Protection of threaded connections against corrosion

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Abstract. The paper presents data on the effect of the addition of D-10TM oligomer in the composition of standard lubricants for processing threaded connections on the degree of corrosion damage, the value of the torque for unscrewing and the value of friction coefficient in threaded connections. The addition of D-10TM oligomer 5% by weight in Litol-24 helps to reduce the torque for unscrewing threaded joints by 1.5-1.7 and 1.3-1.4 times in comparison with G-SKa 2/6-2 Grease and Lithol-24 respectively, therefore, reduces the coefficient of friction in threaded connections by the same amount. When examining the threaded part of fasteners after disassembling the joints pre-treated with the developed composition, traces of corrosion appear only after 720 hours, and in joints treated with G-SKA 2/6-2 Grease and Lithol-24 – after 96 hours. Production tests showed that the developed composition improves the disassembly of the threaded connection by 1.3-1.4 times in comparison with factory processing. The improvement of the protective properties of the composition with the addition of the D-10TM oligomer is explained by the fact that the D-10TM oligomer, having polar urethane groups in the chain and a high molecular weight, exhibits strong intermolecular interactions due to the formation of hydrogen bonds. Its three-dimensional spatial structure provides better filling of cracks and gaps in the threaded joint, seals them, isolates them from aggressive environments and thus provides better protection against corrosion.

1 Introduction

A design feature of modern agricultural and automotive equipment, as well as metal construction structures, is the presence of a huge variety of different connections: threaded, welding, riveting, soldering and other types [1]. In mechanical engineering and in the assembly of metal construction structures, threaded connections are more often used because they are quite reliable, have small dimensions, they are easy to assemble and disassemble, simple, provide high accuracy and control of the degree of tightening of the parts connection [2]. A threaded connection is a connection of two parts using a thread, in which one of the parts has an external thread and the other has an internal one [3]. Basically, studs, screws, bolts, nuts are used as fasteners.

In practice, almost all joints of parts can be considered as a slot or gap [4]. The formation

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of slots and gaps is also facilitated by operational factors: in folds and joints of sheet materials due to their vibration, between gasket materials and parts during loosening of fasteners tension, in film anti-corrosion and paint materials as a result of peeling from the substrate, international corrosion products, contamination of parts and metal, etc. [5]. Slots are formed when dust enters the surface of metals, fouling of structures with various technological residues or microorganisms [6] (Figure 1).

The size of slots and gaps in machine elements can change during their operation for various reasons: vibration, forces that are variable in magnitude, direction and nature of the impact, climatic conditions, etc.

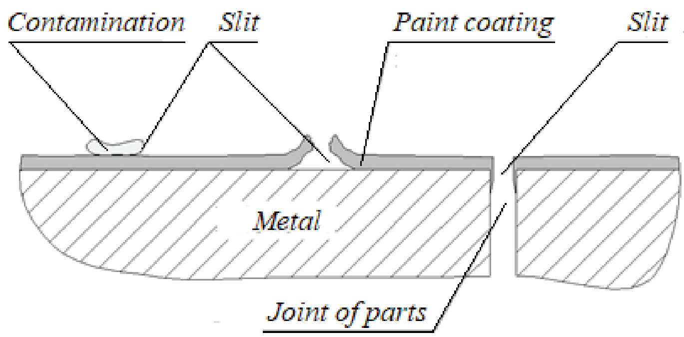

Fig. 1. Possible variants of formation of slits on the surface of metals.

Slots are formed in the thread of the bolt or nut itself (Figure 2), at the outer ends of the fasteners (Figure 3), in the threaded connection and joints of the elements to be joined (Figure 4), etc. [7].

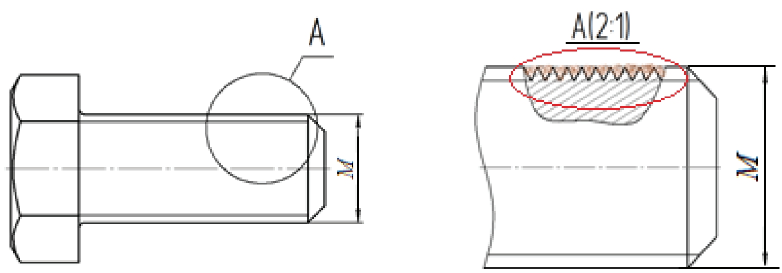

Fig. 2. Slots in the thread of the bolt.

Between the parts to be connected and in the threaded joint itself, there is always a slot or gap where increased capillary condensation of moisture occurs, various impurities are superimposed and slot corrosion develops. The drying of moisture in the slits compared to the open surface takes longer, so the corrosive processes in the slits are intense. Slit corrosion is hidden, making it difficult to detect and neutralize it in a timely manner. This results in significant metal losses and reduced mechanical strength of the machines [8].

Fig. 3. Slots and corrosion products at the outer ends of fasteners.

Protection of threaded connections against corrosion is possible by galvanizing fasteners and applying paint and varnish or other types of protective coatings to them [9]. However, galvanizing has some drawbacks - a high coefficient of friction of galvanized fasteners, which requires the use of special lubricants, and low environmental friendliness [9].

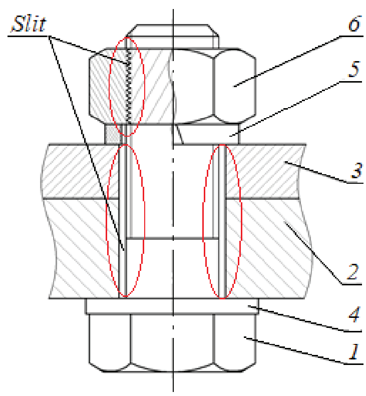

Fig. 4. Slots in the threaded connection and joints of the connected elements: 1 – bolt; 2, 3 – connected parts; 4 – flat washer; 5 – spring washer; 6 – nut.

As for protective coatings, water-based anti-corrosion compounds even having a slight negative charge, are repelled from the surface when they are sprayed onto steel products, because steel also has a negative electrode potential equal to $\varphi = -0.44$ V [10]. In particular, this phenomenon manifests itself on sharp edges of parts, and therefore the required thickness of the protective film is not provided on the thread, therefore, the effectiveness and duration of protection against corrosion of threaded joints using various coatings are limited [11]. It is possible to provide the required thickness of the protective film by inhibiting the corrosion medium by introducing appropriate organic or inorganic compounds into it to shift the potential of protective compounds to a more positive zone, which makes it possible to inhibit corrosion processes [12, 13].

Almost all adjustment work during maintenance and repair of machines involves the mutual relative movement of threaded connection parts, which is difficult due to the presence of corrosion in non-products. An increase in the resistance to twisting or unscrewing the parts of a threaded connection often causes poor-quality adjustment or failure to perform adjustment operations, which contributes to the operation of the machine in suboptimal modes and its premature failure.

To ensure the reliability of the threaded connection, it is necessary to provide the necessary tightening force. Otherwise, under the influence of various operational factors, the fasteners and the connection itself may fail. The required tightening force is provided by using a torque wrench adjusted to a certain tightening force. Part of the effort is spent on overcoming the friction force, the value of which is primarily affected by the presence or absence of corrosion products on the surface of the parts of the threaded connection. To reduce the friction force in a threaded connection, various lubricants are used that also perform protective functions, isolating fasteners from aggressive environmental influences, which improves the disassembly of the connection, if necessary, during the operation of machines.

Currently, the range of materials for lubricating threaded joints is quite wide: grease, Lithol, cleaners, dispersions, anti-friction coatings, pastes and others.

Unfortunately, in practice, threaded connections and their lubrication are not given sufficient attention or lubrication is used at random, not taking into account the working conditions and the characteristics of the threaded connection. For example, grease cannot be used to lubricate threaded joints operating at elevated temperatures, since already at a temperature of 80-85°C, it loses its lubricating properties (becomes liquid) [8].

In view of the foregoing, it would be more efficient to correctly select and apply the appropriate lubricant to the thread before assembly, which eliminates slots and gaps in the connection, sealing it, isolating it from an aggressive environment and thereby protecting it from corrosion.

During operation, as a result of interaction with aggressive components of the environment, threaded connections corrode and “stick”. For this reason, their disassembly may present certain difficulties, the thread may be destroyed, and the fastener itself may be destroyed, especially if the connection has not been previously treated with grease.

In connection with the foregoing, research related to the protection of threaded connections against corrosion is relevant and in demand in the agro-industrial and automotive industries.

The purpose of the study is to develop an effective composition for the protection of threaded connections from corrosion.

2 Materials and methods

The material for the manufacture of threaded fasteners for general purposes are low- and medium-carbon steels St3, St10, St20, St35, St45, etc., therefore, in the experiments, M10 fasteners with a thread pitch of 1.5 mm from St3 steel were used, connecting two products, as shown in Figure 4. The threaded connection was lubricated with the studied compositions and tightened to a certain tightening force (55 N·m) using "AIST" double-acting torque wrench which operates on the principle of a dynamometer, is a knob with a lever made of steel spring. A pointer arrow is fixed on the wrench, on the handle of the fastened valve, by which the moment of tightening or loosening force is determined (Figure 5). When the handle is loaded, the lever bends and the position of the pointer is shifted on a scale.

Fig. 5. "AIST" torque wrench.

G-SKa 2/6-2 Grease (Standard 1033-79); Litol-24 (Standard 21150-87); G-SKa 2/6-2 Grease + D-10TM oligomer 5% by weight; Litol-24 + D-10TM oligomer 5% by weight were studied as experimental compositions for processing threaded joints. D-10TM oligomer was dissolved in grease and Lithol at a temperature of 50°C by simple mixing for 5 minutes.

D-10TM oligomer was developed at the Cheboksary Cooperative Institute (branch) of the Russian University of Cooperation. It is a colorless or light yellow liquid, soluble in organic solvents and compatible with other types of monomers and oligomers, insoluble in water. The film does not change significantly during its storage in air for quite a long time.

During the experiments, the compounds (Figure 4) were labeled, treated with the appropriate experimental composition, and immersed in a corrosive environment, which was a 3% aqueous solution of sodium chloride, and kept in the solution for 8 hours. The solution was periodically stirred, and its temperature was maintained at 22-24°C. The compounds were then removed from the solution and left in air for 16 hours at room temperature. This was one cycle or 24 hours. The duration of exposure in accordance with Standard R 9.905-2007 was 24; 48; 96; 240; 480; 720 hours or 1, 2, 4, 10, 20, 30 cycles. The number of compounds in the experimental variants was 5 pieces, and the number of variants (the number of experimental compositions) was 4 (Table 1). After the corresponding cycle, the connections were disassembled using the torque wrench "AIST", while, at the direction of the arrow on the scale, the value of the force moment for unscrewing the threaded connection was fixed, knowing which, the value of the friction coefficient f in the threaded connections was calculated. For this, we used the expression [14]:

$$M_t = F\left(r_{av}\cdot\frac{tg\alpha+1.15f}{1-1.15f}+f\cdot\frac{R+r}{2}\right)\cdot 9.8\cdot 10^{-5},\ \text{N·m},$$

where M_t – is the torque for unscrewing the threaded pair, N·m;

r_{av} – is average thread radius, mm;

F – is the tensile force, N;

α – is thread helix angle, degree;

f – is the coefficient of friction in the thread and on the contact surface of the nut and washer;

R – is the outer radius of the surface between the nut and the washer, mm;

r – is the inner radius of the surface between the nut and the washer, mm.

After disassembling the connection the fastener threaded parts were examined for signs of corrosion.

The number of parallel experiments for each lubrication option was 5, the results of which were averaged.

3 Results and discussion

The results of laboratory studies of the studied lubricant compositions are shown in Table 1 and Figure 6.

Table 1. Results of laboratory studies of the compositions of lubricants.

№ Lubricant composition	**Lubricant composition**	**Experiment duration, h**	**Average values for 5 compounds**		**Presence of corrosion traces as per 5-point scale**
			torque for unscrewing the threaded connection, M_t, N·m	**coefficient of friction in a threaded connection, *f***	
1	2	3	4	5	6
№1	G-SKa 2/6-2 Grease	0	25.0	0.08	-
		24	30.3	0.10	-
		48	33.8	0.11	-
		96	42.4	0.14	1
		240	62.0	0.20	2
		480	83.1	0.27	3
		720	97.5	0.32	4
№2	Litol-24	0	25.0	0.08	-
		24	30.4	0.10	-
		48	30.2	0.10	-
		96	39.4	0.13	1
		240	54.5	0.18	1
		480	75.8	0.25	2
		720	88.5	0.29	3
№3	G-SKa 2/6-2 Grease + + D-10TM oligomer 5% by weight	0	25.0	0.08	-
		24	30.3	0.10	-
		48	30.3	0.10	-
		96	37.0	0.12	-
		240	48.5	0.16	1
		480	63.6	0.21	2
		720	73.0	0.24	2
№4	Litol-24 + + D-10TM oligomer 5% by weight	0	25.0	0.08	-
		24	30.2	0.10	-
		48	30.3	0.10	-
		96	33.8	0.11	-
		240	42.4	0.14	-
		480	52.3	0.17	-
		720	62.0	0.19	1

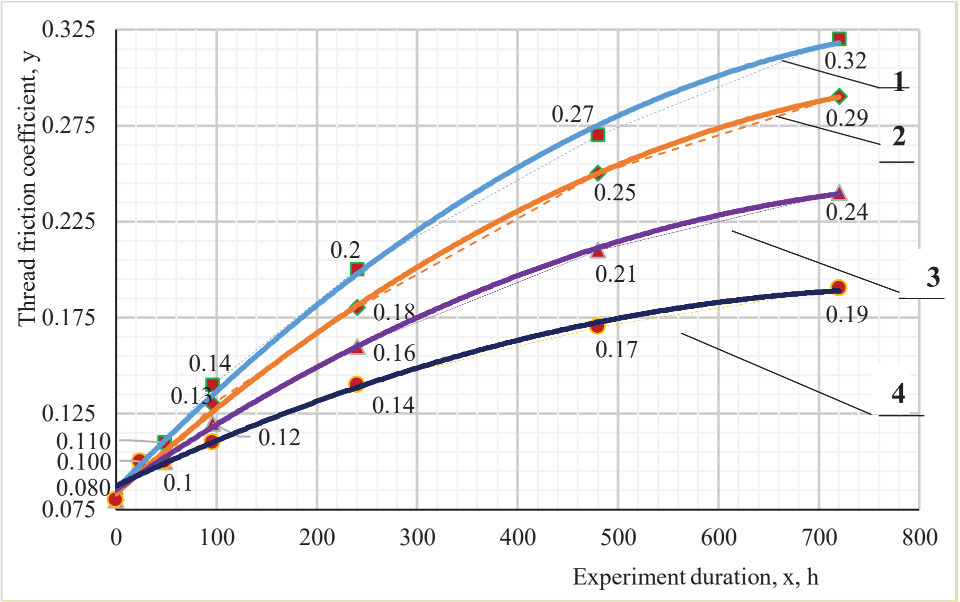

Fig. 6. Dependence of the friction coefficient in a threaded connection on the duration of experiments by type of lubricant: 1 – G-SKa 2/6-2 Grease; 2 – Litol-24; 3 – G-SKa 2/6-2 Grease + D-10TM oligomer 5% by weight; 4 – Litol-24 + D-10TM oligomer 5% by weight.

As can be seen from Table 1 and Figure 6, grease No. 4 better protects the threaded connection from corrosion. With an increase of the experiment duration up to 720 hours, the values of the friction coefficient in threaded joints treated with compositions No. 1 and No. 2 increase intensively from 0.08 to 0.32 and 0.29, respectively, in joints with composition No. 3, an intensive increase in the friction coefficient takes place up to 480 hours, then the boost process levels off. In joints with composition No. 4, a gradual slight increase in the value of the friction coefficient is observed, which is explained by the absence of corrosion traces in the threaded part of the joints. When examining the threaded part of the fasteners after disassembling the joints with lubricant No. 4, the first slight traces of corrosion were detected only after 720 hours of experiments, when in joints treated with compounds No. 1, No. 2 and No. 3, already after 96 and 240 hours, respectively.

In comparison with compositions No. 1 and No. 2, when using composition No. 4, the moments of force for unscrewing threaded connections are reduced by 1.5-1.7 and 1.3-1.4 times respectively, therefore, the friction coefficients in threaded connections.

Corrosive wear in the threaded part of the bolt shaft reduces its strength, which can lead to its destruction when unscrewing the nut with a large torque [15].

The improvement in the protective properties of compositions No. 3 and No. 4 can be explained by the fact that D-10TM oligomer, having polar urethane groups in the chain and a high molecular weight, exhibits strong intermolecular interactions due to the formation of hydrogen bonds [11]. Its three-dimensional spatial structure provides better filling slots and gaps in the connection, seals them, isolates them from aggressive environments and thus provides better protection against corrosion.

The atmosphere of the premises of livestock complexes is characterized by the content of corrosive gases of high concentration, high humidity and poor air circulation, which contributes to the corrosion of threaded joints and the formation of corrosion products in them [16, 17]. For this reason, in the machines and technological equipment of livestock complexes during their operation, the number of hard-to-disassemble and non-disassembled threaded connections increases, and easily disassembled - decreases, and production tests of composition No. 4 were carried out in the atmosphere of a livestock complex, which confirmed the results of laboratory experiments.

The studies were carried out on two KTU-10 feeders manufactured in 2015 and 2017, operated and maintained in identical conditions. On the feeder produced in 2015 threaded connections in the amount of 48 units were disassembled, treated with composition No. 4 and assembled. On the feeder produced in 2017 the threaded connections were left with factory processing. Every 12 months of operation 12 identical threaded connections of both feeders were checked for the presence of traces of corrosion and the degree of disassembly, the results of which are shown in table 2.

Table 2. Characteristics of threaded connections depending on the processing and duration of KTU-10 feeders operation.

Duration of operation, months	**Presence of corrosion traces as per 5-point scale**		**Disassembly of threaded connections, %**					
			easily disassembled		**difficult-to-disassemble**		**non-disassembled**	
	Factory processing	Processing with composition No. 4	Factory processing	Processing with composition No. 4	Factory processing	Processing with composition No. 4	Factory processing	Processing with composition No. 4
12	1	-	90	100	1	-	-	-
24	2	-	80	90	10	10	10	-
36	4	1	60	80	20	20	20	-
48	5	1	30	60	40	30	30	10

The degree of disassembly of the threaded connection was determined as follows:

– easily disassembled – the threaded connection is disassembled with a simple wrench without additional wetting with a special compound (WD-40 penetrating spray, hydrogen peroxide, etc.);

– difficult-to-disassemble – to disassemble the threaded connection, additional wetting with a special compound is required, after which the threaded pair is disassembled with a simple wrench;

– non-disassembled – the threaded connection is not disassembled after additional wetting with a special compound.

From the data in Table 2 it can be seen that with an increase of operation duration of KTU-10 feeders the number of difficult-to-disassemble and non-disassembled threaded connections increases and the number of easily disassembled ones decreases. At the same time, the corrosion protection of threaded connections treated with composition No. 4 is higher than that of threaded connections with factory processing. This gives the reason to recommend this composition for the treatment of threaded connections in order to protect them from corrosion and facilitate disassembly after long-term operation in a corrosive environment.

4 Conclusion

Based on the research carried out it can be argued that:

1) threaded connections must be treated with a special lubricant before assembly, preferably using the composition we offer Litol-24 + D-10TM oligomer 5% by weight;

2) when choosing a lubricant, it is necessary to take into account the working conditions and features of the threaded connection;

3) threaded connections from the outside must be treated with protective or paint coatings that isolate them from the environment;

4) the part of the bolt protruding from the nut should not exceed 1-2 thread turns.

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