CSAVARKÖTÉS SÚRLÓDÁSI TÉNYEZŐ VÁLTOZÁSA TÖBBSZÖRI MEGHÚZÁS ESETÉN

NUT FACTOR VARIATION OF A BOLTED JOINT IN CYCLIC TIGHTENING

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ABSTRACT

This paper deals with the repeated tightening of the bolted joint. Black surface finished bolts and nuts of grades 10.9 and 8 are used in three different diameter sizes. Four lubrication cases were considered. The torque-preload experimental data are presented and discussed. The generated preload is compared to the result of various torque-tension relationship computations

1. INTRODUCTION

When the joint surfaces are aligned, and the prevailing torque is absent (e.g., nut that has a plastic insert) [1], Motosh [2] the input torque to the turning head in the bolted joint can be divided into three main components:

$$T_{input} = T_{Pitch} + T_{Underhead} + T_{Threa} \qquad (1)$$

Only the pitch torque (T_{pitch}) causes the stress in the bolt, while the $T_{Underhead}$ and $T_{Threads}$ are the torque consumed to overcome the friction at the underhead and threads contact area, respectively. According to the DIN EN ISO 16047[3] standard, the relationship between the input torque and the generated preload in the bolt can be given with the following equations:

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

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

Equation (2) is a theoretical expression obtained from the engineering principle that deals with the bolt 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 with the advantage of including the influence of all the variables that affect the preload (F), even those not defined or complicated to be quantified. 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][7][8][9]. For safety concerns, it is recommended to replace a fastener once dismantled [10]. However, from engineering practice, in some applications the fasteners are widely reused due to their particular design (ex.: wheel bolts) or the lack of fastener with certain material specifications.

A previous study [11] reported the effect of retightening of M22x1.5 black finish wheel bolt resulted in up to 70% preload reduction after the third tightening when the nut is degreased. Another research [12] 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/ untightening process on the same bolt, tested with different bolt diameter size, under different lubrication conditions.

2. EXPERIMENTAL SETUP AND PRELOAD MEASUREMENT

The experiments are carried out on bolts with black surface finish. Three sizes were employed: M6, M8, and M10, with a mating nut. The grade of the bolts is 10.9, and the mating nut is 8. For examining the generated preload under four lubrication conditions, 80 new bolts/nuts were used for each size. The bolts are divided into four groups of twenty assigned for each lubrication type.

The lubrication conditions are the following: as is, dry, solid molybdenum disulphide powder (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 MoS_2 powder was applied for the third one. For the last condition, drops of 15W-40 oil were applied. For the third and fourth conditions, 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 condition and the experimental procedure.

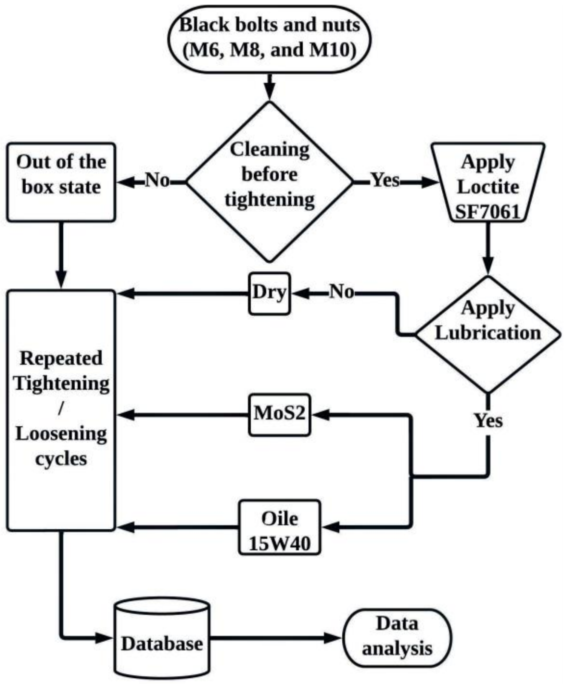

Figure 1. Experimental flow diagram

The measurements and the data collection were realized the same as in previous work [13]. A torque wrench was used for tightening the bolt to a specific torque based on the bolt size. After tightening, a data acquisition system was used to measure and record the peak bolt force, then the bolt 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 for the experiments. Table 1 summarizes the geometrical and technical information and the calculated parameters for the tested bolts.

3. RESULTS

3.1. Generated preload

The measured data for the first tightening are summarized in Table 2. For each diameter, the effect of the lubrication state influences the initially generated preload even though the tightening torque is the same. The lubrication performance order from highest to lowest value of the achieved preload was: the MoS_2, the as is, the oiled, then the dry state lubrication for the M6 and M10. 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 the rust preventative lubricant applied in the bolt factory.

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, β (°)		60	60	60
computed angle ρ' (°)		6.587		
Thread lead angle α (°)		4.386	3.168	3.168
Thread pitch (mm)		1.25	1.25	1.25
grade	Bolt	10.9		
	Nut	8		

Table 2. First tightening measured preload and calculated nut factor

	Measured preload (kN)			Calculated nut factor		
Lubriction	M6	M8	M10	M6	M8	M10
As is	10.53	22.83	23.57	0.162	0.110	0.171
Dry	8.38	12.95	21.71	0.201	0.197	0.186
MoS_2	16.13	23.71	27.03	0.105	0.109	0.149
Oiled	11.74	17.71	26.58	0.143	0.143	0.151

The box plot Figure 2 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. There was a similarity in the preload trends between the as is and the oiled lubrication, which can be related to the presence of protection oil film used to prevent the black bolt from rusting during the storage.
2. MoS_2 gives the highest initial preload, but also the highest scatter (wider box and longer whisker line) in the measured data.
3. 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.
4. Even though the mean of the bolt preload for the dry condition is the lowest among the tightening repetitions, the scattering is the least.

Table 3 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 MoS2, while for the M8, this case was the dry one.

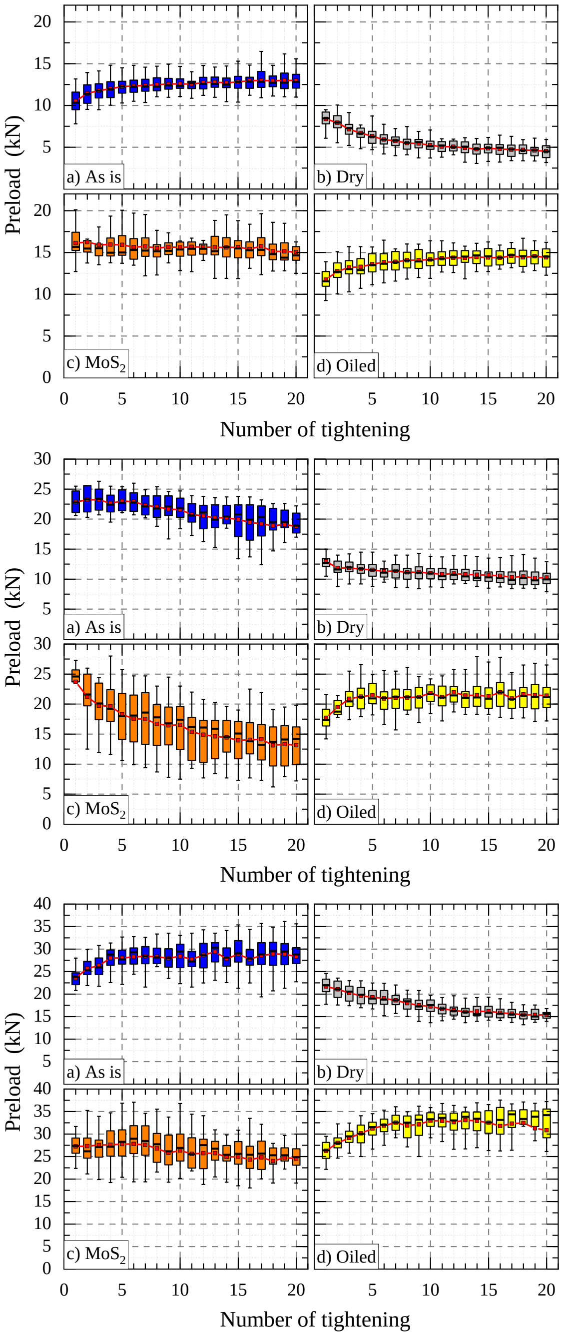

Figure 2. Box plot of the generated preload for the bolt diameter: I) M6, II) M8, and III) M10 under lubrication conditions: a) as is, b) dry, c) MoS_2, d) oiled

Table 3. Range of preload

	Lubrication	As is	Dry	MoS_2	Oiled
M6	Max	13	9.38	16.24	14.60
	Min	10.53	4.52	15.06	11.74
	Range	2.47	3.86	**1.18**	2.86
M8	Max	23.2	13.0	23.7	22.0
	Min	18.8	10.2	13.1	17.7
	Range	4.5	**2.8**	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	**4.03**	7.55

3.2. Nut factor

The overall interaction between the input tightening torque and the generated preload in the bolt can be investigated to compute the nut factor using equation (4). During the repeated tightening cycles, the nut factor was computed for every individual tightening process for all bolts. 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.

$$K = \frac{T_{input_D}}{D * F_{Measured}} \tag{4}$$

$$K_{Mean_R} = \frac{\sum_{B=1}^{N} \frac{T_{input_D}}{D * F_{Measured_B}}}{N} \tag{5}$$

In the equations, K is the nut factor. $K_{Mean\ R}$ represents the mean of the nut factor for repetition $R=1,2,3 \ldots 20$. B is the bolt number, $N=20$ is the total number of tested bolts for each case, D represents 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.

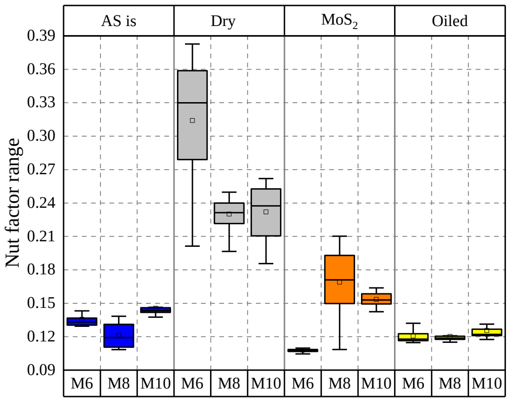

Figure 3. Nut factor range through the twenty tightening repetitions.

Figure 3 represents the summary of the nut factor mean grouped by different lubrication conditions. It can be seen that:

1. Between different lubrication conditions, there is a similarity in the bolting performance for the case of as is and oiled lubrication even though the tightening torque and the diameter differ.
2. The nut factor shows a good agreement during repetitive tightening for the three diameters in case of oiled lubrication, which can be due to a uniform friction coefficient state at both level threads and under the turning head, i.e., contact surfaces more likely polished (good contact surface quality).
3. For the dry case, the gradually increasing nut factor can be explained due to the gradually increased wear and tear of the contact surfaces (poor contact surface quality), which consumes more torque and lowers the preload value.

4. CONCLUSION

The nut factor was used for evaluating the generated preload in three different diameter sizes under different lubrication conditions. This method gives the ability to compute the overall bolting performance without considering many variables which are complex and costly to measure. The type and presence of lubrication film at the contact surfaces matter for enhancing the surface contact quality. This stabilizes the preload during the repeated tightening /release cycles. Recycling bolts without lubrication, even using the same manufacturer-prescribed tightening torque, will not reproduce the same preload.

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