CSAVAR LAZULÁS MÉRÉSÉNEK LEHETŐSÉGEI

ON MEASURING OF BOLT SELF-LOOSENING

Talal Alsardia, PhD student, talal.alsardia@mail.bme.hu
Dr. László Lovas, associate professor, lovas@kge.bme.hu
BME Department of Vehicle Elements and Vehicle Structure Analysis

ABSTRACT. This paper deals with the measurement possibilities of bolted link self-loosening. Theory of self-loosening is shortly presented, then common measurement principles are shown. Different test rig layouts are discussed, then a novel layout is proposed.

1. INTRODUCTION

The loosening of bolted links is a common problem in the industrial practice. Loosening happens either in structures under static load, or under time-depending load. In vehicles, the loads are typically time dependent, periodical or stochastic. There are key cases such as truck or bus wheel bolts, in which loosening prevention or re-tightening period estimation is of primary importance. In this paper, actual state of loosening theory is shortly presented. Then, current test rig layouts are discussed. Limit conditions and their relation with those of real bolts are shown. Finally, an improved test layout is proposed.

2. PHENOMENON OF SELF-LOOSENING

At the author's knowledge the first study on threaded fastener self-loosening was performed by Goodier in 1945 [1]. They suppose that in case of a bolt under pretension, the cyclical variation of the work load results in variations in the bolt force. This variation causes small rotations on the nut, leading to the loss of pretension.

This idea was proved 25 years later, in 1969. A German engineer, Gerhard Junker supposed that the effect of cyclic transversal loading has more influence than that of cyclic axial loading [2]. Junker proved by experiments, that a tightened fastener under transversal load will get loose, when relative motion between male and female threads and relative motion between the flat contact surfaces occur. This relative motion is the result of an external transversal force acting on the bolted link. That force should be greater than the friction forces within the bolted link. The relative motion can occur either on the thread surfaces or on the contact area between the bolt head and nut with the members. When the relative motion (sliding) starts on the thread level, it will bend the bolt shank. Due to this, sliding of the bolt head contact surface will happen. Junker supposed that during sliding, the threads and the bolt head will turn friction-free. The loosening torque is issue from the bolt preload applied on the helix surface. Under the effect of a cyclic transversal load this can lead to the complete loosening of the bolted link.

Further on, Daadbin and Chow [3] made experiments concerning bolt loosening. They supposed that the contact between the threads has elastic damping. The application of an cyclic external load increases the frictional forces, leading to the rebounding of the parts due to the elastic contact. If this rebounding is increasing, then the friction forces will decrease. This makes the nut possible to slide due to the helical shape of the threads. They concluded that a smaller helix leading angle, increase of loading duration, and increase of the friction coefficient will minimize the joint loosening.

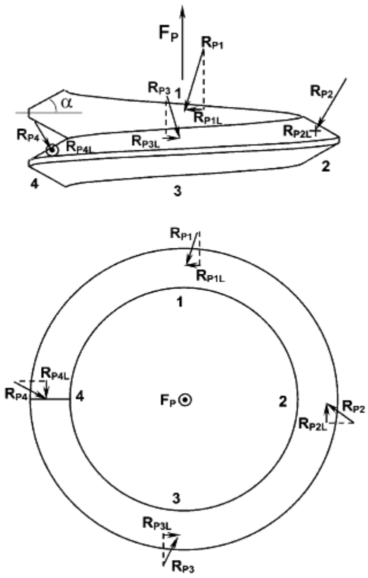


Figure 1. Different tangential force components around the thread, forming the loosening torque [4]

Pai and Hess [4] made experimental studies on bolt loosening. They built a test rig similar to Junker's, and performed experiments under various sliding distances. They tested different pretension forces, and find that loosening starts at less shear load than expected. To explain this, the proposed the idea of localized slip superposition on the bolt thread.

The DIN 25201 standard describes the bolt loosening causes in a diagram. Here, the first cause is the plastic deformation of the materials. The second cause is the flattening out of the surfaces pressed together. The third cause is the relative motion of the clamped surfaces.
The plastic deformation, either increase of the bolt length or decrease of the compressed material width, results in a decrease of the pretension force. The decreasing surface roughness has similar result. When a motion perpendicular to the bolt axis appears, the bolt head starts to rotate, and loosening takes place.

State variation of the clamped surfaces is studied by the tribology. Researches of Kounoudji [5] show that the friction coefficient changes from tightening to tightening, both globally and locally.

Based on the previous researches, Baek et al. [5] studied the bolted link of a truck twin wheel. They supposed that the loosening due to a load perpendicular to the bolt axis happens at two levels. The first level is when the perpendicular displacement is smaller than the gap between the bolt shank and the hole. In this case, the friction happens between the clamped parts, the wheel rim and the brake drum. The bolt self loosening does not takes place at this level. The second level is when the displacement amplitude is higher than the gap between bolt and hole diameter. In this case, either the bolt head lower surface and the nut surface are excited, and self-loosening takes place.

Baek et al. made experiments using different bolt sizes, clamping forces and displacement amplitudes and forces. They have not continued the experiments till a complete release, they stopped at given number of cycles.

Izumi et al. [7] studied the loosening based on the load distribution among the loaded thread pitches. They studied the first four thread experimentally and with numerical modelling. They find out that the slippage happens first at the thread level, and rotation of the bolt head comes after.

From the literature above, it can be seen, that the bolt loosening is a problem that is still actual. The development of the computing science and the test methods allow to clarify more and more details, but there is no general solution to the problem till this day.

2. CURRENT TEST RIG LAYOUTS

Nowadays, a common measuring device of bolt loosening is the Junker test rig (*Figure 2*). It has been elaborated by Gerhard Junker at the end of the 1960s and become standardised in the DIN 65151. This test rig is based on the observation that a periodical load acting in the plan perpendicular to the bolt axis results the loosening of the bolted link. The periodical load is generated by a cam mechanism. Its effect is increased by the fact that there are rollers between the clamped materials to eliminate the friction at this level. This leads to small energy consumption at the level of the test rig. Furthermore, the loosening appears in a relatively small number of cycles (500-1500). The test ends when the bolt preload disappears. Such test rigs are common product, they can be bought at dedicated companies.

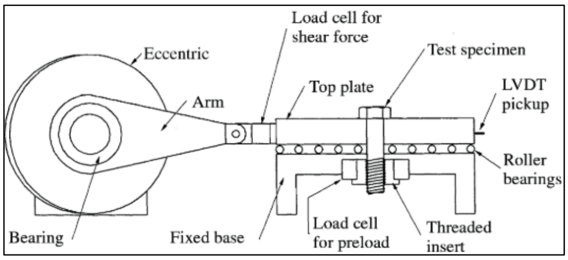


Figure 2. Junker test rig [5]

There are two basic problems with the Junker rig. First, it does not consider the friction between clamped part surfaces. Secondly, it neglects the effect of the periodical load parallel to the bolt axis.

These problems are well known by the literature [6]. In fact, the friction on the clamped material surfaces is an important factor of the shear force required to loosen the bolt. *Figure 3* shows how it increases with the bolt size increase. Here, the shear force increases exponentially, if the bolt pretension force is given as a standard value.

Supposing a displacement of 0,1 mm, the power required to the excitation goes quickly up to tenth of kilowatts (*Figure* ***4***).

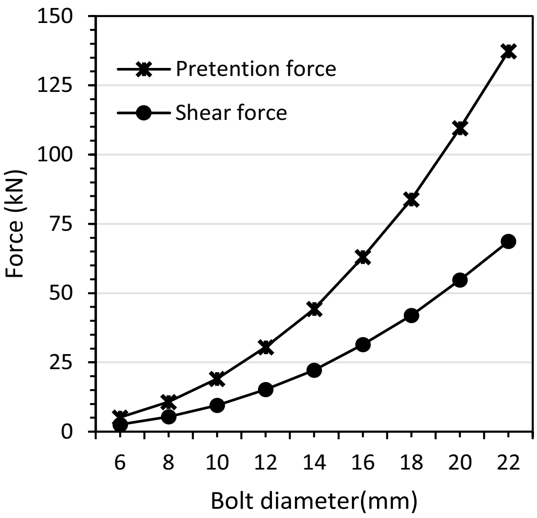


Figure 3. Pretension and shear forces at various bolt diameters

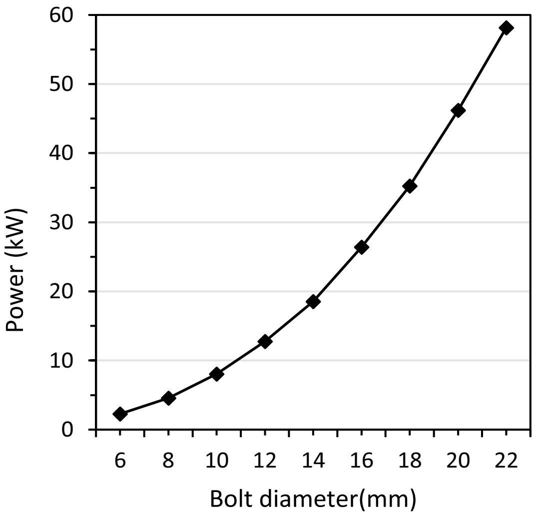


Figure 4. Shear power need at various bolt diameters

It can be seen, that at small bolt size, the shear force is not so high. In the literature [8] we can find a smart test rig layout that takes into consideration the real position of the clamped elements (*Figure 5*).

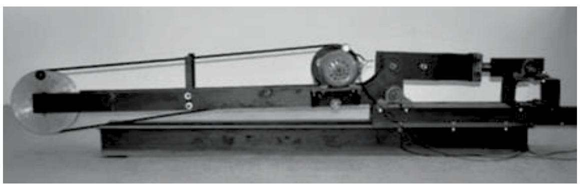
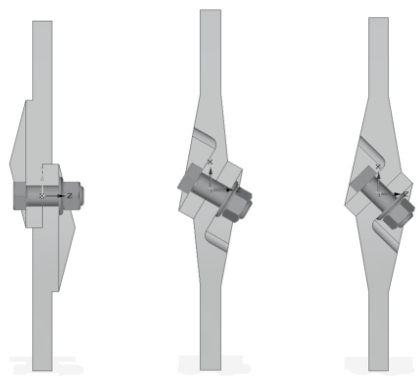


Figure 5. Test rig for bolted link including friction on clamped surfaces [8]

Also here, the excitation force comes from an excenter, whose force is amplified through a lever mechanism. This test rig requires relatively small amount of energy to operate. The number of cycles required to the bolt loosening is sensibly higher (10^4-10^5) than in the Junker test rig case.

Bolt loosening can also be studied in classic tensile test machines with pulsating abilities. Using appropriate clamping heads, a shear force can be applied on real clamped parts [5].

Pulsating tensile test machines can also be applied to study the compound effect of coaxial and shear excitation. If the bolt axis is not perpendicular to the pulling direction, both shear and axial force can be applied to the test specimen (*Figure 6*, 60° and 45° case). The limitation here is that the period of the coaxial and perpendicular excitations is always the same.



a) b) c)

Figure 6. Specimens with load direction at 90° (a), 60° (b) and 45° (c) of the bolt axis

3. NEW TEST RIG LAYOUT

To overcome the problem of independent periods and excitation in two perpendicular axis, a new test rig design is required. This test rig must be able to load the bolted link both in parallel and perpendicular direction to the bolt axis. Moreover, it must provide a load that can overcome the friction between the clamped materials in the perpendicular direction.

A development work has been started in our department to seek solutions to the test rig design. For simplicity, a mechanical exciter model has been developed. It consists of a trolley moving on horizontal rails. The motion is driven by excentric masses, rotating on a pair of shafts (*Figure 7*).

The pair of shafts turns in opposite direction, thus, the excitation force has only horizontal component. The shafts are driven by an electric motor, via toothed belts. The specimen is placed horizontally, aligned with the centre of gravity of the trolley. The frame around the trolley contains the rails and the fixation of the specimen. In the first development stage, one load direction is planned to be built. After testing and proof of concept, a second trolley will be added in an enlarged frame. This layout would allow the frequency-independent excitation that occurs in real conditions in given bolted links.

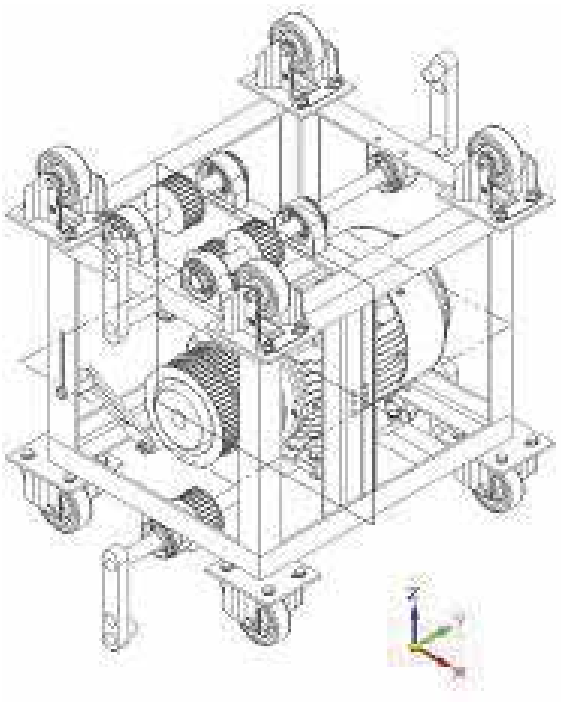


Figure 7. Exciting trolley of the test rig

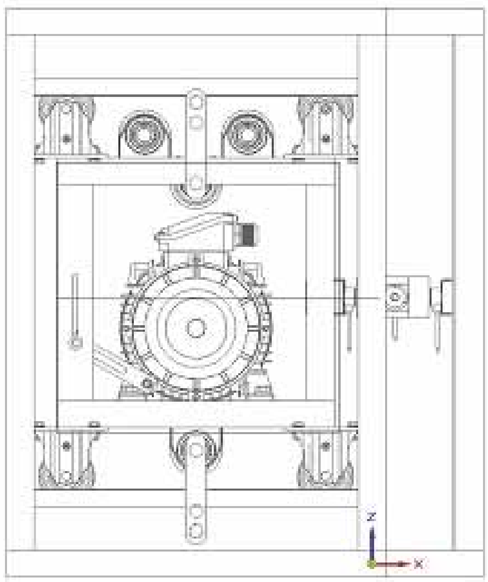


Figure 8. Trolley test rig with pulled speciment at the right

4. CONCLUSION

The research on the origins of bolt loosening is a scientific field in development. Many approaches exist, as well as many test procedures. It is clear that the actual standard test procedure (Junker type test) results are not satisfying when faced to real bolted structure problems. Tribology of the surfaces and multiaxial load analysis are also required to have clear view on the loosening. Our test rig concept will be a further step in this direction.

7. REFERENCES

[1] Goodier J. N. Loosening by Vibration of Threaded Fastenings. Mech,Engg., vol. 67, p. 798, 1945.

[2] Junker G. New criteria for self-loosening of fasteners under vibration. Transactions of the Society of Automotive Engineers, vol. 78, pp 314–335, ISSN: 0148-7191, 1969.

[3] Daadbin A, Chow Y. M. A theoretical model to study thread loosening. Mechanism and machine theory, vol 27(1), pp69-74, 1992.

[4] Pai N. G., Hess D. P. Three-dimensional finite element analysis of threaded fastener loosening due to dynamic shear load. Eng. Fail. Anal., Vol. 9, pp. 383–402, 2002.

[5] K. A. Kounoudji. "Intimité tribologique" des contacts d'un assemblage boulonné. PhD thesis, INSA-Lyon, 1996.

[6] Baek K.H., Jeong N.T., Hong H.R et al. Loosening mechanism of threaded fastener for complex structures. Journal of Mechanical Science and Technology, vol. 33(4), pp 1689-1702, 2019.

[7] Izumi S., Yokoyama T., Iwasaki A., Sakai S. Three-dimensional finite element analysis of tightening and loosening mechanism of threaded fastener. Engineering Failure Analysis, Vol 12(4), pp 604-615, 2005.

[8] Dravid S., Triphati K., Chouksey M. Experimental study of loosening behaviour of plain shank bolted joint under dynamic loading. Int. Journal of Structural Integrity, Vol. 6(1), pp 26-39, 2015.