

# SÚRLÓDÁS VÁLTOZÁSA CSAVARKÖTÉSSEN TÖBBSZÖRI MEGHÚZÁS ESETÉN

## FRICITION VARIATION IN A BOLTED JOINT DURING CYCLIC TIGHTENING

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**ABSTRACT** This paper deals with the influence of cyclic tightening/loosening on the generated preload in a bolted joint. Black surface finished bolts and nuts of grades 10.9 and 8 are used in three diameter sizes. Four lubrication cases were considered. The torque-tension experimental data are presented and discussed.

### 1. INTRODUCTION

Threaded fasteners are widely used in various mechanical and industrial applications, with the primary function of clamping two or more components together with easy assembly/disassembly functionality. Generating the bolt clamping force is usually made by torquing the bolts to a specified torque value, which is a broad and commonly used way due to its simplicity of operation. For a typical bolted joint, when the surfaces in the joint are aligned, and the prevailing torque is absent (e.g., nut that has rotation resistance in tightening and unscrewing, ex.: the presence of a plastic insert) [1], Motosh equation [2] shows that three main reaction torque resist the input torque to the turning head in the bolted joint as follow:

$$T_{input} = T_{pitch} + T_{Underhead} + T_{Thread} \quad (1)$$

Only the pitch torque ( $T_{pitch}$ ) causes the bolt to stretch and produce the clamping force. At the same time, the  $T_{Underhead}$  and  $T_{Threads}$  are the torque consumed to overcome the frictional resistance at the underhead and threads contact area, respectively. Another representation for the torque-tension relationship, according to the DIN EN ISO 16047[3] standard, can be given in equations (2) and (3). Equation (2) is a theoretical expression based on the bolted joint geometrical and frictional parameters at the level of the threads and under the turning head. On the other hand, Equation (3) is an empirical expression

based on the bolt nominal diameter  $D$  and the experimentally measured *torque coefficient*  $K$ , also called the “*nut factor*”. Here,  $K$  is a dimensionless constant that combines the influence of all the variables that affect the preload ( $F$ ), even those not defined or complicated to quantify.

$$T = F \left( \frac{1}{2} \cdot \frac{P+1,154 \cdot \pi \cdot \mu_{th} \cdot d_2}{\pi-1,154 \cdot \mu_{th} \cdot \frac{P}{d_2}} + \mu_b \cdot \frac{D_o+d_h}{4} \right) \quad (2)$$

$$T = K \cdot F \cdot D \quad (3)$$

Equation (3) has a straightforward format and is simple to apply since it uses standardized measurable data. That is why several studies in the literature used this approach [4][5] [6]. In industrial applications is advised to replace a fastener once dismantled for safety reasons [7]. However, in engineering practice, the fasteners are widely reused in some applications due to their particular design (ex.: wheel bolts) or the lack of fasteners with certain material specifications. A previous study [8] reported the effect of retightening of M22x1.5 black finish wheel bolt resulting in up to 70% preload reduction after the third tightening when the nut is degreased. Another research [9] made on electro-zinc plated M12x1.75 fasteners reported doubling the friction coefficient after the ten retightening cycles. This paper focuses on how the bolt-generated preload behaves under the cyclic tightening/ un-tightening process on the same bolt, tested with different bolt diameter sizes, under different lubrication conditions.

### 2. EXPERIMENTAL SETUP AND PRELOAD MEASUREMENT

The torquing experiments were performed on black surface finish bolts. Three sizes were utilized: M6, M8, and M10 of grade 10.9, with a mating nut of grade 8. For each size, 80 new bolts/nuts are divided into groups of twenty assigned for four lubrication cases.

The lubrication conditions are the following: as is, dry, solid molybdenum disulphide powder ( $\text{MoS}_2$ ), and engine motor oil. The as is represents the out-of-the-box state: usually, the bolts are coated with a rust preventative lubricant. For the remaining three conditions, the bolts and nuts are cleaned using Loctite SF 7061 to have a surface free of lubricant or contamination, and this represents the second case dry condition. A thin layer of the solid  $\text{MoS}_2$  powder was applied for the third one. For the last one, a few drops of 15W-40 oil were applied. For the third and fourth cases, lubrication was added to the bolt threads and the underhead surface of the turning head (the nut) only before the first tightening. Figure 1 illustrates the preparation of the lubrication cases and the experimental procedure.

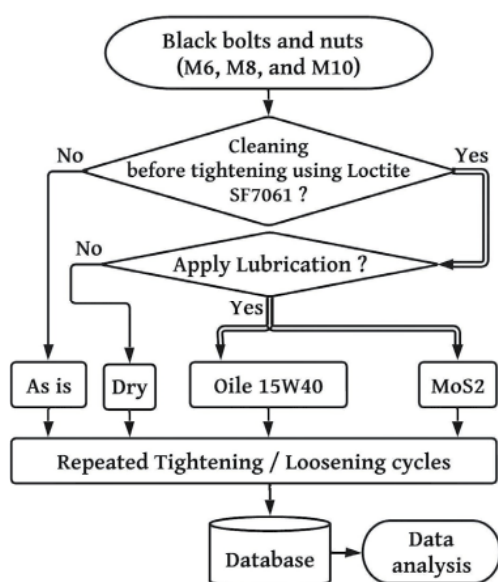


Figure 1. Experimental procedure diagram

The measurements and the data collection were realized the same as in previous work [10]. Two torque control methods were used. A torque wrench was used for tightening the nut to a specific torque based on the bolt size. After tightening, a strain gauge with a data acquisition system was used to measure and record the peak force generated in the bolt; then, the nut was released. This process forms one cycle, which was repeated 20 times for each bolt under the same torque value. A total of 240 bolts were used in the experiments. Table 1 summarizes the geometrical and technical information and the calculated parameters for the tested bolts.

Table 1. Tested bolt specifications

Size	M6	M8	M10
Torque (N.m)	10	20	40
$d_1$ (mm)	5.188	7.188	9.188
$d_2$ (mm)	9.75	10.75	11.75
Metric thread profile angle, $\beta$ (°)	60	60	60
computed angle $\rho'$ (°)	6.587		
Thread lead angle $\alpha$ (°)	4.386	3.168	3.168
Thread pitch (mm)	1.25	1.25	1.25
grade	Bolt	10.9	
	Nut	8	

### 3. RESULTS

#### 3.1. Generated preload

For the first tightening cycle, the influence of the lubrication presence on the generated preload is plotted in Figure 2, where each point on the graph represents a mean of twenty measurements. As can be seen, even though the tightening torque is the same for each diameter, the initially achieved preload is different. There is a similarity in the lubrication performance in the case of M10 and M6, such that the achieved preload order based on the lubrication type from the lowest to the highest value was: dry, as is, oiled, then  $\text{MoS}_2$ . Note that for the M8 size, the as is performance was better than when the oiled film was applied. This can be related to the amount and the type of rust preventative lubricant applied in the bolt factory.

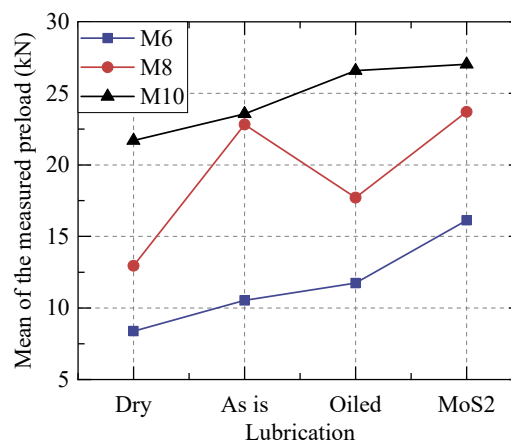


Figure 2. First tightening measured preload mean vs. lubrication types

Figure 3 shows the behaviour of the generated preload during the twenty tightening replications for the three bolt diameters under four lubrication states. The following remarks can be made:

1. The dry lubrication state gives the lowest achieved preload, with the least scattering in the measured data. So it is not good practice to clean the fastener before tightening.

- The performance of the as is lubrication is similar to the oiled one, and this can be linked to that at the bolt factory the black bolt is coated with rust preventing oil for storage purposes.
- MoS<sub>2</sub> gives the highest initial preload, but also the highest scatter (wider box and longer whisker line) in the measured data.
- Applying oil film gives the best preload performance in the function of the number of tightenings. Two slopes can be identified in the curve: the preload increases up to the fifth cycle, then it is stabilized.

Table 2 summarizes the maximum and the minimum of the generated preload mean. The smallest preload mean range for the M6 and M10 was when the lubrication condition was MoS<sub>2</sub>, while for the M8, this case was the dry one.

### 3.2. Nut factor

The overall interaction between the input tightening torque and the generated preload in the bolt can be investigated by computing the nut factor using equation (4) for every individual tightening process for all bolts during the repeated tightening cycles. After that, the nut factor's mean for the tightening cycles is given by equation (5). The nut factor is inversely related to the generated preload: a higher nut factor indicates poor bolting performance and vice versa.

$$K = \frac{T_{input D}}{D * F_{Measured}} \quad (4)$$

$$K_{Mean R} = \frac{\sum_{B=1}^N T_{input D}}{D * F_{Measured B}} \quad (5)$$

In the equations,  $K$  is the nut factor.  $K_{Mean R}$  represents the mean of the nut factor for repetition  $R=1, 2, 3 \dots 20$ .  $B$  is the bolt number,  $N=20$  is the total number of tested bolts for each case, and  $D$  is the bolt nominal diameter.  $T_{input, D}$  indicates the input tightening torque for the nominal diameter, and  $F_{Measured B}$  is the experimentally measured preload. Figure 4 represents the summary of the nut factor mean grouped by different lubrication conditions. It can be seen that:

- For dry case, the nut factor range is high and more dispersed. This can be related to the increased wear and tear of the contact surfaces (poor contact surface quality), which consumes more torque and lowers the preload value.

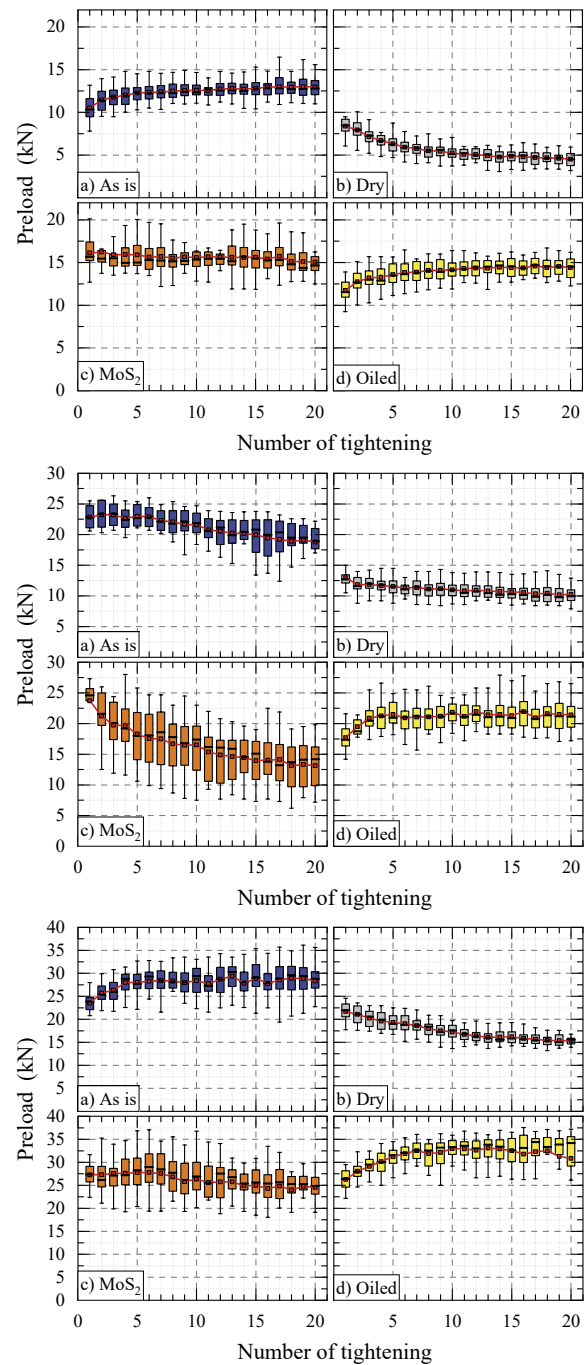


Figure 3. Box plot of the generated preload for the bolt diameter: I) M6, II) M8, and III) M10

Table 2. Range of preload

	Lubrication	As is	Dry	MoS <sub>2</sub>	Oiled
M6	Max	13	9.38	16.24	14.60
	Min	10.53	4.52	15.06	11.74
	Range	2.47	3.86	<b>1.18</b>	2.86
M8	Max	23.2	13.0	23.7	22.0
	Min	18.8	10.2	13.1	17.7
	Range	4.5	<b>2.8</b>	10.6	4.3
M10	Max	29.38	21.71	28.76	34.13
	Min	23.58	15.36	24.73	26.58
	Range	5.80	6.35	<b>4.03</b>	7.55

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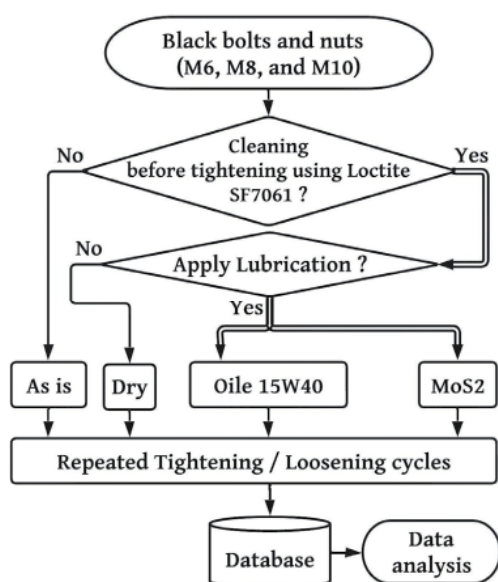


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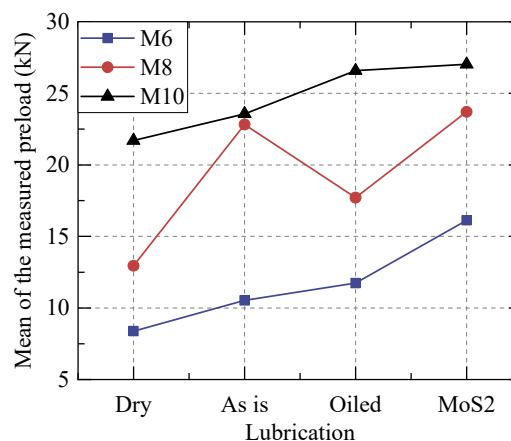


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