

Fatigue strength of screw joints at loading variable

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Abstract:

In the article was described an influence of the construction of screw joint on the strength at loading variable. Relation of the type of material of the bolt was described to strength from the technology of making thread. Presented findings of cracking of double – nutted bolts at low – cycles loading.

KEYWORDS: screw joints, fatigue strength, heat treatment

Stabilization of the connection

In the process of tightening the fastener screw is tight initial strength. This force should be large enough that the applied work load there was no loosening of the connector. Selection of proper fastening torque values, however, does not close the whole issue. An important problem is to stabilize the connection that is unchanging in the bolt axial force caused by the tightening of the appropriate moment, in the process of exploitation. Undermining preload forces can destabilize the call and it may be caused by:

1. Bolt elongation as a result of short-term forces for large values.
2. Deformation of the elements of thread and combined forces as a result of variable.
3. Relaxation of stresses in the screw and assembled parts while working in conditions of high temperature.

4. Loosening the nut and vibration.

In addition, there is a decrease in tension, depending on the number of loading cycles. The decrease of the initial tension increases with an increase in the number of pins connecting elements (fig. 1).

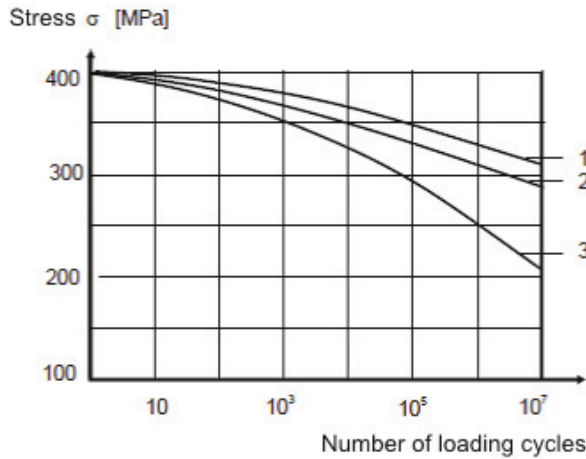


Fig.1. Change of the value of stress depending on the number compression elements [4]
 1 – without washers separate, 2 – two washers separate, 3 – five washers separate.

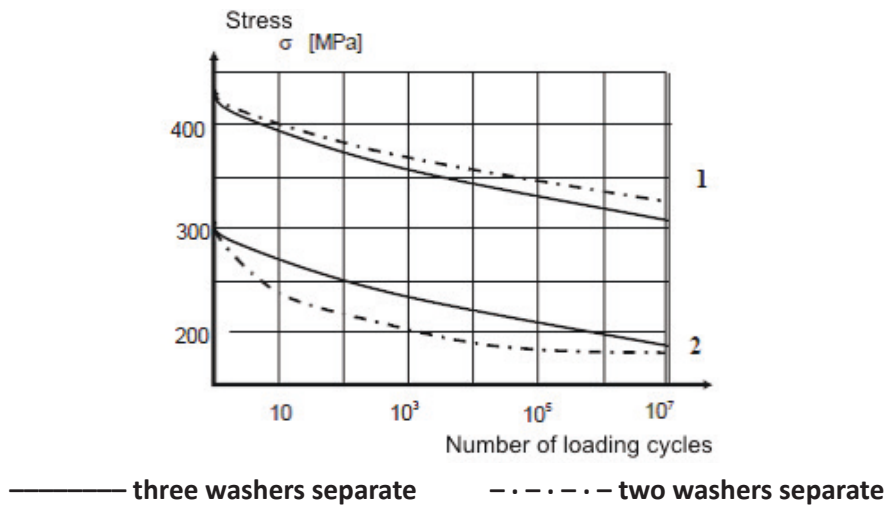


Fig 2. Change of the value of stress depending on the size stress preliminary. [4]
 Preliminary stress – 1 - 450 MPa, 2 - 300 MPa.

Increasing the value of the initial stress increases the connectors (fig. 2). But you can not tighten the connection too much, as it may cause to be felled or destroyed screw thread from the excess of reduced stress while stretching and twisting. Fall pre-tension force is related to the way threaded mechanical surface treatment (fig. 3).

During the rolling process the material cure-oriented structure and compressive stress have a direct impact on the increase in the strength of the thread in the static and dynamic loads.

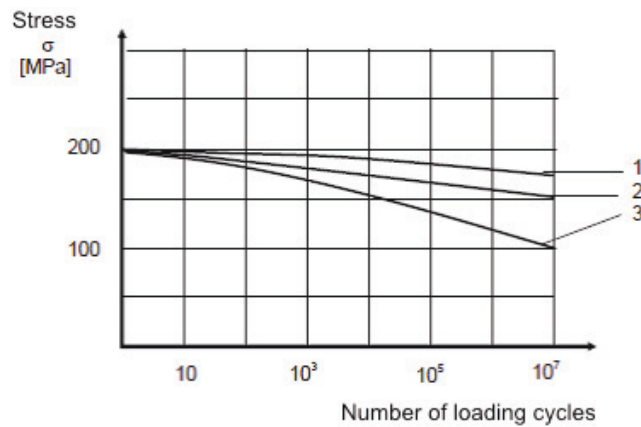


Fig. 3. Influence of the way of carrying screw area for stabilizations of screw joint surrendered to variable stresses [6]. 1 – rolling screw, 2 – cutting screw, 3 – cutting screw and then annealing.

Table 1. Comparing the strength shearing the made screw with method of the cutting and rolling

Shearing stress τ [MPa]	Material					
	1H18N9T		C22		CuZn39Pb2	
	cutting	rolling	cutting	rolling	cutting	rolling
	28	40	26	34	19	22

In each case (table 1) thread rolled had a higher shear strength of about 25% for the bronze to about 38% of the nuts made of steel. Significant impact on the strength of threaded joints has surface roughness of the thread groove. It was found that the limit cycle amplitude of the stress in the connector with thread rolled by about 50% compared with the thread heads. Changing the physical and mechanical properties of the surface layer is even more important for the fatigue strength than surface roughness. The resultant cold work during machining of the surface layer and fibrous construction metal structure substantially increases the cyclic strength of threaded joints.



Fig.4. Burnishing screw-tap M16 made joint similar to rolling screw

2. Effect of temperature

During the design of structures working in high temperatures should be carried out to check the calculation because of the long-term creep and fatigue [1]. At high temperatures, the materials have poor ductility and brittle destruction of the screws have character. In the case of variable bolt-bearing loads to be used alloy steels, which have high values of fatigue strength and flow. High durability and flow ranges can be obtained for carbon steel and hardened using a temperature of 1113 ± 10 K and drawing tempering at 573K. In carrying out the screws alloy steel to be used high tempering (773 - 823)K in order to obtain sufficiently high yield, which allows you to

use them in case of complex loads. Effect of heat treatment on the number of loading cycles is shown in fig. 5.

Research indicates that for short heating (20 min) strongly reduced strength of the bolt. Molybdenum bolts may maintain its long-term strength at temperatures $T \leq 1273K$ and temporarily up to $1923K$. In order to increase high-temperature creep resistance bolts they are covered with silicon. At higher temperatures the sensitivity to stress concentration and creep resistant steel castings is increasing rapidly, therefore rounding radii in outline line and the transition between the threaded rod and the head must be increased.

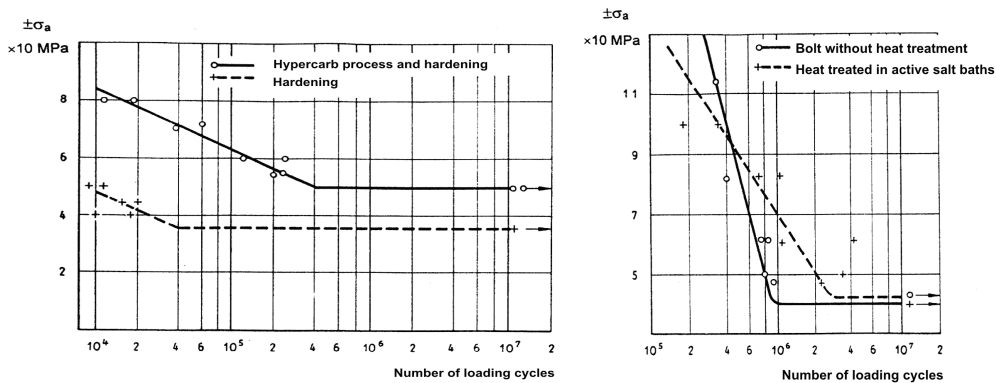


Fig. 5. Dependence of the amplitude of the stress on the number of loading in case of applying thermal treatment (bolt M10×1, material 40H) [4]

Creep at normal temperature called the slow destruction occurs in brittle materials with low plasticity.

The reasons for the slow destruction of the fragile high-steel screws are:

1. tightening torque is too large for the assembly, putting in the holes with interference, tightening the nut on the threaded output,
2. poor surface quality, small radius curves, the presence of corrosive, the strength calculation of the static load safety factor for creep - $x = 1.4 - 2.5$, when the long-term strength - $x = 1.6 - 4$

3. Load of highly threaded joints

Basics causes fatigue failures threaded joints are reduced under the action of tightening force of variable loads, improper implementation of the technological process of threading, the use of improper heat treatment and prevent the strengthening of the surface object of the study described in [2, 4] M10 bolts were made of martensite steel. Research was conducted on the hydraulic pulsator busy cycle and asymmetric load ($R_m = 600 \text{ MPa}$) with load frequency 6 cycles/min. The base number of cycles used in the studies was $N \geq 10^4$ cycles. The results stress σ_N limit for a given life $N = 10^4$ cycles are shown in table 2.

Table 2. Findings low-cycles of fatigue bolts

Temperature [K]	Cycle of loading	Presence of the strain	σ_N [MPa]
673	Pulsation	Without the strain Strain	620 690
	Asymmetrical	Without the strain Strain	870 870
723	Pulsation	Without the strain Strain	550 550
773	Pulsation	Without the strain Strain	480 440

Conclusions regarding the durability of screws:

1. The maximum limit of endurance have screws in an asymmetric load cycle. It is 24% larger than the bolts tested at the busy cycle of the load (at 673K)
2. Strengthening surface (shot peening) gave a positive effect only when the busy cycle loading at 673K. The increase in fatigue limit screws for a given life was about 10%, and increase sustainability in relation to $N = 10^4$ cycles for the strained screws increased 1.3 fold.
3. At a temperature of 723K and the durability of strain and without the strain screws is virtually identical, and a temperature of 773K durability reinforced bolt appears to be less than 1.3 times without the strain. With increasing temperature from 673 to 773K screws on the busy life cycle burden is reduced about 2.5 fold.

While other studies found that the asymmetric load cycle, when the volume reaches a maximum value of $\sigma_{max} = (800 - 1000)$ MPa, no observed effect of strengthening the positive impact of even surface at 673K, although the overall life cycle of bolts in such a case the burden is clearly greater than the pulsation cycle of the load. The results of observation of fatigue crack screws shown in table 3.

Table 3. Characteristics of destruction bolts in the low- cycles fatigue

Temperature of examination [K]	Cycle of loading	Presence of the strain	% destruction	
			At bolt head	On screw thread
673	Pulsation	Without the strain Strain	89 87,5	11 -
	Asymmetrical	Without the strain Strain	- 16,7	75 83,3
723	Pulsation	Without the strain Strain	66,7 40	33,3 60
773	Pulsation	Without the strain Strain	- -	100 100

Destruction followed two screws cross: crossing at the head of the screws, the furrow of the first reel of thread.

Proposals for fracture of screws:

1. At a temperature of 673K at the busy cycle of destruction screws without the strain load going down the most at the head of the screws was observed in individual cases, rupture of the threads. In the case of reinforced screws on thread destruction was not observed. In addition, screws without the strain

which was destroyed on thread, also showed the presence of cracks in the transition at the head of screw.

2. During asymmetric load cycle without the strain bolts damaged and destroyed only on thread, although at all damaged screws after studies found the presence of cracks at the head of the screw.
3. At 723K, most without the strain screws were destroyed at the head. Cracks in this place had a screw, which was destroyed in the threads. After strengthening the basic type of destruction was the destruction of the threads, although these bolts were also found cracks in heads.
4. At 773K, all bolts were damaged only on thread, but on all the screws were also cracks in the heads.

Example of fatigue failures stud bolt used in the construction of a lift the size of M16 (fig. 6), constructed in accordance with SAE standard. Frequent damage (fig. 7) bolts in the structure resulted in the need for replacement. Using new bolts, made in accordance with the guidelines according to standard ASTM A193. Breakthrough fatigue tests (fig. 8.) Damaged screws. Microscopic analysis was carried out broken bolts on the cross and longitudinal diameter.

Results:

1. The area of final fracture (fracture ad hoc), was located between two areas of fatigue propagation, suggesting the presence of bending loads.
2. Additional crack formed between the strands of thread near the fracture area. This means that the screw is very sensitive to initiate fatigue.
3. Broken screw also has signs of chipping the core diameter (fig. 7). Scaling, however, is permitted when the bolts work for such a burden.



Fig. 6. Double – nutted bolt M16



Fig. 7. View from the side for the cracked double – nutted bolt

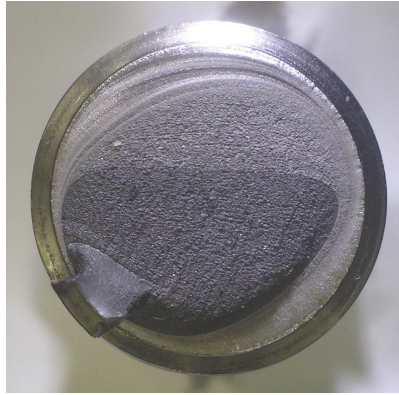


Fig. 8. Fatigue fracture of bolt

The results of chemical analysis.

The original screw contained less carbon than the required standards of SAE. A lower carbon content is likely to influence the reduction of material properties. Results of chemical analysis of the damaged screws and bolts made by the requirements of standard ASTM A193 / A also presented in table 4 etching revealed the microstructure of the cross - coarse perlite in the structure of ferrite. Standard SAE standard requires that the screw is improved heat, resulting in what should have tempered martensite structure.

Martensite has higher mechanical properties such as yield strength and the strength and hardness, which increase its resistance to initiate fatigue. Defective bolts were not improved thermally. Their ferritic structure is a lower limit of endurance, which in turn contributed to reduced resistance to fatigue initiation. Bolts made according to the requirements of ASTM have a martensite structure which means that they have been quenched and tempered.

Table 4. Chemical analysis of screws

Element	Content in the exanimate bolt (%)	Content according to the standard SAE (%)	Content in the new bolt (%)	ASTM Standard B7 (%)
Carbon	0.20	0.28-0.55	0.42	0.37-0.49
Magnesium	0.65	--	0.85	0.65-1.10
Silicon	0.22	--	0.22	0.15-0.35
Phosphorus	0.013	0.048 max.	0.015	0.035
Sulfur	0.011	0.058 max.	0.030	0.040
Chromium	0.08	--	0.79	0.75-1.20
Nickel	0.06	--	0.07	--
Molybdenum	0.01	--	0.15	0.15-0.25

Tensile tests of bolts in order to compare with the standards. The results (table 5) showed that the yield strength and tensile strength of the original bolt is only 60%

required by the standards. Ownership of the new bolts were consistent with the standards and even slightly higher than the required.

4. Tighten - up strength bolts with plastic deformation

Tighten - up strength bolts with plastic deformation of the static calculations show that an increase in bolt tension force to the limit of plastic deformation results in improving the performance of threaded connections. Followed by a more even load distribution on strings of thread and a decrease of stress concentration in check (at the bottom of the thread.) Pin screw normally is subjected to tension and torsion, the stress values show oscillations with a frequency and amplitude of vibration

Table 5. Comparing properties of strenght bolts

	Original bolt	New bolt	Standard 5 SAE	Standard ASTM
Tensile strenght (MPa)	640	1022	820	1000
Yield point (MPa)	427	934	640	960
Elongation (%)	26	20	min 16.	min 16.

caused by machines. Oscillations can lead to fatigue and, with suitably large values of stress, causing the process vibrocreep. Stability tests connections [5] were carried out with assumptions:

- 1 - M12 bolts tested were introduced in the state of elastic and plastic deformation by changing the torque,
- 2 - variable dynamic load-pulsing amplitude equal to 2 [mm] and frequency $f = 6$ Hz,
- 3 - the tests were carried out until the crack registering the number of cycles.

Results:

- 1 - steel bolts class 8.8 has a small plastic deformation due to the strengthening and are mainly suitable for operation in the elastic,
- 2 - in terms of elastic, there was no permanent deformation caused vibrocreep,
- 3 - after loading the material beyond the elastic limit (plastic deformation) and the imposition of cyclical changes in the value of stress, there is a permanent deformation caused vibrocreep; value of the strain decreases with time,
- 4 - longitudinal strain caused vibrocreep are for a given number of cycles the greater the larger the value of longitudinal stress and the increased value of the oscillation amplitude,
- 5 - the size of the initial plastic deformation of the material has no significant effect on the volume strain caused vibrocreep,
- 6 - the results of the fatigue life of bolts plastically deformed show more than 3 - fold increase in fatigue life in relation to the screws fastened to elastic deformation.

In [4, 6] presented results of comparative studies stability threaded connections at different states of tension bolts in a changing dynamic loads at the load cycle zero -

suppression busy. The study was conducted over the bolts M12x1, 75 8.8, threaded its entire length when closing:

1. Torque PN-81 / M-82065
2. Moment that causes plastic deformation of the screws, in which case a tightening was performed using a gradient assuming that the decline in the value of tightening gradient of 50% in constant gradient indicates the achievement by the screw of the plastic deformation.

During the endurance tests carried out screws, threaded its entire length, often bursting bolts at the head of the first reel of thread. Many cracks occurred in the middle of the thread at a relatively low number of cycles leading to fracture. The largest number of cycles to crack reached screws plastic deformation. Breaking in the threads in the middle nut bolts appeared in a several times higher fatigue life. Stress values in the tested screws were relatively large, hence the low number of cycles to fatigue cracks. Tests have shown a significant advantage of the fatigue life of the plastic deformation of the screws compared with screws tightening by the date specified in PN.

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