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Experimental Evaluation of a Prestressed Bolt Connection Mounting Prestress

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Abstract: In this work, a stress on the surface of a planetary gearbox ring gears caused by tightening screws of prestressed bolt connection was measured. The measurement design was based on the prestressed bolt connection theory using 120 Ω strain gauges and the measured stress values were than compared with adequate values from FEM analysis. The measurement was repeated for various tightening torques.

Keywords: Strain Gauge; Prestressed Bolt Connection; Mounting Prestress.

1 Introduction

Although the theory of prestressed bolt connections based on a stress respectively deformation of connected components and a bolt is well known and is also supported by theoretical FEM analyses, there is one parameter (thread friction factor), which can be chosen and its unsuitable choice may negatively affects the prestressed bolt connection calculation.

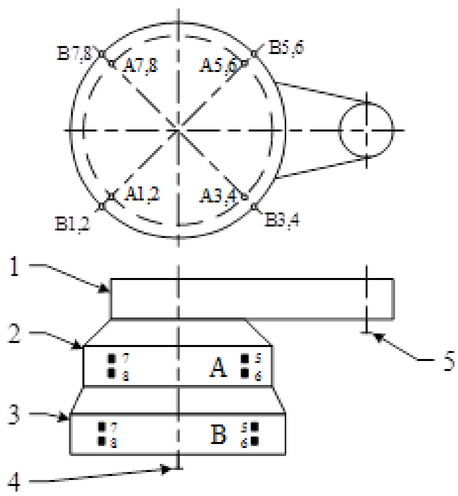

Fig. 1: Scheme of the gearbox with position of strain gauges. 1. Three stage helical gearbox with first planetary gearbox, 2. Second planetary gearbox, 3. Third planetary gearbox, 4. Output shaft, 5. Input shaft.

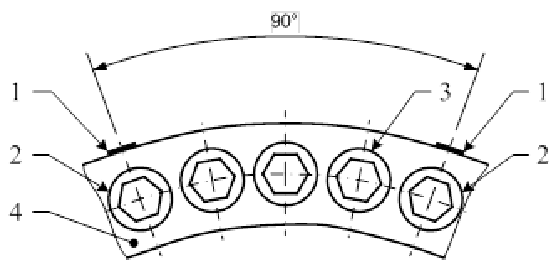

Fig. 2: Position of the strain gauges on the gearbox flange. 1. Strain gauges, 2. Measured screws, 3. Neighbouring screws/screws array between the measured screws, 4. Gearbox flange.

The Fig. 1 shows a scheme of a three stage helical gearbox with a three stage planetary gearbox of the gear ratio i≈ 7500. Just because of the fact that relative motions between helical gearbox and the second planetary gearbox and between second and third planetary gearboxes were obtained the evaluation of the prestressed bolt connections calculation and its parameters was needed. For this purpose a measurement of a surface stress using strain gauges placed on the gearbox flanges (see Fig. 1 and Fig. 2) was performed.

2 Theory

Prestressed bolt connections are mostly represented bolts tightened to a relatively large axial force Q_0 (a mounting prestress; ca. 60 % of an allowable tensile load) using a tightening torque. The mounting prestress provides a necessary force bond of contact surfaces of connected components so the connection seems to be a one compact part.

The theory of prestressed bolt connections gives us known formula for calculating the tightening torque defined as

$$T_T = Q_0 \frac{d_2}{2} \tan\left(\gamma + f'\right) \tag{1}$$

where T_T is tightening torque, Q_0 is mounting prestress, d_2 is effective thread diameter, γ is lead angle and f' is thread friction factor [1].

In our case, the prestress bolts must prevent relative motions between connected flanges respectively connected gearboxes. Therefore must apply

$$T = \sum_i Q_{0i} \cdot f \cdot r \tag{2}$$

where T is output gearbox torque, f is friction factor between the gearbox flanges, r is a pitch diameter of a screw array and Q_{0i} is mounting prestress of one screw.

By modifying the Eq. (2) and substituting into the Eq. (1) we obtain

$$T_T = \frac{T}{n\, f\, r} \frac{d_2}{2} \tan\left(\gamma + f'\right) \tag{3}$$

where n is number of screws. Can be seen that the value of the tightening torque depends not only on the screw geometry, which is given, but also on the thread friction factor f' and on the friction factor between the gearbox flanges f, which can be chosen and, as it was written in the chapter introduction, its unsuitable chosen cause inaccuracy of the calculation.

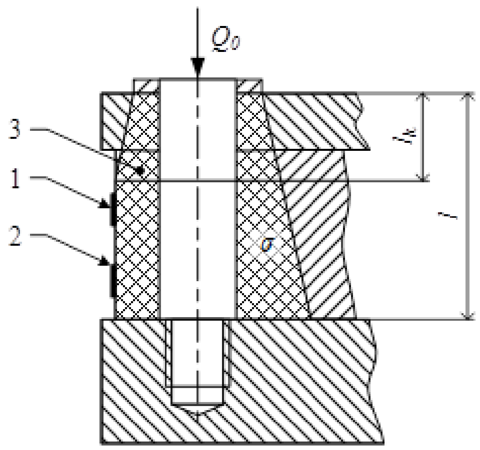

Fig. 3: Stress distribution of the prestressed bolt connection. 1. First strain gauge placement, 2. Second strain gauge placement, 3. Stress distribution – truncated cone.

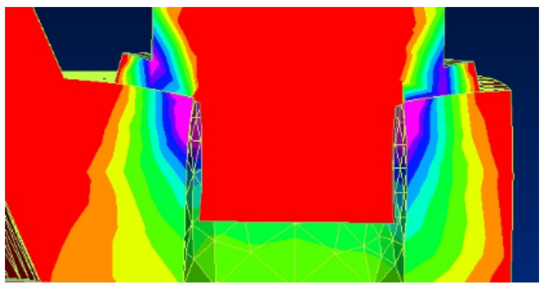

Fig. 4: FEM analysis of the prestressed bolt connection stress distribution.

In Fig. 3 there can be seen a stress distribution under a screw head of the prestressed bolt connection. According to the theory of the prestressed bolt connection, the stress distribution in material under the head of bolt has a shape of a truncated cone. It can be seen that at a distance l_k measured from the head of screw a stress can be easily estimated so it was chosen as a place, where a strain gauge could be placed to measure a deformation respectively a surface stress.

3 Measurement

The measurement of the surface stress was carried out using standard 120 Ω strain gauges [2]. According to the Fig. 1, 16 strain gauges were placed on the surface of the second and third planetary gearbox. It means 4 measuring points with 2 strain gauges.

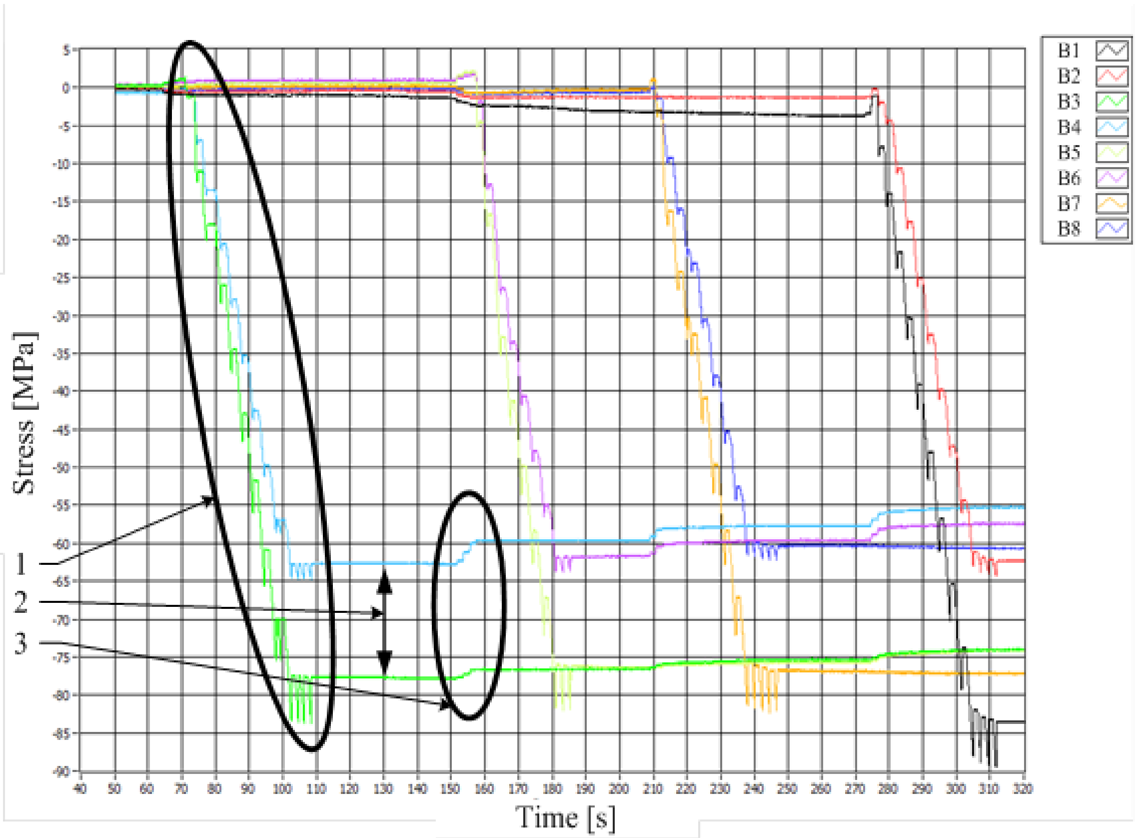

Fig. 5: Surface stress changes during tightening the third planetary gearbox screws.

In the Fig. 5 there is the measurement of the surface stress changes during the tightening the screws of the third planetary gearbox. On the presented lines (see Fig. 5, section 1) can be seen that the tightening of the screws is not straight but small steps can be obtained there. These steps are caused by using pulse tool to tighten the screws. After the tightening the screws (see Fig. 5, section 2) there are seen differences between the maximal reached stress values at one measuring point for all strain gauges (B1/B2, B3/B4, B5/B6 and B7/B8). This phenomenon is caused by the positioning of the strain gauges and by the stress distribution under the screw head as it was described in the chapter Theory.

Another interesting phenomenon (see Fig. 5, section 3) can be seen when the first screw was tightened and the tightening of the second screw began. There can be seen significantly stress drops which can show us interaction between the screws. The same drops can also be observed when the third and fourth screws get tightened.

Fig. 6 shows changes of the surface stress when the screws array of the second planetary gearbox was tightened. In first section of the measurement (0 - ca. 300 s) can be seen tightening of the four measured screws. The phenomena of the stress drops described above can be seen too. At the time ca 300 s, where the tightening of the screws array began, are shown significant increasing of the stress, which are caused by the tightening the screws close to the measured points.

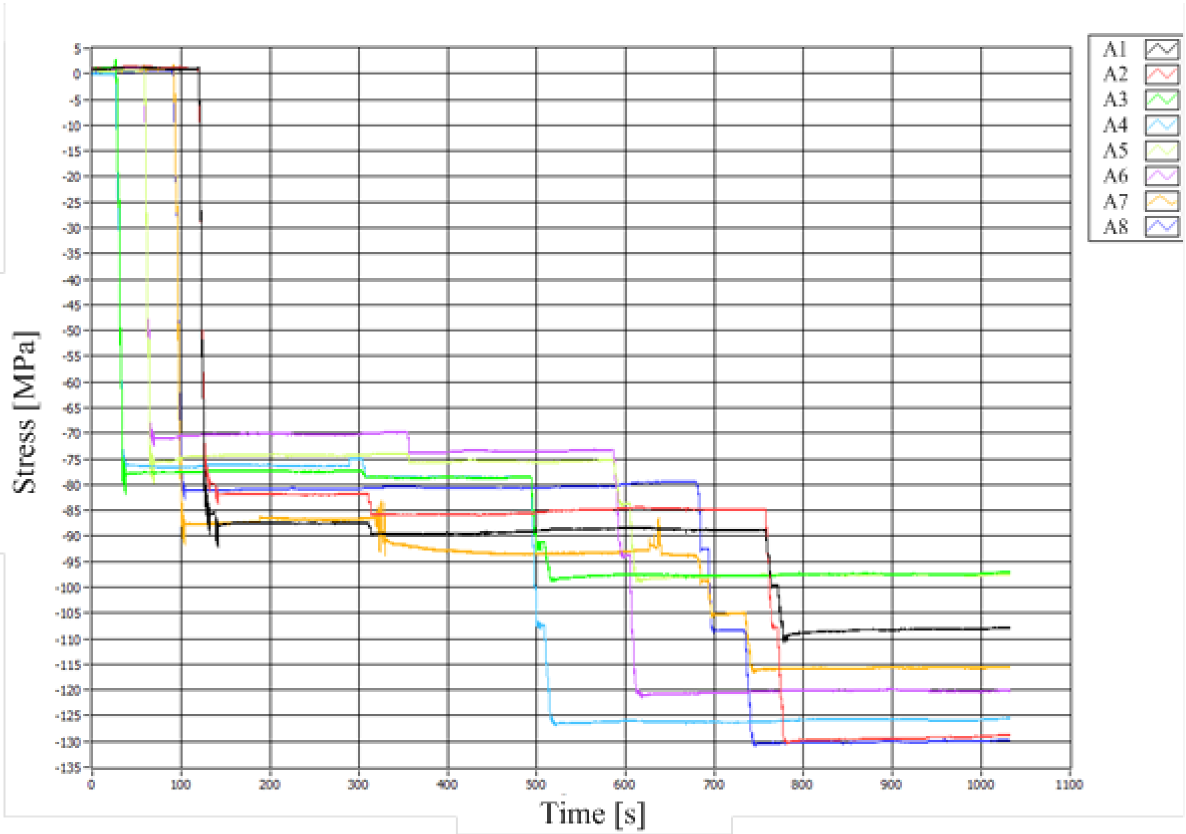

Fig. 6: Surface stress changes during tightening the second planetary gearbox screws array.

4 Conclusion

The measured surface stress caused by the prestressed bolt connections of both planetary gearboxes was than compared with FEM analysis (see Fig. 4). On the basis of this measurement and the FEM analysis we can conclude: first, the FEM analyses of the bolt connections correspond with the measurement with maximal error ca. 10 % from the measured values. On the basis of the correspondence FEM analyses and the measurement is shown that the design of the prestressed bolt connection is correct and it should be sufficient for the right function of it but it is incompatible with behaviour of the gearboxes (chapter 1).

Second, because there can be obtained significant stress drops when the series of screws is tightened (see Fig. 5 in the chapter Measurement), therefore is really important to prepare detailed installation instructions for constructions with arrays of prestressed bolt connections.

Acknowledgement

This work was supported by the industrial cooperation with Wikov MGI a. s.

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