Theoretical Analysis of the Experiment: Changing the Axial Force in the Bolts of the Clamping Sleeve Under its Axial Load

Lukáš Hruzík(✉), Jiří Struž, and Květoslav Kaláb

Faculty of Mechanical Engineering, Technical University of Ostrava, 17. Listopadu 2172/15, 708 00 Ostrava, Czech Republic
lukas.hruzik@vsb.cz

Abstract. This paper deals with theoretical analysis of experiments for measuring axial forces in bolts of a clamping sleeve. A dynamic force occurs in the bolts of the sleeve where the clamping sleeve transmits axial force. FEM analysis of the clamping sleeve proves that the axial force has a dynamic character, which was the inspiration for this experiment. This dynamic character causes the necessity of the fatigue analysis of clamping sleeves bolt. Strain gauges are used for measuring axial forces.

Keywords: Clamping sleeve · Bolt pretension · Experiment · Axial force

1 Introduction

This article deals with the design process of axial forces measurement in bolts of a clamping sleeve, which is loaded by the axial force. In addition to the transmitted force and torque, the manufacturer also states the tightening torque of the bolts. At first, there is a need for the calculation of the axial pretension in the bolt. From the FEM analysis, it was discovered that there is a pretension decrease in the bolts. If the transmitted force is cyclic, the force in the bolts will change cyclically and should be checked for fatigue. The analysis will be made on TLK 400 50 x 80 clamping sleeve from Tollok manufacturing [1–5] (Fig. 1).

2 Materials and Methods

The measurement will be made on the clamping sleeve loaded only by the axial force without torque. The torque acts perpendicular to the axis of the screw and should not affect the axial force in the bolts. The torque is transmitted by friction on the conical surface. The test will be carried out on a bursting machine. For measurements on a bursting machine, it is necessary to produce additional elements replacing the shaft and the hub. It will be measured in tension and in compression, and different components will have to be used for each direction of measurement. In both directions, the force will be transmitted through the spherical surface (Fig. 2).

J. Homišin et al. (Eds.): ICMD 2020, AHE 17, pp. 234–242, 2023.
https://doi.org/10.2991/978-94-6463-182-1_25

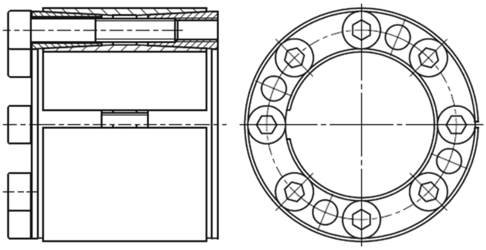

Fig. 1. Clamping sleeve TLK 400 50x80.

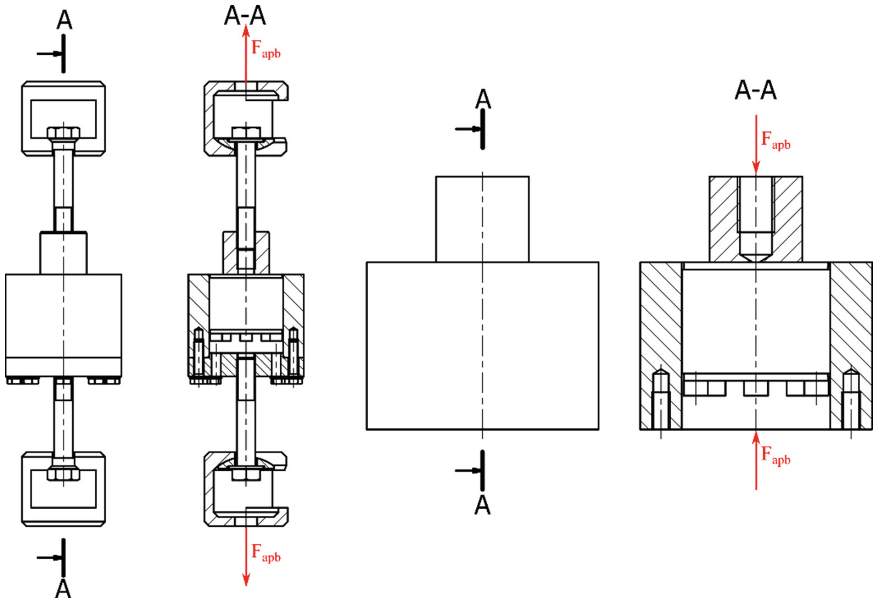

Fig. 2. Measurement principle.

2.1 Axial Force in the Bolt

The axial force will be measured by strain gauges located on the bolts of the clamping sleeve. There will be two strain gauges on a bolt, where each will be connected into one bridge. It will be, therefore, possible to measure the bending of the bolts. Temperature compensation will not be taken into account. For the purposes of the experiment, all bolts will be adjusted so that they all have the same stiffness. Preparation for all bolts is required due to the even distribution of the force between all bolts. For accurate measurements and also for the observation of the force distribution, strain gauges will be placed on each bolt (Figs. 3 and 4).

The strain gauges will be glued to the turned cylindrical surface of the bolt. The diameter of this section will be equal to the small diameter of the bolt thread.

For measurements will be used strain gauges from HBM manufacturer 1-LY41–1,5/120. These strain gauges have solder tabs. These strain gauges have a resistance of

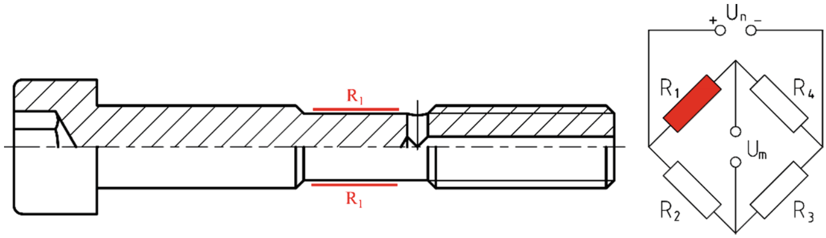

Fig. 3. Strain gauges on the bolt.

Fig. 4. Bolt with strain gauges.

120 Ω. The bridge will be supplemented with 120 Ω resistors. For the connection of the strain gauges, bolts must be drilled in their axis. The drill will have 2 mm diameter for four isolated wires.

2.2 Axial Force in Drilled Bolts

The tightening moment on the drilled bolts must be lower than the original; therefore, this moment must be calculated for the weakened screw. For calculated need pretension axial force in original bolts, determine other unknown like frictional on the thread and frictional coefficient under the bolt head and on a conical surface. I suppose that frictional coefficient on the conical surface, on shaft surface, on inner hub surface and under screw head is equal. Equation from [4] was used for the calculation of axial pretension.

$$\begin{aligned} M_u &= F_o \cdot f \cdot ((D_d + D_k)/4) + F_o \cdot tg\psi + \varphi' \cdot d_2/2 => \\ F_o &= M_u/(f \cdot (D_d + D_k)/4 + (tg(\psi + \varphi)' \cdot d_2/2)) \end{aligned} \tag{1}$$

$$\psi = arctg(P/(\pi \cdot d_2)) \tag{2}$$

$$\varphi' = arctg\left(f_z/cos\,30^\circ\right) \tag{3}$$

Mu is a tightening moment of the bolts, f is a frictional coefficient under the bolt head, on conical surface, hub and shaft, D_d is a diameter of hole from the bolt, D_k is the diameter of the bolt head, F_o is an axial force, and d_2 is mean thread diameter. P is a pitch of thread, f_z is a frictional coefficient of thread.

Another equation there must be fulfilled is the equation for pressure on the shaft or hub. I calculated only shaft pressure because these equations are equivalent.

$$p_w = (8 \cdot F_o)/(\pi \cdot d_w \cdot L_w \cdot (tg(\beta) + f)) \tag{4}$$

p_w is a contact pressure on the shaft, d_w is the diameter of the shaft, L_w is the length of the clamping sleeve on the shaft, β is a cone angle of the clamping sleeve.

Solutions of these equations by numerical method give unknown F_o, f, f_z. With these values, we can solve equivalent stress in the screw, which the screws manufacturer used during calculation.

$$\sigma_t = F_o/\left(\left(\pi \cdot d_3^2\right)/4\right) \tag{5}$$

$$\tau_k = \left(F_o \cdot tg\left(\psi + \varphi'\right) \cdot (d_2/2)\right)/\left(\left(\pi \cdot d_3^3\right)/16\right) \tag{6}$$

$$\sigma_{red} = \surd\left(\sigma_t^2 + 3 \cdot \tau_k^2\right) \tag{7}$$

$$\sigma_d = \sigma_{red} \tag{8}$$

σ_t is tensile stress, d_3 is a minor diameter of the thread, τ_k is torsional stress, σ_{red} is equivalent stress on the bolt.

Pretension axial force can be determined from σd, now. The radial hole was neglected.

$$F_{op} = \sigma_d/\surd\left(\left(1/(\pi\left(d_3^2 - dp^2\right)/4)\right)^2 + 4\left(\left(tg\left(\psi + \varphi'\right) \cdot d_2/2\right)/((\pi/16)(\left(d_3^4 - dp^4\right)/d_3))\right)^2\right) \tag{9}$$

The tightening moment for drilled bolts was determined by using the axial force calculated above.

$$M_{up} = F_{op} \cdot tg\left(\psi + \varphi'\right) \cdot d_2/2 + F_{op} \cdot f \cdot (D_d + D_k)/4 \tag{10}$$

2.3 Maximum Testing Axial Force

The tightening moment on drilled screws is lower than on original screws. Reduction of the tightening moment has an effect on contact pressure and on a transmitted torque and axial force. We are forced to reduce axial testing force. At first, a safety factor was established for original screws and sleeves.

$$F_a = \pi \cdot p_w \cdot d_w \cdot L_w \cdot f \tag{11}$$

$$k_p = F_a/F_{av} \tag{12}$$

F_a is an axial force transmits with clamping sleeve, F_{av} is a maximal transmit axial force from the catalogue, k_p is a producer safety factor. I use the same factor for an adjusted clamping sleeve.

Contact pressure on a shaft and safety axial force for experiment with axial bore was solved now.

$$p_{wp} = \left(8 \cdot F_{op}\right)/(\pi \cdot d_w \cdot L_w \cdot (tg(\beta) + f)) \tag{13}$$

$$F_{apb} = \left(\pi \cdot p_{wp} \cdot d_w \cdot L_w \cdot f\right)/k_p \tag{14}$$

F_{apb} is safety axial force, which will be used for an experiment. There will be no slip with this force, p_{wp} is a contact pressure on the shaft with an adjusted sleeve and reduced tightening moment.

I reduced the tightening moment from 41 Nm to 20 Nm. The manufacturer allows in his catalogue reduced tightening moment on 40% from maximal. It is 16,4 Nm, 20 Nm is possible.

3 Results

The sleeve for the experiment must be adjusted. The measured values will not apply exactly to the unadjusted sleeve. The stiffness change of the bolts has a major role in the axial force in the bolt. The experiment will take place at a lower than maximum load of the sleeve. The contact pressure will be lower, and his distribution may not be the same. For results comparison, the FEM analysis of the experiment was created. This simulation respects the fixing method of a clamping sleeve in a burst machine. If the setting of FEM is right, the results of the experiment and FEM analysis will be correlated. Then we can set FEM analysis with the same settings. The original sleeve will be loaded by maximal transmitted axial force. Change of the axial forces in bolts will be measured.

3.1 Calibration of the Bolts

Each bolt used in the experimental analysis must be calibrated. Calibration is necessary for accurate measurements. For the detection screw bend, two strain gauges must be on the screw. These strain gauges are connected separately. On the screw head, there will be marks indicating the orientation of the strain gauges and the direction of the screw bending.

A linear dependence between force and measuring voltage is assumed. Calibration and measuring will be made on the burst machine. For the best measurement and little mistake during the experiment, axial pretension was used as a maximal calibration force (Fig. 5).

Calibration Process

To achieve the most accurate transfer of the calibrating force and elimination of bending moments, special components with spherical surfaces were used. This problem is described, for example, [5]. Despite the use of spherical surfaces, there was a partial bending of the screw, so the statement in this article was confirmed. At this point, it was a great advantage to have each strain gauge connected separately. The effect of bending was visible, and the calibration process could be adjusted.

During the experiment, it was found that the best way to eliminate bending of the bolt is to load the screw, abutment of the spherical surface, then reduce the preload to 8000 N, as this point was reset apparatus and start calibrating from 8000 N. During the calibration performed in this way, both strain gauges already showed a tensile character.

The beginning of the calibration at 8,000 N is not important for us; only the direction of the tangent is important. In addition, the calibration took place in the area where forces during the measurement are assumed (Fig. 6).

During the calibration, mV/V values are written with 1000 gain for each strain gauge separately on defined levels. These values were then plotted to find the value of the linear relationship. In the graph, the values are shifted by a constant, which consists of the second coefficient in linear interpolation. This coefficient will be zero so that the line starts at zero (Fig. 7 and Table 1).

Example for strain gauge 1: $y[kN] = 25,758 \cdot x[mV/V]$

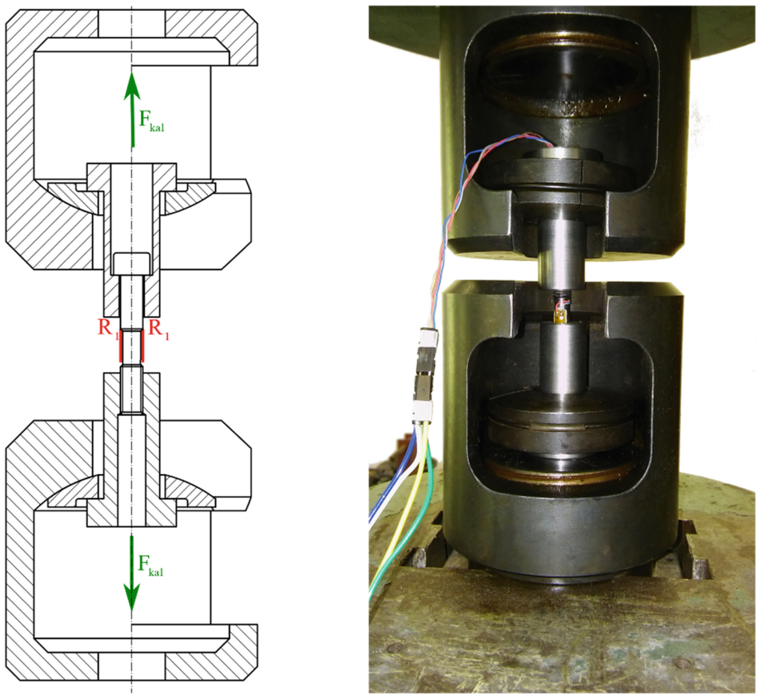

Fig. 5. Calibration scheme.

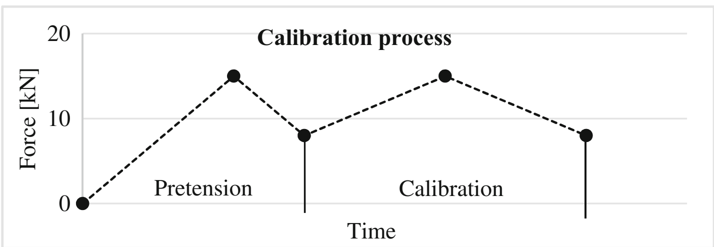

Fig. 6. Calibration process.

Table 1. Direction of calibration curves shifted to zero.

Strain Gauge 1	Strain Gauge 2	Strain Gauge 3	Strain Gauge 4	Strain Gauge 5	Strain Gauge 6	Strain Gauge 7	Strain Gauge 8
25,758	24,198	24,678	26,289	23,863	26,716	24,837	23,011
Strain Gauge 9	Strain Gauge 10	Strain Gauge 11	Strain Gauge 12	Strain Gauge 13	Strain Gauge 14	Strain Gauge 15	Strain Gauge 16
24,906	27,192	24,813	25,042	24,301	27,220	28,481	21,939

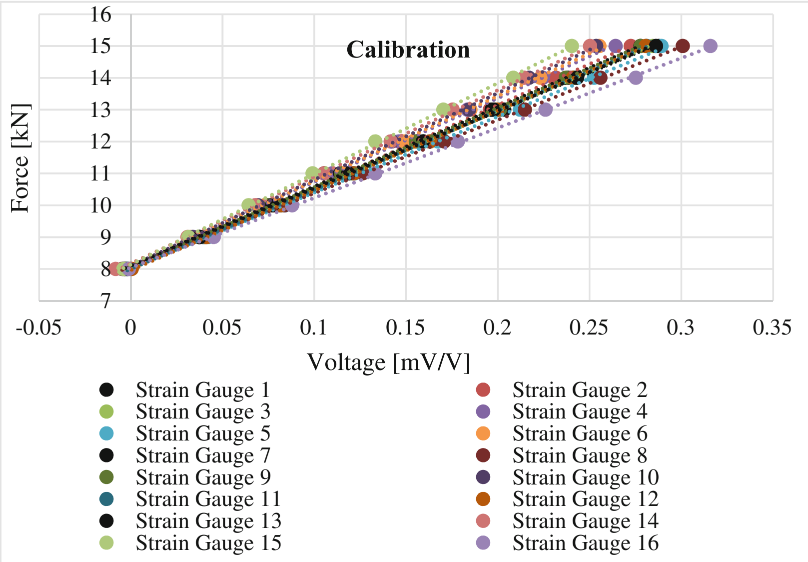

Fig. 7. Graph of calibration

3.2 FEM Results for Adjusted Sleeve

Push and pull cases were analysed with FEM on the Ansys workbench. Both cases report the same pretension force decrease. A static structural module with a linear increase of axial force was used. Values of axial force in bolt depended on axial force from burst machine was plotted in the graph (Fig. 8).

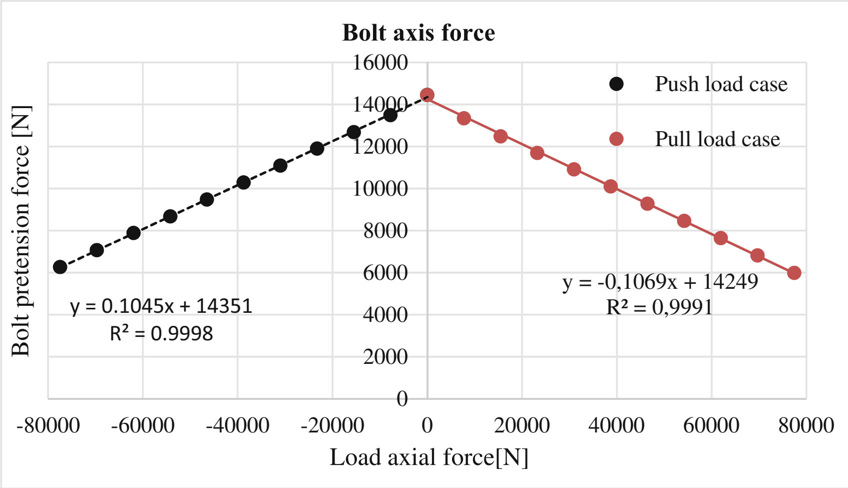

Fig. 8. Bolt axial force.

4 Discussion

Measurement of axial force in bolts using strain gauges is relatively commonly used in technical practice. Strength control is often the reason for measurement. The experiment in this measurement serves for the verification of the FEM analysis. The combination of the clamping sleeve and bolt with strain gauges is a new way of applying this measurement method.

The impact of the bolt pretension decrease can be different. In the worst case, there could be a dynamic loading of the clamping sleeve bolts and therefore their fatigue. Reducing the pretension can cause the housing bolts to be loosened during operation.

5 Conclusions

This article deals with the issue of measuring the axial force in bolts. Bolts are the most important component in clamping sleeves.

The measurement was designed for the TLK clamping sleeve with an inner diameter 50 mm and outer diameter 80 mm. The clamping sleeve with this shaft dimension enables the use of the many variations of the others clamping sleeves. Measurement methodology for different clamping sleeves will be the same, and results will be compared.

This measurement methodology was designed for a lower price, but for an initial experiment is good. In the next step, loading of the clamping sleeve by the axial force and torque is considered.

Acknowledgements. This paper has been supported by SGS 2020. Experimentální a výpočtové metody dimenzování strojních součástí 2020: Experimentální určení změny osové síly ve šroubech svěrného pouzdra při jeho zatížení osovou silou.

References

1. FOLTA, Zdeněk, 2009. Odporová tenzometrie. Pracovní verze C.
2. HBM TEST AND MEASUREMENT, Strain gauges [online]. [cit. 2019–10–14]. From: https://www.hbm.cz/wp-content/uploads/S01265.pdf
3. KALÁB, Květoslav, 2007. Části a mechanismy strojů pro bakaláře: části spojovací [záznam a]. Ostrava: VŠB - Technická univerzita Ostrava, 90 s. ISBN 9788024812908.
4. Rexnord Tollok Locking Assemblies [online], 2017. Rexnord [cit. 2019–10–14]. Dostupné z: https://www.rexnord.com/contentitems/techlibrary/documents/pt2-001m_a4_catalog
5. ZAČAL, Jiří, Zdeněk FOLTA a Lukáš JANČAR. DESIGN OF A SENSOR FOR MEASUREMENT OF BOLT PRETENSION. In: 58th International Conference of Machine Design Departments (ICMD). KAMYCKA 129, PRAGUE 6 165 21, CZECH REPUBLIC: CZECH UNIVERSITY LIFE SCIENCES PRAGUE, DEPT SYSTEMS ENG, KAMYCKA 129, PRAGUE 6 165 21, CZECH REPUBLIC, 2017, s. 426–429.