Some New Aspects of Bolted Joints Locking

by:
Jozef Dominik, Ph.D.
Ferodom, s.r.o.
Štefánikova 58,
01001 Žilina, Slovakia
www.ferodom.sk

The effectiveness of locking fastener elements is dependent on the type of loading operation.

Bolted joints under dynamic stress and vibration have the tendency to self-loosen. This property is very dangerous, because it can cause damage to the assembled structures. There is a large variety of more or less effective locking measures for such bolted joints.

The traditional market offers a wide range of locking elements that are also used in practice. However, are all of these elements and measures really effective? Do all of them offer the proclaimed characteristics? The target of this article is to investigate the broad array of locking elements and to provide knowledge of their effectiveness.

Theory

Bolted joints are exposed to the influence of various statically or dynamically affecting forces[1,2] when operating (see **Table 1**). These forces either support each other or operate against each other, and strongly affect the original stress state of the bolted joint. System instability is a result of the loss of prestress. In extreme cases, total damage of a structure can occur as a result of this loss of prestress.

The self-loosening process of bolted joints takes place in three phases: releasing, self-loosening and a total loss of prestress[3]. In order to prevent self-loosening, various prevailing elements can be used, and the efficiency of each can be tested under laboratory conditions. Not considering chemical methods in this article, radial and axial mechanical methods of locking are most often used (**Figure 1**).

As seen in **Figure 1**, while the axial locking methods (for example, serrated washers and flange bolts and nuts) directly depend on prestressing force F_M, which involves the pressure p, most radially operating locking elements are effective also when F_M=0. In other words, the radial locking is absolutely independent of general prestressing force.

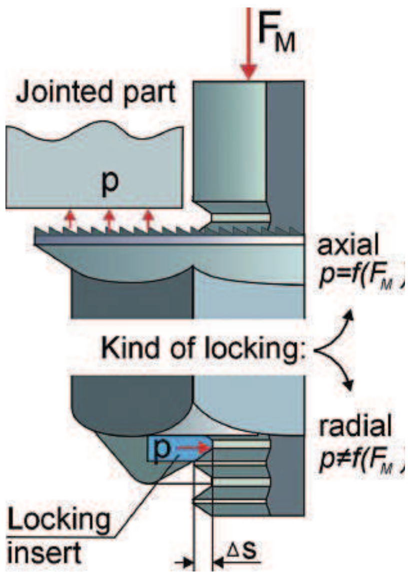

Fig. 1 — Principle of the radial and axial locking of bolted joints: F_M = montage force, p = pressure, Δ S = overhang.

Testing Methods & Results

Principally, there are three basic types of assessment of bolted joint resistance against vibration and dynamic loading (**Figure 2**).

The A type (*Junker structure—DIN 25201*) functions on the principle of variable cyclical transversal loading; the B type (also described in **Figure 3**) is based on alternating axial loading; and the C type (*National Aerospace Standard 3350/3354, USA*) is a horizontally or vertically oriented vibrational method of amplitude ±19 mm.

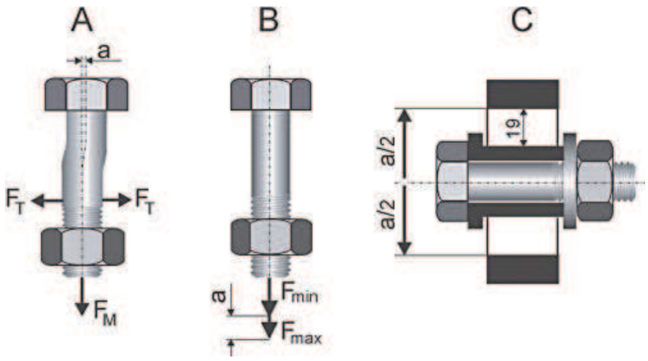

Fig. 2 — Test methods of bolted joints: A-dynamic transversal loading, B-dynamic axial loading, C-vibrational method (*NAS 3350/3354*), a-amplitude, F_M-montage prestressing force and F_T-transversal forces.

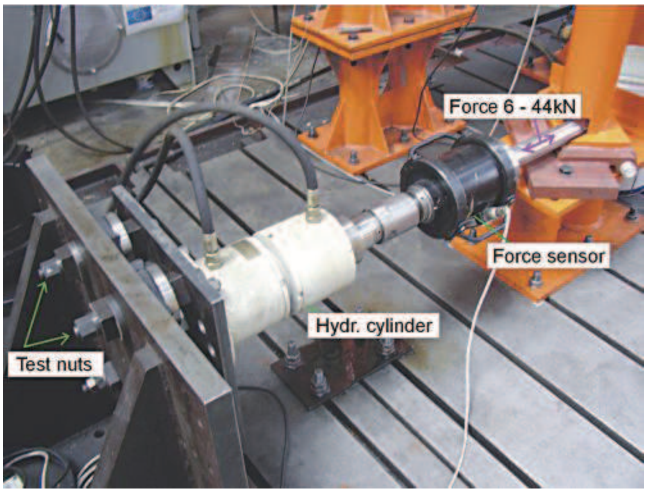

Fig. 3 — EDYZ device for dynamic testing in the axial direction.

Comparing different loading (**Table 1**) of bolted joints with limited test method options, it is clear that the real operating conditions are difficult to simulate. It would be more objective if all testing methods could be used. Every single method does not have to represent real loading, which can lead to incorrect results interpretation.

Table 1. Various Operating Forces.

Kinds of operating forces	axial	axial tensile or pressure	static
			dynamic
		eccentric tensile or pressure	static
			dynamic
	transversal	static	
		dynamic	unilateral
			bilateral
	torsional	static	
		cyclically repeated torsional forces	

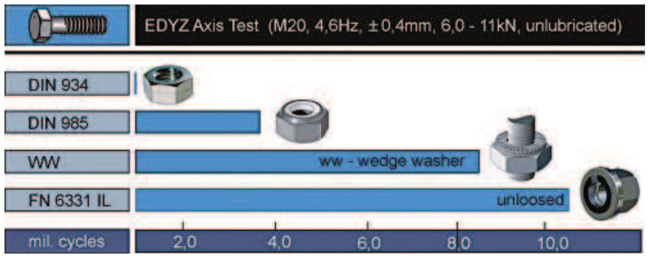

Fig. 4 — Residual prestressing force of a bolted joint after testing on axial pulsator EDYZ (M20, cl. 10) *FN 6331IL-DIN 6331*, modified to variant IstLock®.

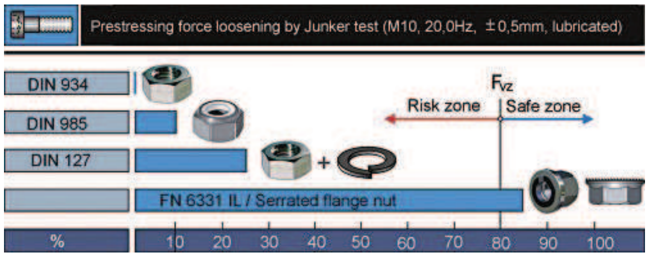

Fig. 5 — Residual prestressing force of bolted joint after testing on a device Junker (M10, cl. 8).

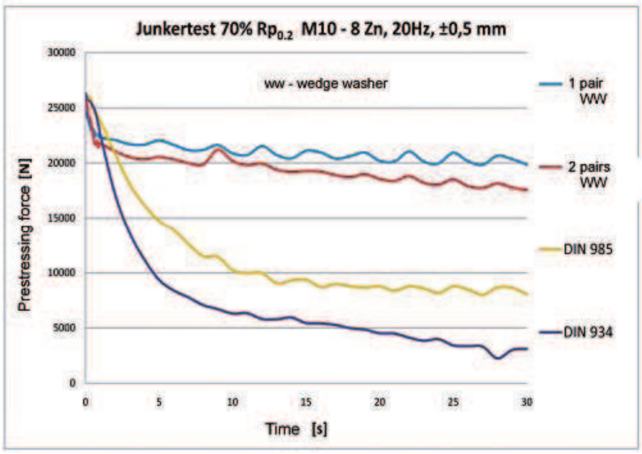

Fig. 6 — Junker test-various variants of wedge washers' application (WW).

It is necessary to add that there is no technical standard; there exists only some recommendations. As already mentioned, *DIN 25201* describes just one of many possible methods. The individual can decide which testing method will be used.

The reduction of prestressing force is observed when testing with all the methods depending on the number of loading cycles at a specific frequency and amplitude, and it is registered appropriately. Measured values are then mutually compared and evaluated (**Figure 4**, **Figure 5** and **Figure 6**). It is generally accepted by professional practice that a bolted joint is secure when the reduction of prestress is lower than 20%.

Result Interpretation & Discussion

Attention was paid to two typical representatives of radial and axial locking:

- Radial: self-locking nuts with nylon insert *DIN 985 (ISO 7040)*.
- Axial: wedge washers (WW).

DIN 985: Paradoxically, despite some negative references in relevant literature, nylon insert locking nuts are very popular. This paradox also proves a problematic objectivity of model testing. It is necessary to add that the critical parameter of nylon insert locking nuts is not their inability to lock, but depending on the temperature, difficultly tightening relative to high friction between nylon circle and external thread and problematic repeatability (*DIN ISO 2320*).

As can be seen in **Figure 4** and **Figure 5**, these nuts show better resistance against vibration and alternating dynamic loading in the axial direction of loading rather than in the radial direction. As already stated, their big advantage is the fact that they lock even when there is zero prestressing force. On the other hand, high friction between nylon inserts and nut threads can cause a rise in temperature and possible degradation of the nylon ring (**Figure 7**). In this extreme case, an exact montage is impossible.

Wedge Washers: Wedge washers (WW) resist very well the variable forces operating in a radial direction (as seen in **Figure 6**). As **Sawa, T**. et al[4] showed, wedge washers were surprisingly ineffective during the vibration test, according to *NAS 3350*. Even with axial alternating loading, they did not reach comparable results. All the axial locking elements with profiled contact surfaces are sensitive to the amplitude size of the alternating loading.

It is important to add that wedge washers are assembled in pairs under the head of a bolt and under the nut. This indicates seven interfaces altogether for a bolted joint. Each of the interfaces is affected by the phenomenon of the material flattening out (flattening out the contact surfaces and micro-plastic deformation on these surfaces). The overall value of the material flattening out is in this case totalled. It was also proved by the Junker test (**Figure 6**). It is safe because the variable loading in combination with a huge number of partition lines can cause for example planishing of the fixing disc holes on the automobile wheels (see **Figure 8** on next page) and subsequently also fatigue cracking of the screws (see **Figure 9** on next page).

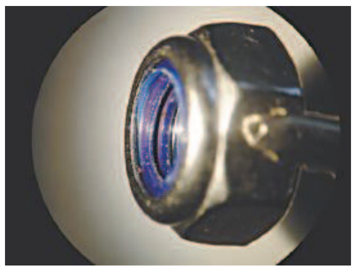

Fig. 7 — Degradation of nylon circle of the nut *DIN 985*.

The tests demonstrated the dependence on effectiveness of bolted joints locking on the loading type. Therefore, it is unsubstantiated to generalize the results. In real operating

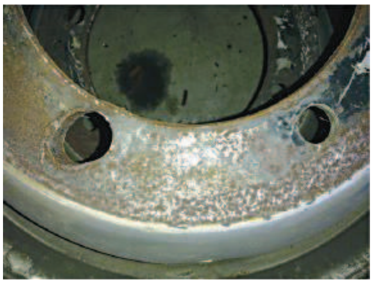

Fig. 8 — Planished holes on the disc (wheel).

Fig. 9 — Screw fatigue crack.

conditions, the relevant structural nodes can undergo diametrically different loading as it was set in the test.

Most of the published articles come from an originator's workshop and describe "a winning variant". Each of the producers and distributors never compare their own products with real competitors. In most cases, it is only confrontation with the weakest "players" in the market such as elastic washers *DIN 127*, locknuts, etc., which then serve as a "whipping boy".

Conclusion

On the basis of the knowledge gained, an experiment was conducted attempting to objectively assess the most often used locking elements.

Table 2 shows that the axial locking elements and partite elastic washers have the strongest dependence on the loading type. Radial elements, such as *DIN 985* nuts are relatively universal even on an average level. Axial elements have an advantage that they are not dependent on lubrication. On the other hand, they leave imprints on the contact surfaces. Conclusion and recommendations are as follows:

- Effectiveness of locking fastener elements is dependent on the operation loading type. Each assembler should pay extra attention to the choice of the locking type. The conditions in which the final structure will operate are crucial. Appropriate measures should be adopted.
- Results of laboratory tests depend on individual testing parameters, and do not concern only frequency and amplitude, but also tightening moment, coefficient of friction, diameter of samples and sometimes temperature. Therefore, it is valid that only practice can bring objective results. Despite this, test simulations are justifiable because they offer a lot of interesting information.
- The combination of axial and radial locking would present ideally locking fastener elements. Technically, this would not be any problem to create (**Figure 10**).
- Remember, the unlocked bolted joint represents the latent danger of the structure's decay.

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Table 2. Locking Effect of Some Fastener Elements.

Locking method		Test method		
Name/illustration	Critical parameters	A radial	B axial	C NAS
wedge washers (WW)	too many interfaces, imprints on contact surface	▲	dependence on the amplitude	▼
serrated washers	dtto less than WW	▲	dependence on the amplitude	∇
serrated flange elementes	damage of contact surface	▲	dependence on the amplitude	∇
DIN 985	dependence on temperature, repeatability	►	►	►
RADAX (radial – axial locking nuts)	damage of contact surface	Δ	▲	-

▲(Δ - assumption) – excellent locking effect
► - average locking effect
▼(∇ - assumption) – low respectively no locking effect

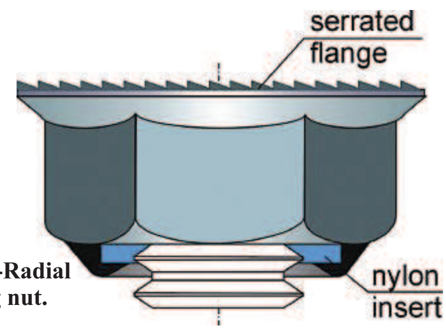

Fig. 10 — RADAX-Radial and axial locking nut.

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