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EXPERIMENTAL INVESTIGATION OF PRELOADED BOLTED CONNECTIONS

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Abstract: The results of the experiments confirms that the torque-force graphs are made of passive and active sections. If we could determine a generalizable relation between the two sections, which would enable the programming of screwdriving machines in mass production in such a way that, based on the measured torque and considering passive resistances, a defined torque or angle could be applied to reduce the scatter of preload forces.

KEYWORDS: bolt connection, preload, measurement

1 Introduction

In mass production, tightening of the preloaded bolted connections are based on torque. In some cases, the torque is also combined with, or replaced by, angle control, which is referred as „angle tightening”.

This paper examines the properties of bolted joints, particularly the initial passive resistances and their individual determinability based on torque. In a previous study [5], it was concluded that the extreme combination of components within the tolerance range may result in either a „loose” or a „tight” joint. In such cases, applying the specified tightening torque may lead to an over-tightening or to insufficient preload force. If the effects of oil and cleaning agents are also considered, it can be stated that their presence increases the risk of over-tightening. Therefore, the present study investigates in more detail the effect of geometric tolerances on bolted joints [1, 2, 3, 4].

2 Measurements

2.1 Assembling the measurement:

The measurement setup can be seen below (see Figure 2).

The theoretical setup can be seen on Figure 1 and the measurement in real life can be seen on Figure 2. This was the setup I used to model pre-tensioning with a screwdriver machine. Next, I will describe the measurement process and the results in details.

The threaded sleeves (6) were fixed in clamping sleeve to which a Hottinger Baldwin Messtechnik T4WA type 200 Nm torque transducer (1) was attached. The screws (8) were connected to the threaded sleeves via hardened washers (2) with a hardness of HRC 63 ±1 and through a 100 kN load cell (9) of type HBM-H103410. The hardened washers eliminated deformation of the clamped parts, ensuring that only the force generated in the screw was measured The socket wrench (10) was driven via a gearbox (3) and a drive motor (4), also through a Hottinger Baldwin Messtechnik T4WA type 200 Nm torque transducer (1).

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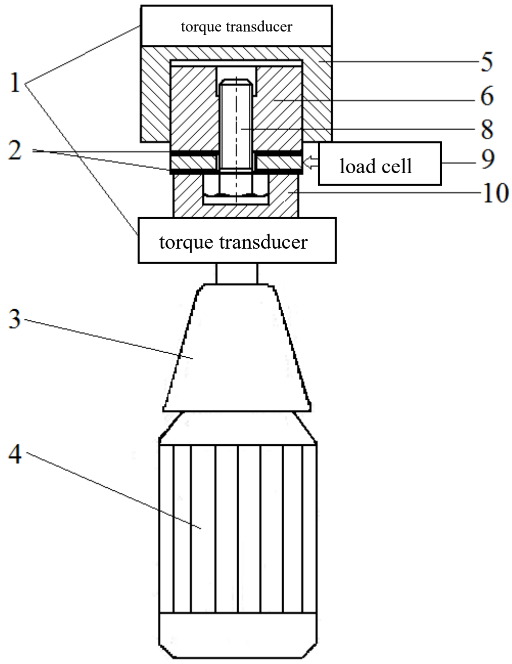

Fig. 1 Theoretical setup

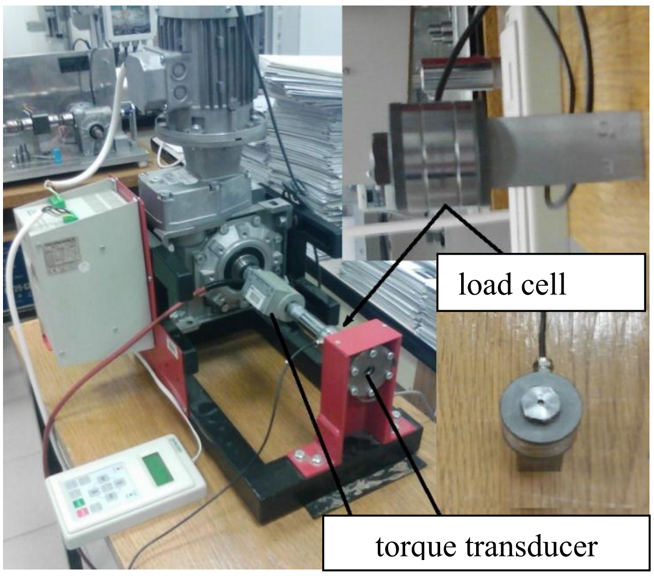

Fig. 2 Real measurement

For the measurements, screws and threaded sleeves (see Figure 2) were manufactured within commonly used metric thread ranges. The dimensions were selected according to the lower limit (A), the middle value (C) and the upper limit (E) of the tolerance field (see Table 1).

- Index “A” refers to components manufactured to the lower limit of the tolerance field.
- Index “C” refers to components manufactured to the nominal middle value.
- Index “E” refers to components manufactured to the upper limit of the tolerance field.

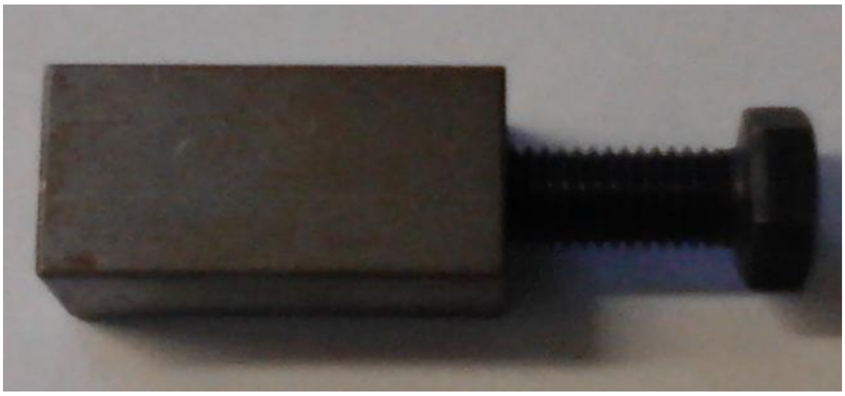

Fig. 2 Threaded sleeve – screw

Table 1 The screw-nut combinations and their dimensions

Size	Tightening torque
M20-6H/M20-6g	191,25 Nm
M20x2-6H/M20x2-6g	212,50 Nm
M20x1,5-6H/M20x1,5-6g	231,25 Nm
M20x1-6H/M20x1-6g	242,50 Nm
M16-6H/M16-6g	95,00 Nm
M16x1,5-6H/M16x1,5-6g	101,25 Nm
M16x1-6H/M16x1-6g	107,50 Nm
M12-6H/M12-6g	38,50 Nm
M12x1,5-6H/M12x1,5-6g	42,00 Nm
M12x1-6H/M12x1-6g	45,00 Nm
M10-6H/M10-6g	22,25 Nm
M10x1-6H/M10x1-6g	23,75 Nm
M8-6H/M8-6g	11,25 Nm
M8x1-6H/M8x1-6g	12,25 Nm
M6-6H/M6-6g	4,95 Nm

3 Results of the measurement

3.1 Characteristics

Preloading was performed for all possible combinations. Based on the measurement results, torque–force diagrams were constructed.

After performing the measurements according to the above-mentioned combinations, torque-force diagrams can be created from the results.

Next, I will describe one of these created diagrams from in order to examine its characteristics.

The diagram (see Figure 3) shows that both the tightening torque curve and the preload force curve consist of an initial nonlinear section followed by an approximately linear section.

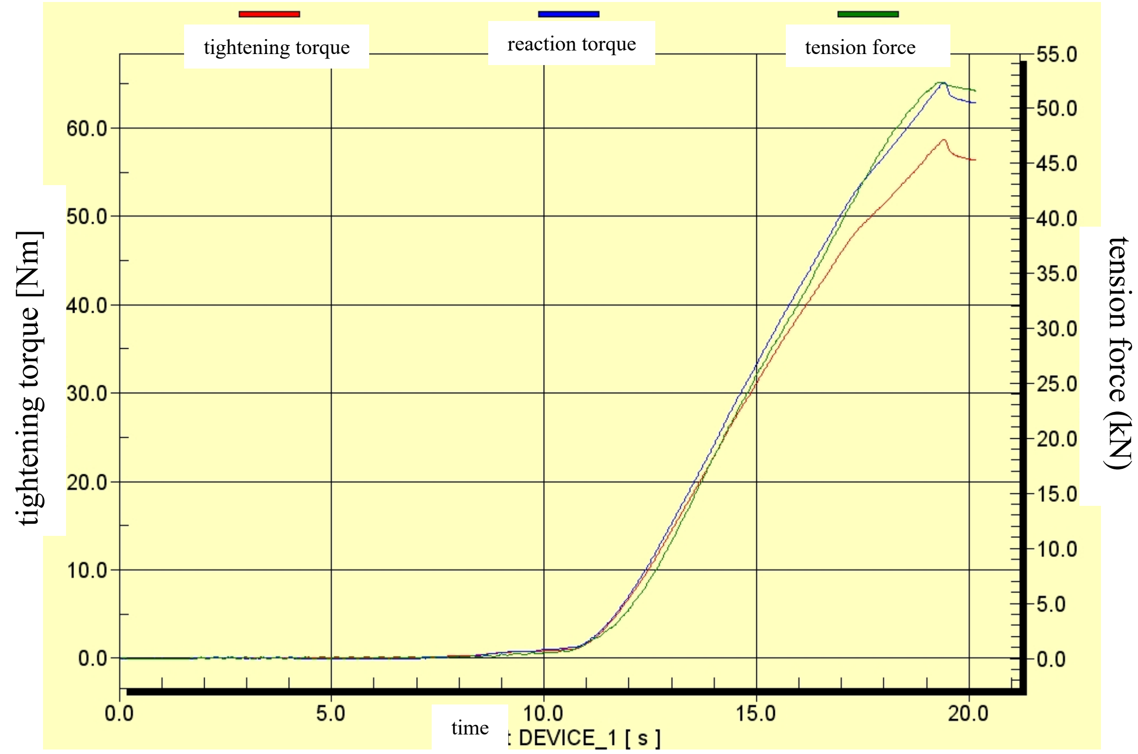

Fig. 3 Diagram 1: (Nm), tension force (kN), (Nm) curves

3.2 Repeated measurements

Repeated measurements were carried out for the same combinations, meaning that identical preloads were measured twice for each combinations. Since the material combinations surface roughness, surface treatments, and lubrication were kept constant, friction was primarily influenced by the resulting fit. Consequently, the frictional behaviour was essentially determined by geometric tolerances. Diagram 2 (see Figure 4) shows the preloads of the first and second measurements of the M10 and M10x1 bolted joints of the same size.

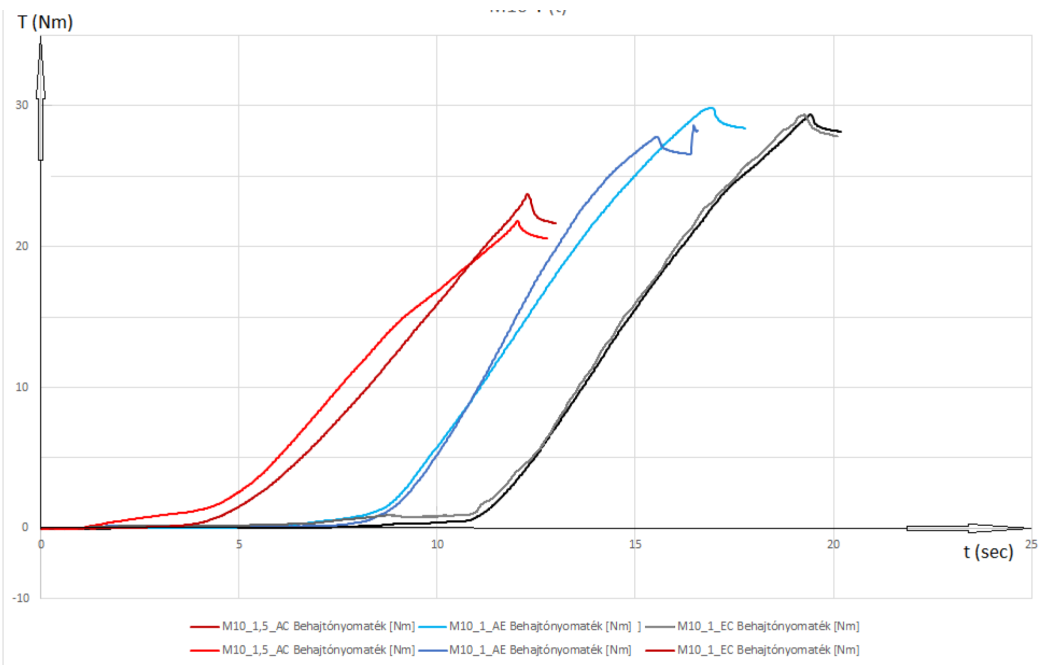

Fig. 4 Diagram 2: Tightening torque (t) curves

The results show that the preload curves corresponding to identical geometries are nearly coincident. As the second measurement did not differ significantly from the first, it can be concluded that identical geometries result in identical friction conditions within the bolted joint.

3.2 Interpretation of measurement results

The force curves of M12, M12x1.5, and M12x1 bolted joints as a function of tightening torque show the actual preloading process. (Diagram 3 – see Fig. 5). When the force curve begins to increase steeply as a function of torque, the tightening torque starts to elongate the screw. This phase can be described by a linear function.

It is evident that different combinations exhibit different slopes in the linear (active) section. In mass production, the same tightening torque is typically applied; however, due to these differences in slope, the resulting preload forces vary.

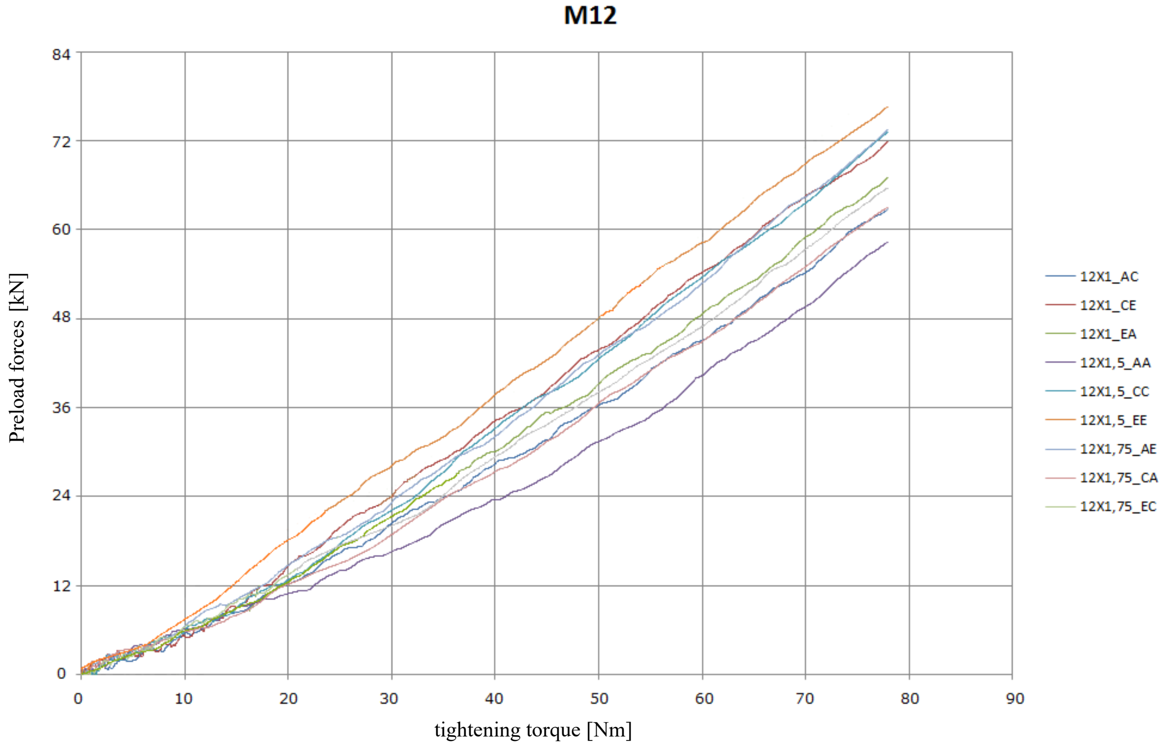

Fig. 5 Diagram 3: Preload forces as a function of tightening torques

If the initial section of the torque–force diagram (the passive phase) is compared with the linear active phase, it can be observed that different passive phases correspond to different active phases. This is illustrated in diagram 4 (see Figure 6).

Conclusions

It can be stated that if the slope of the active section of the torque–force curve were known for a given bolted joint, the tightening torque required to generate a specific preload force could be determined accurately.

The objective of further research is to establish a generalizable relationship between the passive and active phases of the torque–force curve, enabling its application during the assembly of preloaded bolted joints in industrial practice.

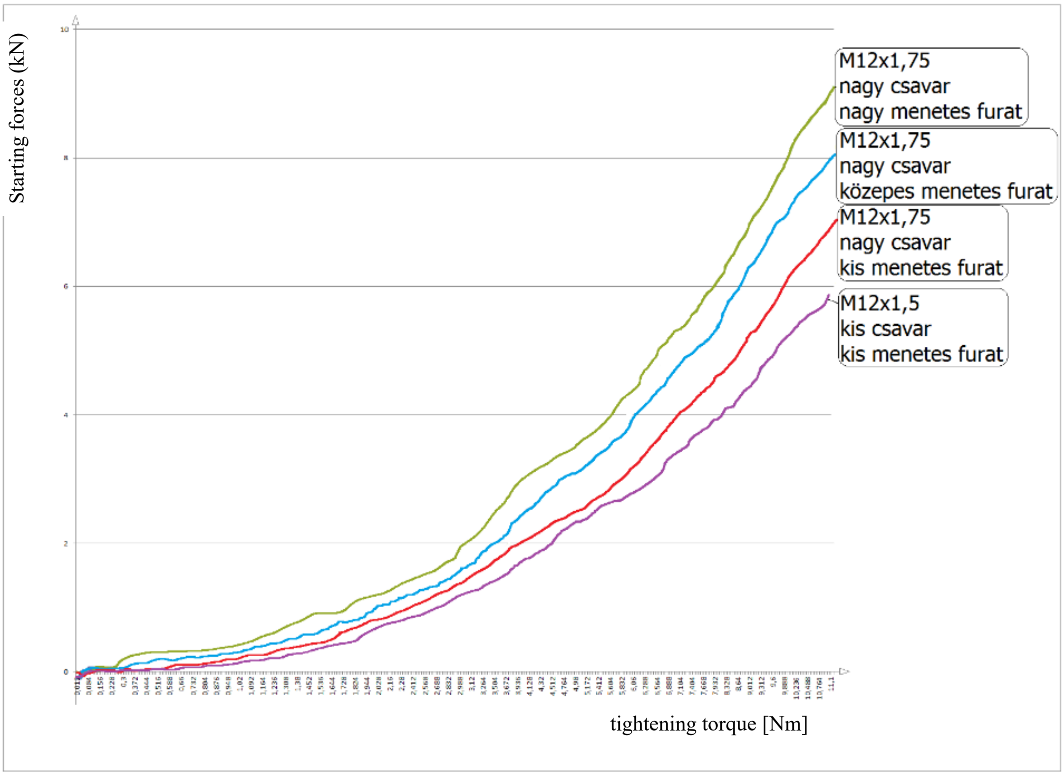

Fig. 6 Diagram 4: as a function of tightening torques (initial section)

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