Some New Aspects of Bolted Joints Locking

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Citation: "There is no absolute protection method of bolted joints, which would be equally effective for all cases of stressing." (C. O. Bauer)[1]

As it is known, bolted joints have an inclination to self-loosening in conditions of dynamic loading and vibrations. So this, "whim" of them is very dangerous especially for means of transport because it can cause a risk of damage leading to being in peril of human's life. Contemporary market offers wide range of various external safety elements and systems many of which are commonly used in practice. But are all these systems effective and really dispose of declared properties? The offered contribution will try to give an answer to this important and highly actual issue.

Theoretical analysis

When the bolted joints are in operation, they are exposed to the influence of complicated statically and dynamically acting external and internal forces [2] **(Tab. 1)**.

These forces either support themselves mutually, namely proportionally or disproportionally or they act against each other. We therefore say about superposition of internal (assembly) and external (operating) forces which then determine final bolted joint stress. The result is usually instability of the system, characterized by decrease of pre-stress, in extreme case even total decay of the joint.

The self-loosening process of bolted joints goes through three stages: loosening – self-turning - decay [3]. Safety precautions are based on the application of axial or radial safety elements **(Fig. 1)** effectiveness of which is tested in laboratory conditions according to various techniques.

The Fig. 1 shows that while the effectiveness of axial safety methods is directly dependent on pre-stressing force F_M, most of radially acting safety elements is effective also when $F_M = 0$.

Tab. 1 Various operating forces

Operating force			
	axial	axial tensile or pressure	static
			dynamic
		excentric tensile or pressure	static
			dynamic
	transversal	static	
		dynamic	one-sided
			two-sided
	torsal	static	
		alternate	

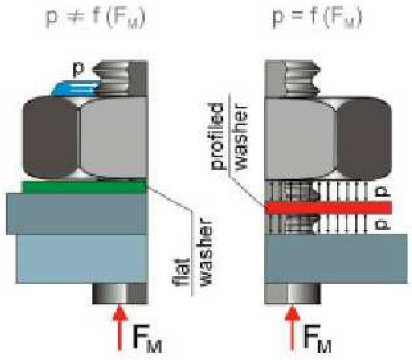

Fig. 1 The principle of radial (left) and axial (right) locking

Testing methods

Principally, there are three basic testing methods **(Fig. 2)**. For our testing we had A and B method at our disposal.

Type A (Junker or Unbrako construction) works on the principle of variable radial cyclical loading, type B **(Fig. 3)** is based on variable axial loading and type C (National

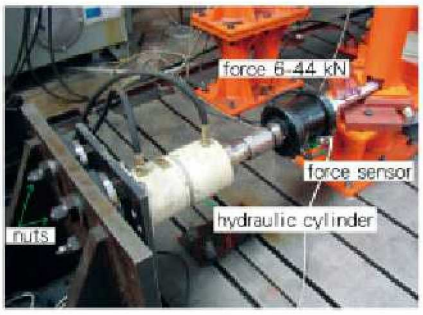

Fig. 3 The equipment EDYZ for dynamic testing in axial bolts direction

Fig. 2 Methods of bolted joints testing
A- dynamic radial loading
B- dynamic axial loading
C- vibrational method according to NAS 3350
a- amplitude
F_M- assembly force
F_T- transversal force

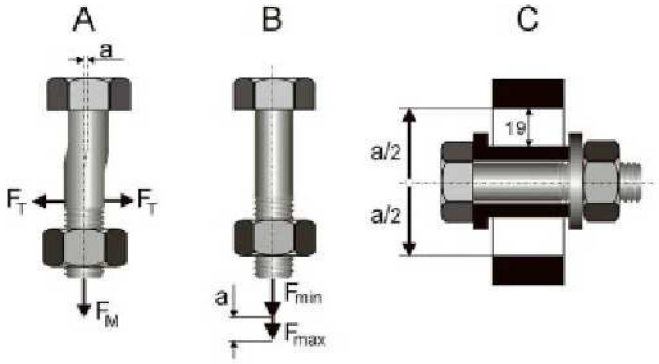

Fig. 4 Residual bolted joint pre-stress after axial test EDYZ (M20, class 10, not lubricated) [4]

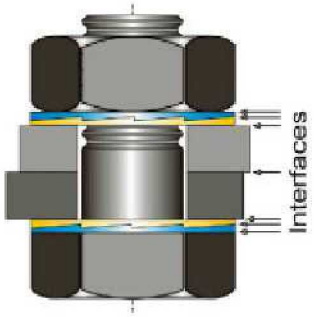

Fig. 5 Interfaces of bolted joint with two pairs of wedge-lock washers

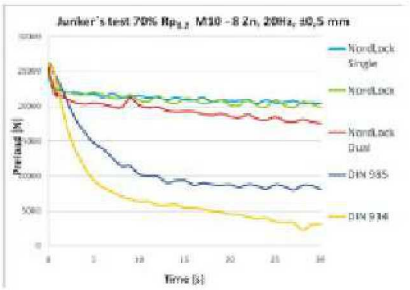

Fig. 6 Junker test (all samples lubricated)

Aerospace Standard 3350/3354, USA) is clearly horizontally or vertically oriented vibrational method.

It is important to emphasize that there is no norm/standard within this respect. Everyone can freely decide which method will be used. Within all methods, there is monitored and recorded decrease of assembly pre-stressing at specific frequency and amplitude depending on time or the number of loading cycles. Measures values are then compared to each other and evaluated **(Fig. 4)**.

By comparing potential types of bolted joints loading with limited possibilities of testing methods, it results that it is very problematic to simulate real operating conditions in the laboratory. It would be objective to test with the help of all the methods. Every single method does not have to unconditionally represent real loading and hence cannot have general validity. In such case, there is a risk of incorrect interpretation of results. There are further introduced some typical examples.

Example no. 1

The first example is dedicated to wedge-lock washers (WLW). These washers perfectly resist transversal dynamic loading (Junker test). But as SAWA, T et al. [5] showed, they are surprisingly ineffective to influence of vibrations, according to NAS 3350. Shaped safety elements, like washers, nuts, or bolts with shaped (rib) flange are generally sensitive to variable axial loading in cases when applied amplitude is too big. It is important to emphasize the fact, that shaped safety elements do not secure against third stage of self-loosening, i.e. decay of joint **(Fig. 1)**. This fact is not often mentioned in the literature and prospectuses.

When dealing with wedge-lock washers, there is further remarkable, that they are assembled in pairs, i.e. under the head of bolt and under the nut **(Fig. 5)**. For bolted joint it indicates altogether 7 interfaces. Each interface is characterized by own material settlements, i.e. complete settlements (pre-stress decrease in the first stage of loosening) multiplies what was confirmed with separate tests according to Junker **(Fig. 6)**.

Fig. 7 Pushed out gap on automobile disc

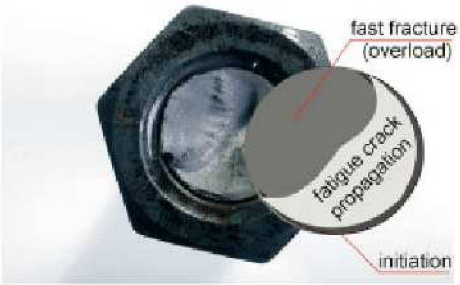

Fig. 8 Fatigue fracture of the bolt

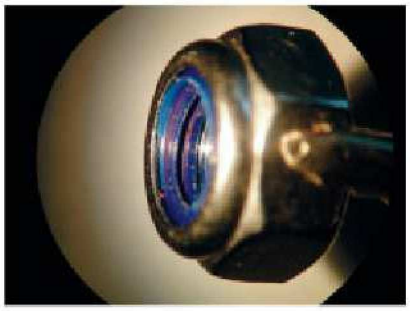

Fig. 9 Damaged plastic ring on the nut DIN 985

The combination of variable loading and of too big number of interfaces can cause, e.g. pushing fastening gap on automobile discs out **(Fig. 7)**, and lead to fatigue fracture of the bolt **(Fig. 8)**.

Example no. 2

Paradoxically, in spite of negative literary references the safety nuts DIN 985 are very popular and relatively reliable structural part. Even this paradox manifests disputable objectivity of model testing. The practice does not trust them in this case. The critical parameter of these nuts is not their insufficient safety effectiveness but temperature dependency, more difficult tightening and problematic repetitiveness of use (DIN EN ISO 2320). As a consequence of friction, already caused by too fast tightening there is produced heat which can cause damage of plastic ring **(Fig. 9)** and by that also unpleasant change of friction coefficient.

Example no. 3

This example is general and deals with objectivity of proclaimed tests. Most of published contributions come from the workroom of the originator of "winning variant", with only for minor exceptions. Producers and distributors do not compare own products with real competitors. Mostly, it is only confrontation with the weakest "players" on the market, like above mentioned safety nuts DIN 985, elastic washer DIN 127, contra-nuts, etc. which serves only as "whipping boy". In literature, for example, you do not find correct mutual comparison of various types of shaped washers at all. Concrete attempt for objectivity was recorded in [6], unfortunately, it still remained as an attempt. Discussed book, within the chapter on safety bolt joints, deals with obsolete literal assumptions, which do not correspond with the current state of technology.

Tab. 2 The effectiveness of safety elements

Safety element			Testing method (Fig. 1)		
Figure	Name	Critical parameter	A	B	C
	wedge-lock washers (WLW)	interfaces	▲	in dependency on amplitude	▼
	profiled washers	dtto	▲	in dependency on amplitude	▽
	nuts with profiled flange	dtto	▲	in dependency on amplitude	▽
	nuts Vargal	properties dissipation	▶	▶	-
	nuts DIN 985	temperature dependency, reproducibility	▶	▶	▶
	washers DIN 127	properties dissipation	▶	in dependency on amplitude	▼
	adhesive on the thread	temperature dependency, reproducibility	▲	-	▲

▲ – excellent effectiveness, ▶ - average effectiveness

▼(▽ - presumption) – weak resp. no effectiveness

Summary

On the basis of theoretical knowledge and own tests we can confirm the justifiability of the citation in the beginning of this contribution. There is no absolute protection method of bolted joints, which would be equally effective for all cases of stressing. Therefore whatever attempts for generalization results are baseless. **Tab. 2** shows supports for our claim. We attempted for objective review of the most used safety elements.

As it is shown, axial safety elements and partitioned elastic washers show the biggest dependency on type of testing method, hence on type of loading. Radial safety elements, i.e Vargal and DIN 985 seem to be relatively universal, even if at average level. Without taking into consideration the temperature dependency and practically no reproducibility, relatively effective is anaerobic adhesive. For more objectivity, it would be good to add, that the advantage of axial safety elements is their effectiveness even in lubricated state. On the other hand, they leave ugly imprints on the contact spaces.

Conclusions

- **Resistance of fastening parts against vibrations and dynamic loading is strongly dependent on the type of loading.** The constructor would be very careful when selecting safety method. Operating conditions, in which the future construction will work, have decisive influence on it.
- **The results of laboratory tests depend on constituent testing parameters.** It is not only about frequency and amplitude but also about tightening moment, friction coefficient, diameter, eventually temperature. Therefore it is valid: just practice can provide reliable results. In spite of this, the simulated tests have their importance because they provide us a lot of useful information.

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