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Investigations of friction-relevant parameters to ensure reliable bolted joints

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Abstract. During the process of torque-controlled tightening of bolted joints, the reliability of load transmission is limited by the achieved accurate preload. The preload is mainly influenced by head- and thread friction. The knowledge of reliable coefficients of friction and the dependence on assembly parameters are essential. Although a variety of friction coefficients were published but the overall ranges ask for more precision. So called windows of friction coefficients are available in known guidelines, to define permissible scattering. However, there are practical doubts about useful friction coefficients, especially if newly developed lubricants, corrosion-resistant coatings and securing devices against bolt-loosening are used. In this study, different parameters of a bolted joint connection, such as lubrication, the surface protection of the screw connection or used security systems, have been investigated on their frictional influence. To make a reliable conclusion about the coefficients of friction, only a measured examination like DIN EN ISO 16047:2013-01 can help. By means of a designed test bench those values could be detected by measurement and supplemented with the collected data of vibration test results at the TH Köln. On this way practically useful coefficients of friction and their scattering have been made available.

1 Introduction – Task of the investigations

High duty bolted joints are tightened torque-controlled in most of all cases. Both the thread flanks as well as the head bearing areas are subject to sliding friction. In the elastic deformation range and under constant friction conditions between the tightening torque T and the produced preload F_V exists a linear relationship.

The tightening torque T is composed of the head friction moment T_b. and the thread torque T_{th}. The thread torque T_{th} is required for obtaining the assembly preload F as well as for overcoming the friction forces at the thread flanks (fig.1).

As shown in fig. 2 the generated preload is substantially dependent on the friction in the bearing areas of the thread and the head. Usually about 85% of the tightening torque T is used to overcome the friction forces and only a small amount is left for generating the assembly preload F.

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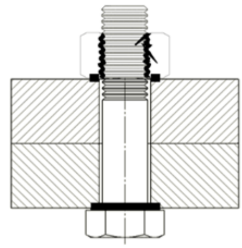
$$T = \overbrace{T_{th,P} + T_{th,F}}^{T_{th}} + T_b = F_V \cdot \left[\frac{P}{2 \cdot \pi} + \frac{d_2}{2 \cdot \cos\left(\frac{\alpha}{2}\right)} \cdot \mu_{th} + \frac{D_b}{2} \cdot \mu_b \right] \quad (1)$$

$$T_{th,P} = F_V \cdot \frac{d_2}{2} \cdot \tan(\varphi)$$

$$T_{th,F} = F_V \cdot \frac{d_2}{2} \cdot \tan(\rho_{th})$$

$$T_b = F_V \cdot \frac{D_b}{2} \cdot \mu_b$$



$T_{th,P}$ [Nm] thread pitch torque
$T_{th,F}$ [Nm] thread friction torque
T_{th} [Nm] thread tourque
T_b [Nm] head friction torque

Fig. 1. Relations between assembly preload F_V and tightening torque T.

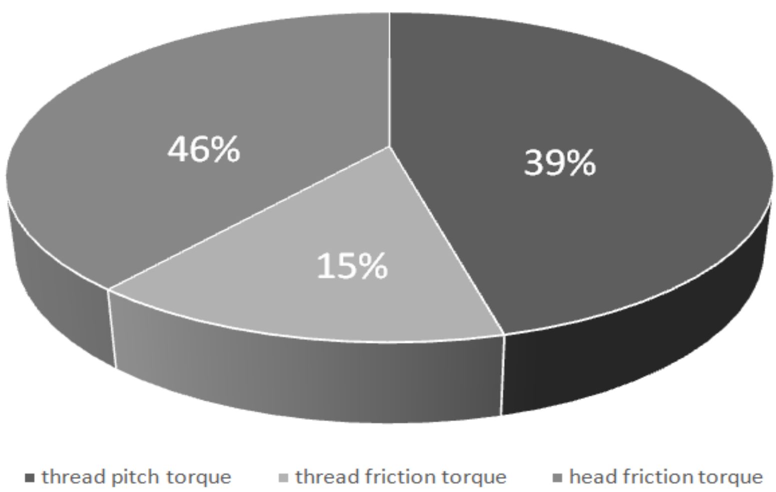


Fig. 2. Typical components of torque generating the preload, thread friction torque and head friction torque (example: hex. bolt ISO 4017, M12 – 8.8, T = 83 Nm; F_V= 43 kN μ_{tot}= μ_{th}= μ_b= 0,12).

The accurate preload is the essential factor for reliable load transmission of high duty bolted joints. In practice the preload is not measurable. Therefore, the preload is only adjustable indirectly via the torque. The friction coefficients in the thread and head contact areas are uncertain quantities. As the following chart fig. 3 shows different preloads are achieved with a determined tightening torque. With a low coefficient of friction which is lower than the value adopted for the mounting, the bolt can be broken or overstressed. Therefore minimal possible friction values for the calculation of the tightening torques according to VDI 2230 [1] should be used. If the actual coefficient of friction is too high, the required minimum assembly preload is not achieved. For this reasons, the knowledge of actual range of the friction coefficients taking into account the impact parameter is of vital importance for the durability of the bolt connection.

This paper deals with the evaluation of an extensive data pool of TH Köln [2-3], as well as specific parameters investigated with the testing apparatus for determination of coefficients of friction between threads and head bearing surfaces [4]. The result shows a differentiated picture of the friction effect of different parameters for different bolt connections.

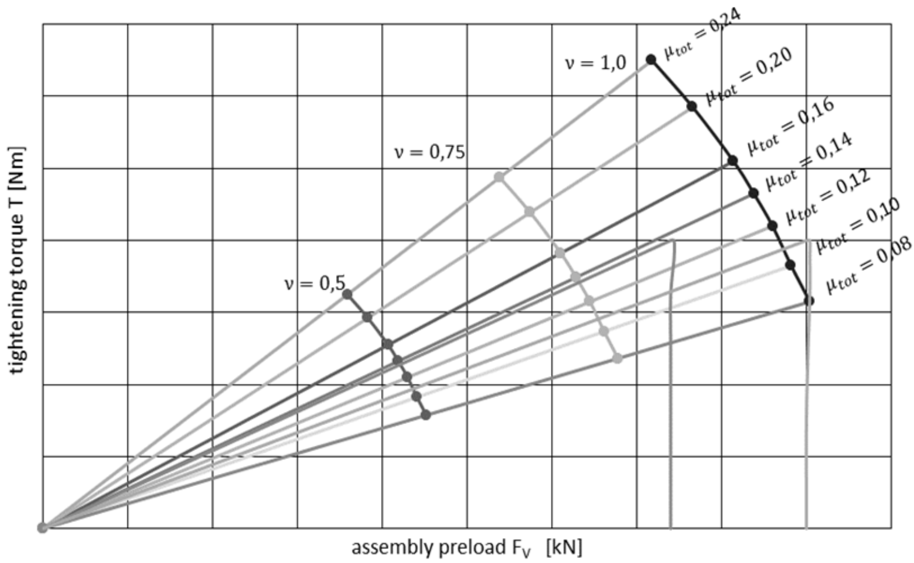


Fig. 3. Effect of different coefficients of friction on the assembly preload F_V at a determined tightening torque T.

2 Testing apparatus for determining coefficients of friction between threads and head bearing surfaces

In order to describe the general friction conditions without regarding shape and dimension of the connecting elements, it is expedient to determine the different coefficients of friction such as thread friction and head friction. The standard method for determining these coefficients of friction is described in the standard DIN EN ISO 16047 [5].

The measurements required are relatively complex because of the need of sensors for the tightening force and at least two different torques. If all data are measured in one setting, the device is very expensive.

The test rig designed at the TH Köln is far less costly [4]. The values are determined in three steps:

1. Experimental determination of the total coefficient of friction: μ_{tot}.
2. Experimental of thread friction μ_{th} (the head friction is isolated by use of an axially acting antifriction bearing).
3. Evaluation of head friction coefficients μ_b using the values of steps no. 1 and 2 and equation (2).

$$\mu_b = \frac{\frac{T}{F_V \cdot d} - 0{,}0222 - 0{,}528 \cdot \mu_{th}}{0{,}668} \qquad (2)$$

The design of the device as shown in fig. 4 complies to the requirements of DIN EN ISO 16047. The mating test parts and the test standard conditions corresponds to this

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standard. The test bolt is inserted through a replaceable, hardened test washer and connected with the test nut. The test nut is secured by a milled groove against rotation. The installed axial cylindrical roller bearing beneath the removable test washer allows separate consideration between the thread and the total friction of the examined bolt assembly.

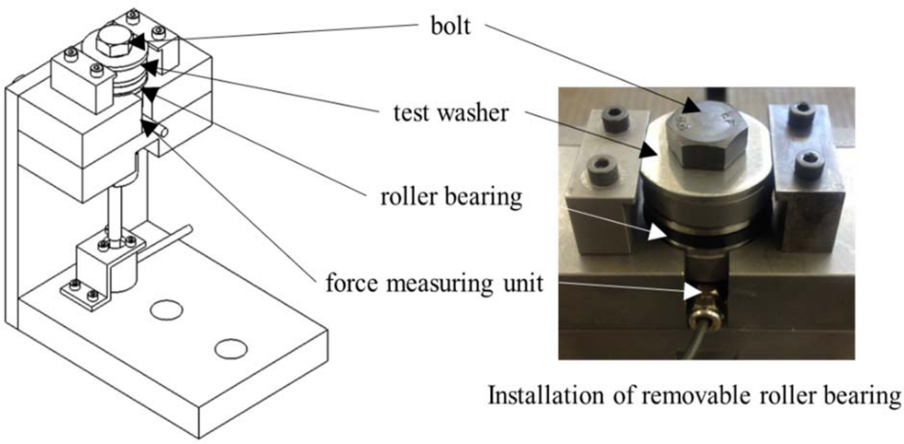

Fig. 4. Test apparatus.

3 Experimental results

The following friction-relevant parameters were isolated during preceding studies: lubricants, corrosion preventing coatings and a choice of securing elements. Table 1 shows the selected test conditions.

Table 1. Test conditions.

bolt	ISO 4017 M12 x 70 – 8.8
nut	ISO 4032 M12 – 8, bright
assembly load	100 % (F=42,3 kN)
lubricants	varies
coatings	varies
securing elements	varies

3.1 Parameter study: lubricants

The examined lubricants described are typically used for the assembly of bolted joints in the industry. The coating of all bolts was black oxide. Nuts were in bright condition.

ENGINE OIL HD 30

Conventional heavy dutyoil for passenger cars without additives, SAE viscosity grade 30.This oil is applied with a brush on the fasteners. In the test series of this lubrication state it is described by the term "lightly oiled".

VOLER AC

The non-soap grease paste is mixed with additives of aluminium particles, which are intended to compensate for the unevenness of the mounting surface. Thus the influence of friction is lower. The paste is able to prevent contact corrosion even at high surface pressures.

GLEITMO 805®

The high-performance grease paste is based on mineral oil with a synergistic effective combination of active-reaction white solid lubricants (means various inorganic compounds in the form of smooth, soft powders).

MOLYKOTE 1000®

This lubricant is on molybdenum disulfide base. It belongs to the group of fatty pastes. It consists of highly concentrated solid lubricants in oil, which can easily be applied with a brush.

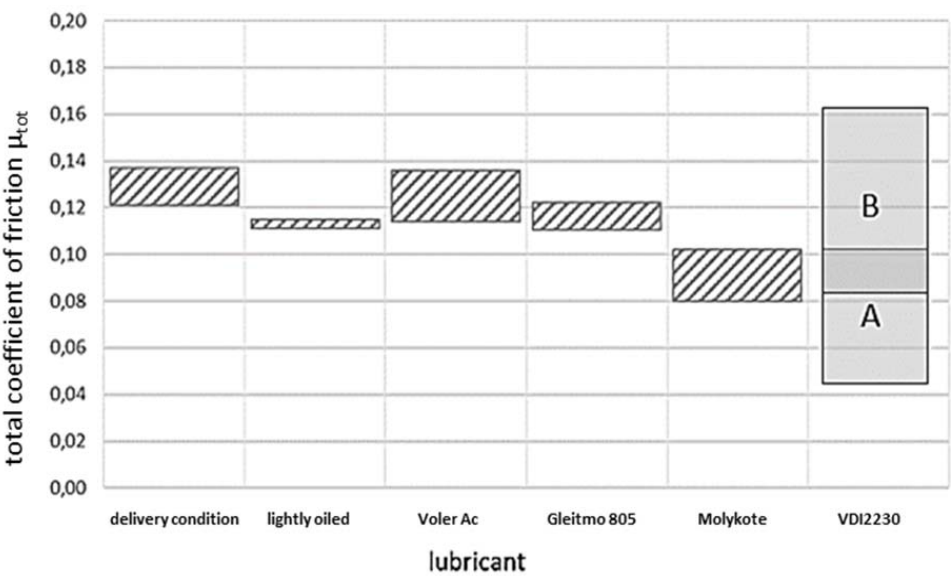

Fig. 5. Experimentally determined total friction coefficients μ_{tot} depending on the examined lubricants.

SUMMARY OF THE EXPERIMENTAL RESULTS

By applying a lubricant to the connecting elements lower friction factors are generally achieved. It can be stated that the friction coefficient classes A (0,04 to 0,10) and B (0,08 to 0,16) of VDI 2230-1: 2014-12 [1]as well as the VDA-standard 235-101 [6] (0,09 to 0,14) cover a very large range. It can be observed that some lubricants are found on the top, while others are found at the lower limit of this classes.

3.2 Parameter study: corrosion preventing coatings

Typically in the industry used corrosion preventing coatings were examined. Contribution was made to the fact that in automotive industry only CrVI-free coatings are allowed by EU-acts. During these examinations all interacting surfaces were lightly oiled with engine oil HD30.

BLACK OXIDE

Blackening or "black oxide" is one of the non-metallic surface coatings. The thin, oil-carbonaceous branded oxide leaves a dense surface film in oiled condition. The connecting members have sufficient corrosion protection mainly for transport and storage purposes.

EOMET 321 A +VL

The coating is a chromium-free thin dry-film non-electrolytic corrosion protection system. It consists of passivated zinc and aluminium flakes in a water-based binder. The topcoat +VL ensures low friction. Designation according to DIN EN ISO 10683: flZnnc - 480 h – L.

DELTA PROTEKT

It is a micro-layer corrosion layer system. The base coat is a layer having a high content of zinc and aluminum flakes embedded in a resin-free matrix. The resin-free structure of the layer ensures the electrical conductivity and thus the cathodic remote protective layer and is therefore essential for the corrosion protection. As topcoat organic layers, inorganic sealants or lubricants are used. Designation according to DIN EN ISO 10683: flZnnc - 480 h.

DARCOMET 500 B

The coating is non-electrolytic. It contains zinc and aluminium flakes in a chromium binder and integral lubrication. PTFE in the basecoat is used to ensure consistent torque-tension characteristics without a supplemental sealer. Designation according to DIN EN ISO 10683: flZnycL - 720 h.

ELECTROGALVANIZATION

Electrogalvanized bolts are often used alternatively to blackening. The steel is immersed in an aqueous bath and electricity is used to move electrons from the anode to the cathode which induces the zinc anodes to be "oxidized" and dissolve as zinc ions in the aqueous solution, to be transported as ions through the solution and to be "reduced" as metal onto the work (the cathode).

SUMMARY OF THE EXPERIMENTAL RESULTS

The use of different corrosion preventing coatings combined with light lubricated bolts has no influence on the total friction coefficients without regard to electrogalvanized bolts. It is known that electrogalvanized bolts have the tendency to fret because the pressure between the mating surfaces is high. For different coatings it can be stated that the friction coefficients are approximately in the center of friction class B (0,08 to 0,16) of VDI 2230-1: 2014-12 as well of the VDA-standard 235-101 (0,09 to 0,14)

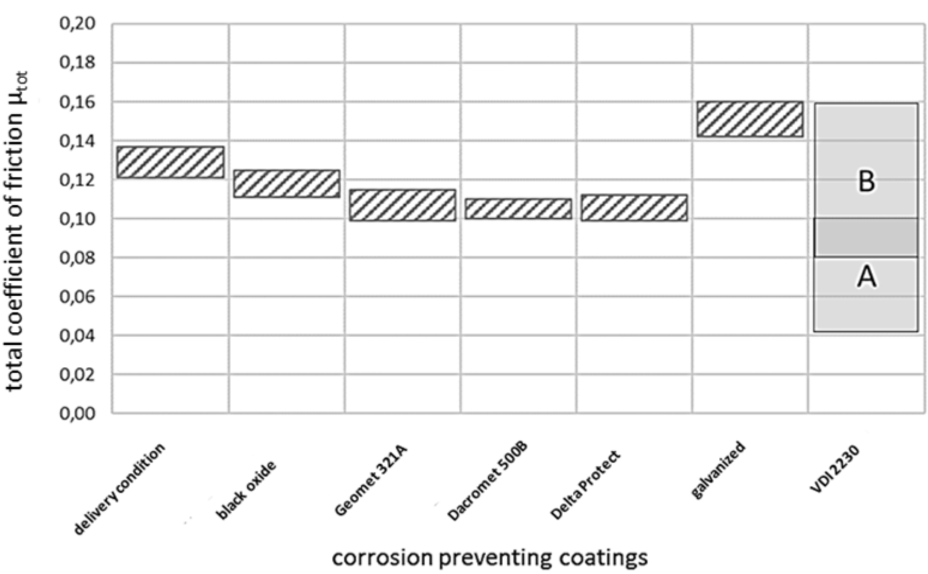

Fig. 6. Experimentally determined total friction coefficients μ_{ges} depending on the examined coatings.

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3.3 Parameter study: securing elements

A variety of common securing elements were examined. The locking effect of the investigated elements against loosening is based on the principles of frictional connection and form closure. The shape of the various security elements, for example profiled surface and wedge effect is specific to increase the frictional connection in the head or nut [7].

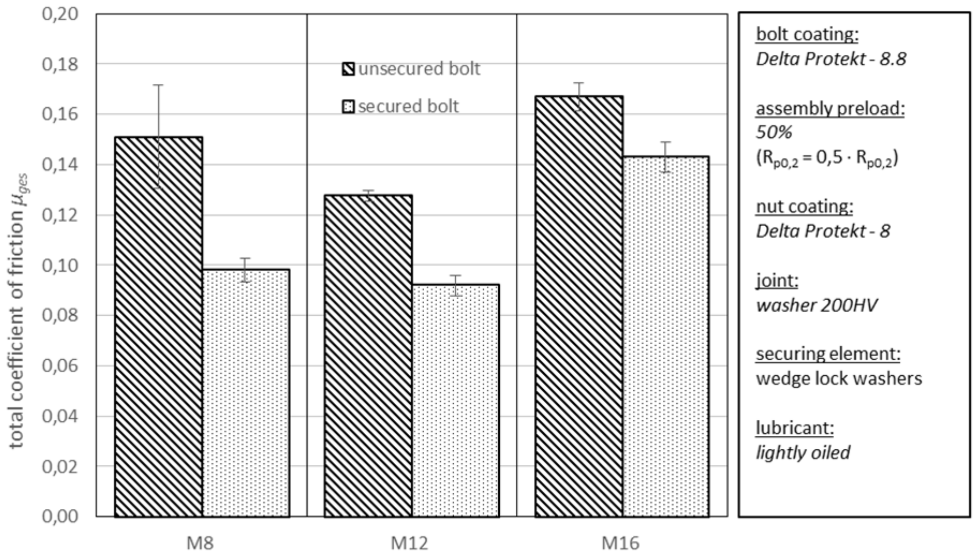

Fig. 7. Experimentally determined total friction coefficients μ_{ges} for unsecured bolts and secured bolts with wedge lock washers.

SUMMARY OF THE EXPERIMENTAL RESULTS

When elements to prevent loosening by rotation as wedge lock washers for example are used, the friction moment may increase. In this case the coefficient of total friction increases significantly, as shown in fig. 7. The results for the various sizes show that the coefficient of friction at small sizes increases more than at larger sizes. In fact attention has to be payed to the increasing total friction if any securing elements are used.

During the study experience has shown that the amount of lubricant applied by each user depends. This may also lead to deviations of the respective friction conditions. For this reason tests were performed on the reproducibility of the results.

3.4 Comments to the measurement results

The data collected with the friction apparatus compare quite well with those obtained on the vibration test rig which covers measurements over some years. For example the test range for a hexagon bolt ISO 4017 M12 x 45 -8.8 with the surface coating "Black oxide" in lubrication condition "Molykote" provides a deviation of the total friction coefficient μ_{tot} of about 5%. Using wedge lock washers with surface coating "Delta Protekt" and lubrication condition "lightly oiled" the deviation of the total friction coefficient μ_{tot} is about 7%. It should be noted that with increasing assembly load the friction decreases. This is about 10% from 25 % of full load.

4 Conclusions

For a safe design of bolted joints an orientation on the friction classes of VDA and VDI standards is not sufficient in each case. The investigations which relate to both experiments and on data pools collected over years at the TH Köln show the wide range of the parameters, in particular of types of lubricants, which cover the values from one window to the other. Even if the evaluated friction coefficients are more in class B than in class A, it must nevertheless be noted that the class B covers a range of 1:2. That results in a relationship of preload F_V of more than 1:0,9 and a range of assembly torque T of 1:1.6, if the preload is limited by the tensile strength. E. g. bolts M12-8.8: F= 45,2 kN to 40,7 kN, T = 63 Nm to 102 Nm. Conclusions are that bolts with a higher coefficient of friction shall be designed with a lower preload. Then a higher assembly torque has to been taken into account. Therefore measurements for determining correct friction coefficients are essential optimizing the design of bolted connections and the required assembly data.

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