembly requires more torque.

1.3 Recent developments on anti-loosening fasteners

Sase et al. [7] tested effectiveness of screw threads, spring washers, nylon inserted nut, metal inserted nut, serrated flange nut, double nuts, cover ring nut 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. Fujii et al. [1][8][9] introduced and evaluated the Step Lock Bolt (SLB) with regard to its anti-loosening performance using a displacement based loosening device. They found the presence of desirable anti-loosening characteristics of SLB.

Sarkar et al. [2] developed a set up to test loosening of threaded fasteners. In this set-up, several tests were carried out with different BSW and metric bolts with various types of nuts and washers to conclude that nylock nuts give substantial resistance to loosening compared to other fasteners tested.

Three basic locking fastener categories have been established [10] by the American National Standards Subcommittee B18:20. These are of free spinning, friction locking, and chemical locking types. Conventional spring lock washers are not recommended, because often they help self-loosening rather than its prevention. An adhesive used in a threaded fastener [10], and use of a nylon washer [11] were also tested to show appreciable anti-loosening characteristics.

1.4 Objective of the present work

With the concept and information discussed above, in the present work, anti-loosening tendency of M16 high tension steel (HTS) bolts with different types of nuts and washers are tested to find out the presence of comparatively high locking property of the tested fasteners.

2 Details of Experimentation

In the present investigation, a loosening test rig is used for performance testing of different threaded fasteners, as detailed in previous publications [4] and [11] of this corresponding author. In this set up, a rocker arm reciprocates, and once in a revolution, it strikes the plate which is clamped by the nut-bolt assembly. In the testing machine developed, controlled vibration is generated. Loosening of the fastener is detected by the drop in clamping force, measured by a load cell (model-SLC 302, Sushma, Bangalore make) and a digital indicator.

With this machine, M16 (2 mm pitch) high tension steel (HTS) bolts with standard nuts, commonly known anti-loosening nuts and washers are tested. The initial tightening torque given is around 1.27 ton. Actual clamping forces with different types of fasteners used in the two repeat experiments are shown in Table 1. Up to 11,000 oscillations, the decrease in clamping force is measured.

The frequency of applying repetitive forces has been maintained to be 300 strokes per minute. This is done keeping in view the previous works reported [1][4][7-9][11]. Fujii and Sase [1], Sase et al. [7-9] carried out extensive work in this area, and they provided 5 Hz frequency (300 strokes/min) up to 5,000 oscillations, whereas in other papers [4] and [11] of the corresponding author, 280 to 290 cycles/min frequency were used for loosening tests carried out for more than 10,000 oscillations.

Table 1: Details of clamping conditions of M16 HTS fasteners tested

Nut and/or Washer Used with a conventional bolt	Initial Clamping Force (ton)	
	Exp1	Exp 2
Conventional nut	1.273	1.257
Flat washer with conventional nut	1.261	1.252
Spring washer with conventional nut	1.274	1.272
Inside serrated washer with conventional nut	1.270	1.260
Outside serrated washer with conventional nut	1.270	1.273
Nylock nut	1.278	1.271
Hybrid double nut	1.261	1.264

3 Results and Discussions

From the experiment on M16 high tension steel (HTS) bolt with conventional nut, results obtained are shown in Fig. (1). A reduction of 82 kg (6.4%) of clamping force for experiment 1 after 11000 oscillations is seen. Experiment 2, that is a repeat of experiment 1, shows the loosening of 59 kg (4.6%). Clamping force shows a decreasing trend even towards 11000 oscillations. This is expected as loosening under hostile vibration is common for threaded fasteners.

Fig. (2) shows the loosening tendency of M16 HTS bolt with flat washer. It is observed that the use of flat washer reduces loosening to some extent. After the initial drop of clamping force, both the experiments show similar trend in the change in clamping force with the progress of the number of oscillations. In two repeat experiments, total loosening of clamping forces observed are 56 kg (4.4%) in experiment 1 and 45 kg (3.5%) in experiment 2 respectively. This loosening is marginally lesser than that with the conventional one as seen in Fig. (1), signifying not to have much anti-loosening characteristics, as also reported earlier [1][4][11].

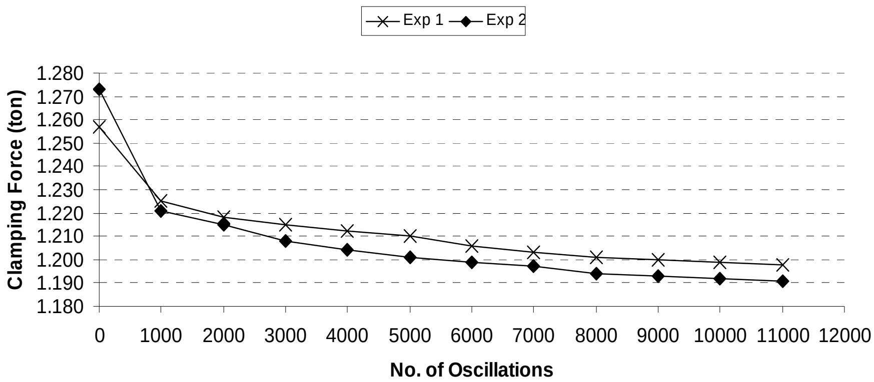

Figure 1: Test results for M16 HTS bolt with conventional nut under vibration

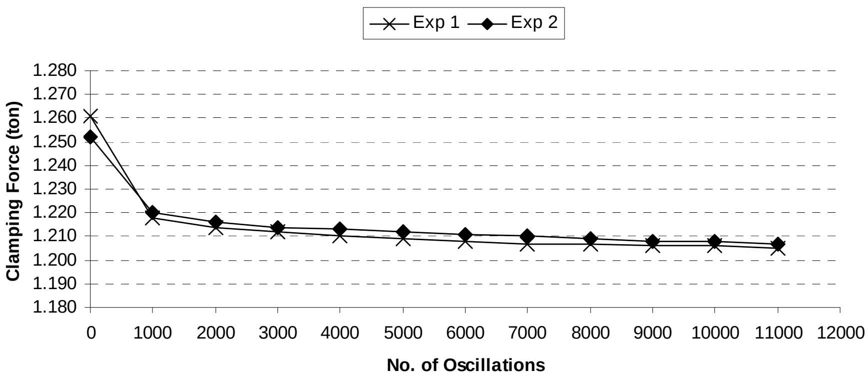

Figure 2: Test results for M16 HTS bolt with flat washer under vibration

Fig. (3) shows the trend of loosening of M16 high tension steel threaded nut and bolt with spring washer for two repeat tests under vibratory condition. Results of repeat experiments 1 and 2 are quite close to each other; loosening in experiment1 is 50 kg and that of the 2nd test is 47 kg. The average loosening obtained is about 3.7% after 11000 oscillations. It is observed that the spring washer looses more or less similar to the flat washer, and lesser than conventional nut under similar vibration condition. This observation is also in-line with the previous observation [1][4].

Fig. (4) shows the loosening characteristics for conventional M16 High Tension steel (HTS) bolt and nut with inside serrated washer under similar vibratory condition. Here, 39 kg (3%) and 42 kg (3.3%) of clamping forces are lost in experiment 1 and experiment 2 respectively after 11,000 oscillations, showing not much anti-loosening characteristics. There are certain indentation marks observed at the contact surface, and loosening is arrested to some extent due to less slip occurring at its surfaces of contact.

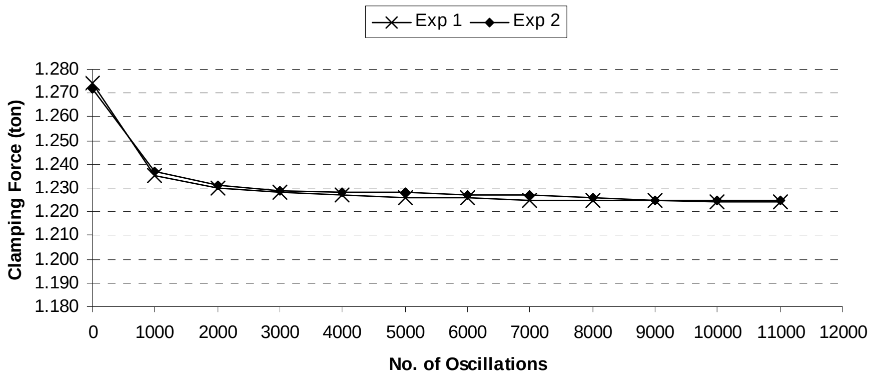

Figure 3: Testing results for M16 HTS bolt with spring washer under vibration

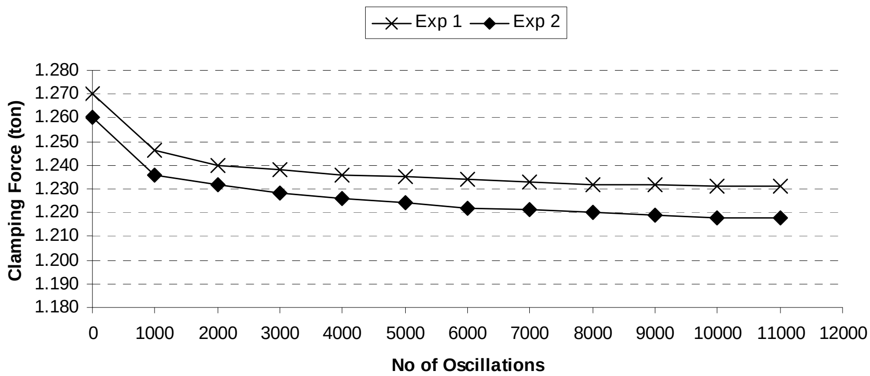

Figure 4: Test results for M16 HTS bolt with inside serrated washer under vibration

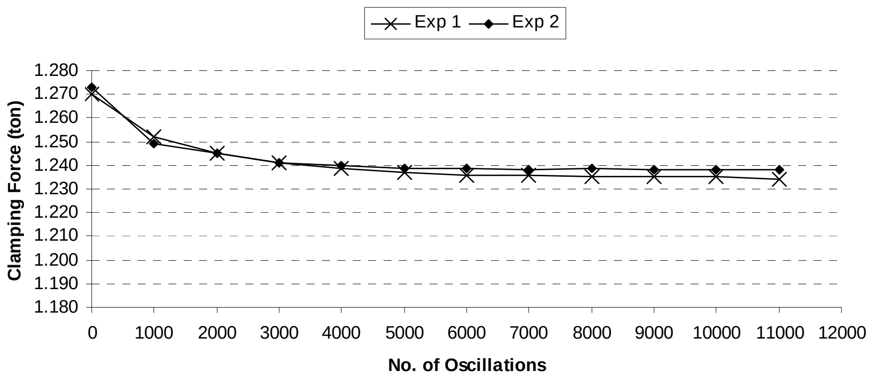

Figure 5: Test results for M16 HTS bolt with outside serrated washer under vibration

Loss of clamping force with the number of oscillations of vibration is depicted in Fig. (5) for M16 HTS threaded fasteners with outside serrated washer. The repeat experiments 1 and 2 results are quite close to each other. Loosening observed in experiment1 is 36 kg, whereas in the 2nd test, 35 kg of loss of clamping force is experienced. The average loosening is about 2.7% after 11,000 oscillations.

Fig. (4) and Fig. (5) show that the use of inside and outside serrated washers provide more resistance to loosening compared to flat washer as shown in Fig. (2) and spring washer shown in Fig. (3). This may be due to the fact that serrated washers are expected to have certain indentation onto face of nut and clamped plate to resist loosening. However, this indentation may not be permitted for repeated use for fastening the components. Fuji and Sase [1] also made similar observation.

Loosening characteristics of nylock nut used on a conventional M16 HTS bolt is shown in Fig. (6) for two repeat tests. Both the two curves become almost flat and parallel to each other after about 11000 oscillations indicating no considerable loss of clamping force. Results suggest that for nylock nut, total loosening is very low about 18 kg and 19 kg respectively that is 1.4% in average for both the two experiments. Nylock nut provides an extra friction grip due to presence of nylon on the bolt thread to resist loosening. Similar results were also found in the experiments of Sase et al. [7] where nylock nut was found to give better resistance to loosening compared to conventional nut with and without a washer.

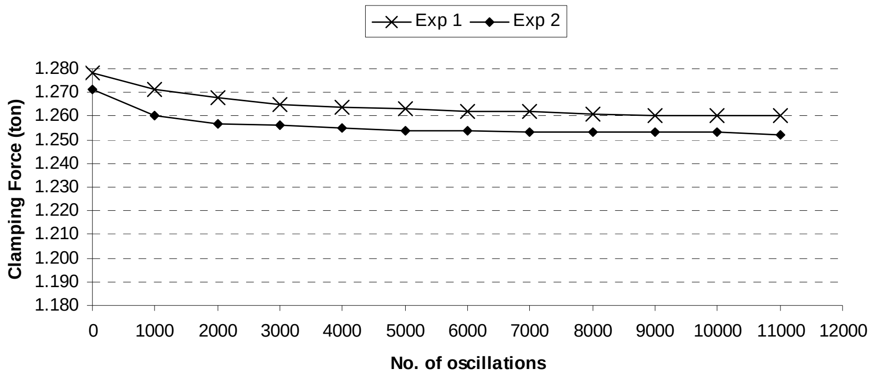

Figure 6: Test results for M16 HTS bolt with nylock nut under vibration

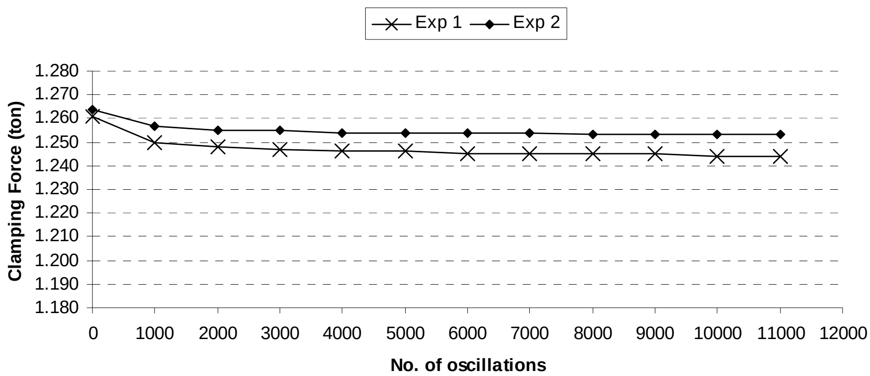

Figure 7: Test results for M16 HTS bolt with hybrid double nut (one conventional nut and one nylock nut) under vibration

Fig. (7) shows the loosening characteristics for M16 High Tension steel bolt with one conventional nut and then one nylock nut, named a 'hybrid double nut' subjected to vibration. From the figure, it is observed that the use of this hybrid double nut in place of single nylock nut can prevent the loosening quite effectively.

In both the two repeat experiments, total loosening of clamping force is 17 kg (i.e. 1.3%) in experiment 1, and 11 kg (i.e. 0.8%) in experiment 2 respectively after 11,000 oscillations. In this case, beneficial effects of the nylock nut having a friction-raising nylon grip and the use of an ordinary nut giving additional contact friction can be considered to give good anti-loosening characteristics.

From the experiments of M16 high tension steel threaded bolt with different nuts and washers, results obtained are compared in Fig. (8). Plots show that the use of flat washer and spring washer can reduce the loss of clamping force to a little extent. Inside serrated washer and outside serrated washer can reduce loosening by small amount. It is found that hybrid double nut shows almost no loosening of clamping force after 2,000 oscillations unlike nylon nut. On the whole, hybrid double nut is found to be a comparatively good anti-loosening fastener under vibration, followed by nylock nut.

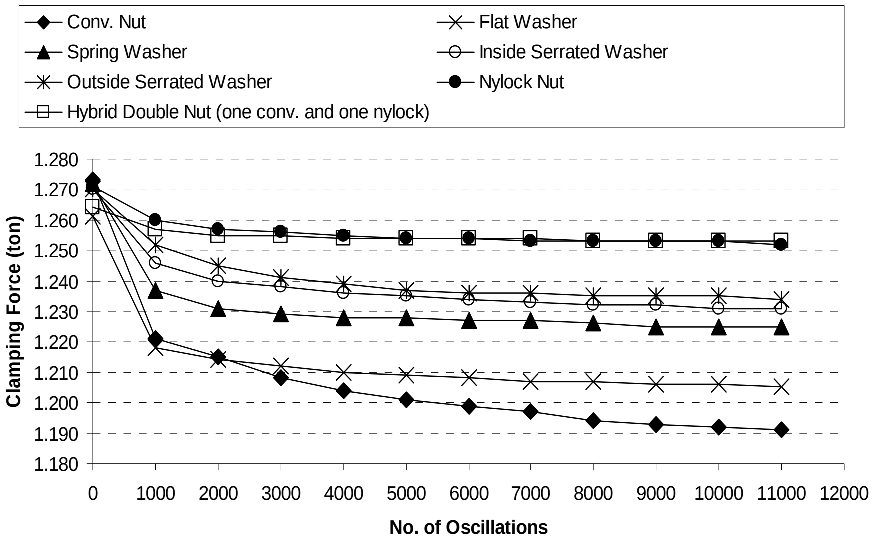

Figure 8: Comparison of loosening for M16 HTS bolt with different nuts and washers under vibration

Tested nuts and washers are listed below in an ascending order according to their increasing anti-loosening ability following the trend of loosing clamping forces with the progress of number of oscillations as shown in Fig. (8).

1. Conventional nut
2. Flat washer with conventional nut
3. Spring washer with conventional nut
4. Inside serrated washer with conventional nut
5. Outside serrated washer with conventional nut
6. Nylock nut
7. Hybrid double nut (one conventional nut and one nylock nut).

Increase in Anti-loosening Ability

4 Conclusions

From the experimental results, following conclusions may be drawn.

1. It is found that flat washers do not prevent loosening considerably in contrast to the common perception but spring washers tend to provide some anti-loosening

tendency. Inside serrated washer and outside serrated washer show some resistance to loosening compared to a spring washer, as serrated washer provides better friction at the bearing surfaces by indenting into its contact surfaces.

2. Nylock nut shows good anti-loosening ability and less possibility to loosen in vibrating environment. The nylock nut provides an extra friction grip of nylon on the bolt thread to resist loosening. 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 that may be due to additional contact friction between fastening elements.
3. Although loosening could not be stopped totally, it can be minimized to a large extent by using proper locking arrangement such as hybrid double nut tested in the present work.

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