Decrease in The Roughness of The Shaft Surface During Application of The Clamping Sleeve

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Abstract. The article deals with the change in the roughness of the shaft surface after several tightening of the clamping sleeve. The roughness of the surface has a major influence on the magnitude of the coefficient of shear friction. The coefficient of shear friction is one of the main parameters for a clamping joint reliability. The change in the roughness of the shaft surface is mainly caused by the contact pressure, which is basic for the function of the clamping bush. The contact pressure is greatly influenced by the applied tightening torque of the clamping sleeve screws. The tightening torque in the case of this application was lower than the maximum according to the manufacturer's catalog. Furthermore, the material of the shaft or hub and its susceptibility to a decrease in surface roughness are also very important. The decrease in surface roughness will also greatly impact the original surface roughness of the shaft or hub. The manufacturer basically prescribes a maximum tightening torque and only one surface roughness. The measurement was performed on the bush TLK 400 50x80 [1].

Keywords: Clamping sleeve, Roughness, Shaft, Hub.

1 Introduction

The roughness of the surface has a basic impact on the size of the coefficient of shear friction, and therefore also on the size of the frictional forces, which are used to transfer operating loads. Defining the exact coefficient of shear friction on the cylindrical surface of the shaft and in the hole of the hub is very complicated, this coefficient is very fundamentally influenced by the roughness of the surface. The first problem appears already here, when manufacturers of clamping sleeves only specify the maximum possible surface roughness [1]. Into this problem comes the complication of changing surface roughness due to repeated assembly. Regarding the choice of surface roughness, we have two options.

M. Petr et al. (eds.), *62nd International Conference of Machine Design Departments (ICMD 2022)*,
Atlantis Highlights in Engineering 28,
https://doi.org/10.2991/978-94-6463-423-5_3

1.1 Choice of surface roughness to the maximum extent allowed by the manufacturer of the clamping sleeve:

Advantages:

- Lower production costs for a shaft or a hub with a higher surface roughness.
- Higher coefficient of shear friction, which is related precisely to the roughness of the surface.

Disadvantages:

- When tightening several times, there will be a relatively large decrease in surface roughness.

1.2 Lower surface roughness than the maximum recommended roughness given by the manufacturer of the clamping sleeve:

Advantages:

- More accurate determination of the coefficient of friction, which will be more stable during the operation of the machine.

Disadvantages:

- Higher costs for the production of a shaft or a hub with a lower surface roughness.

The choice therefore depends primarily on the method of use of the clamping sleeve. The hardness of the material from which the shaft or hub is made must also be taken into account when it comes to surface roughness. For higher quality steels, which are harder and sometimes even refined, this problem has a lower impact on the overall functionality of the joint. A bigger problem arises, for example, with the use of a materials of lower quality. In our case, the measurement was made on a shaft made of C55 material. The hub was also made from C55 steel. The mechanical properties are given, for example, in [2].

2 Materials and Methods

As already described in the introduction of this article, the measurement of surface roughness using a roughness tester Handysurf E35-A [1], (see Fig. 1.) is crucial.

Fig. 1. Measurement of surface roughness using the roughness tester.

To compare the pressure at which the surface roughness decreased to the value measured by the roughness tester, FEM modeling was used. For the FEM model itself, analytical calculations had to be used first to recalculate the tightening torque, which was used in the measurement to the axial force, which is inserted into the FEM analysis.

3 Results and Discussions

Several consecutive steps had to be used to determine the results of the measurement itself. The tightening torque was reduced to 20 Nm for the reasons described in [4].

3.1 Input data for FEM analysis

The equations of the axial force and contact pressure calculating are inspired by the findings presented in [5]. The equation was used to determine the axial force in the screw:

$$F_o = \frac{M_u}{f \cdot \left(\frac{D_S}{2}\right) + (\tan(\psi + \varphi)) \cdot \left(\frac{d_2}{2}\right)} \quad (1)$$

The parameters important for this calculation were determined using a numerical calculation method and can be found, for example, in [6]. To check the FEM model, the value of the contact pressure on the shaft was further calculated using an analytical method:

$$p_H = \frac{8 \cdot \frac{M_u}{f \cdot \left(\frac{D_S}{2}\right) + (\tan(\psi + \varphi)) \cdot \left(\frac{d_2}{2}\right)}}{\pi \cdot d_h \cdot l_h \cdot (\tan(\beta) + f)} \quad (2)$$

If the parameters of the clamping bush TLK 400 50x80 are inserted into these equations, the pressure calculated by the analytical method is $p_H = 71{,}7\ MPa$. The axial force inserted in the FEM analysis was calculated as $F_0 = 14\ 737{,}4\ N$.

3.2 FEM analysis

The task of the used nonlinear FEM analysis was to determine the contact pressure on the shaft. The contacts used in this task are very important. Frictional contacts, which are shown in Fig. 2, are very important for convergence. The setup of the FEM analysis was done with regard to [7].

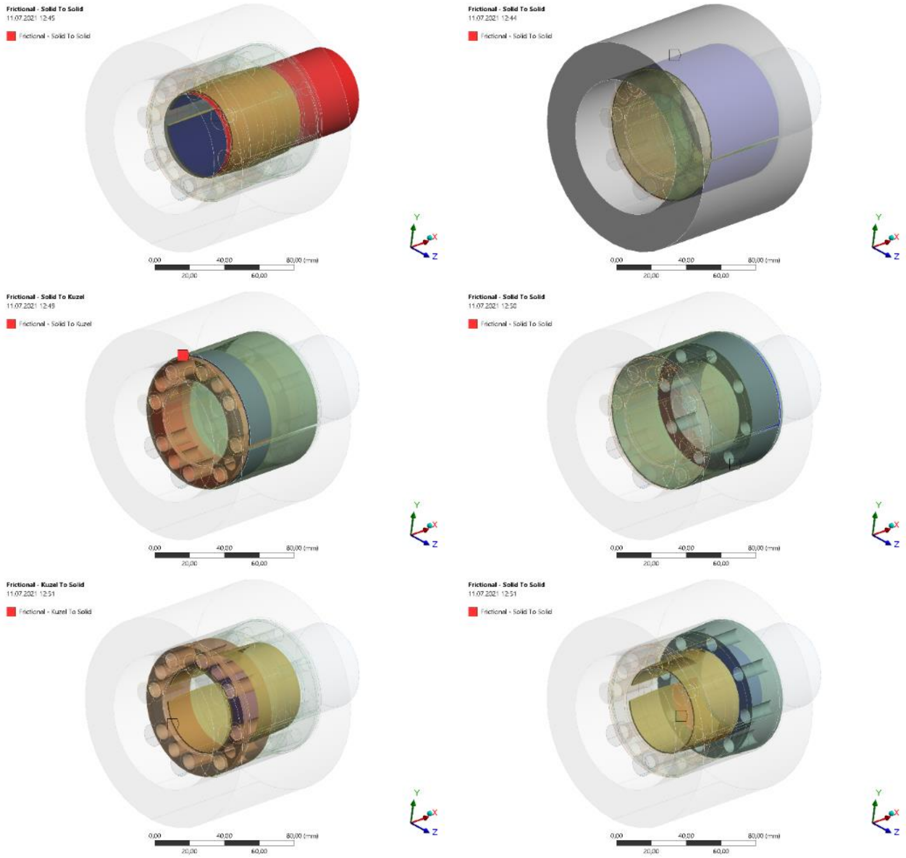

Fig. 2. Frictional contact of clamping sleeves analysis

For easier convergence, they were used contacts frictionless under the screw head. The screw thread was replaced by a bonded contact (see Fig. 3.).

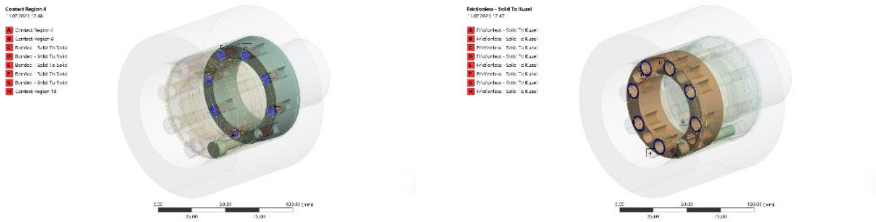

Fig. 3. Contact of a screws

The boundary conditions are primarily the preload in the screws. To fix the assembly in space a Fixed support binding was used on the front of the tube replacing the charge (see Fig. 4.).

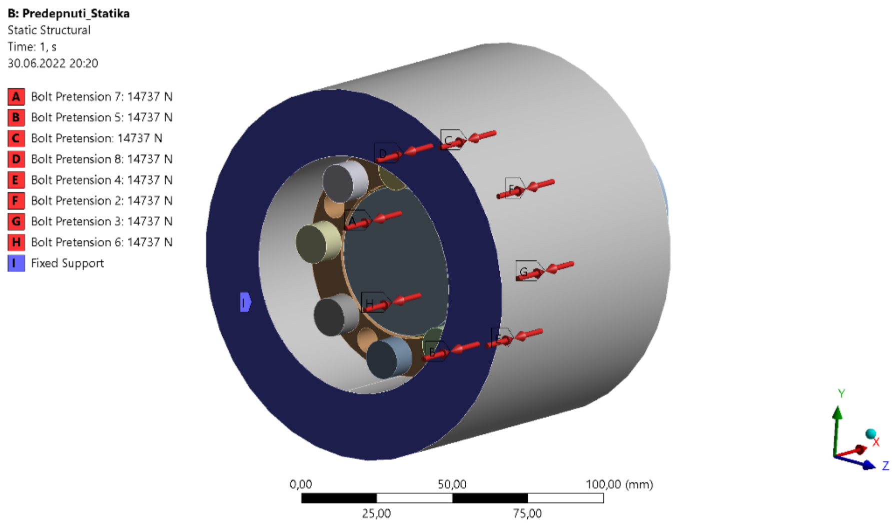

Fig. 4. Boundary conditions of the FEM model

The result of the FEM analysis is the contact pressure on the shaft or on the hub. The results of the analysis are shown in Fig. 5.

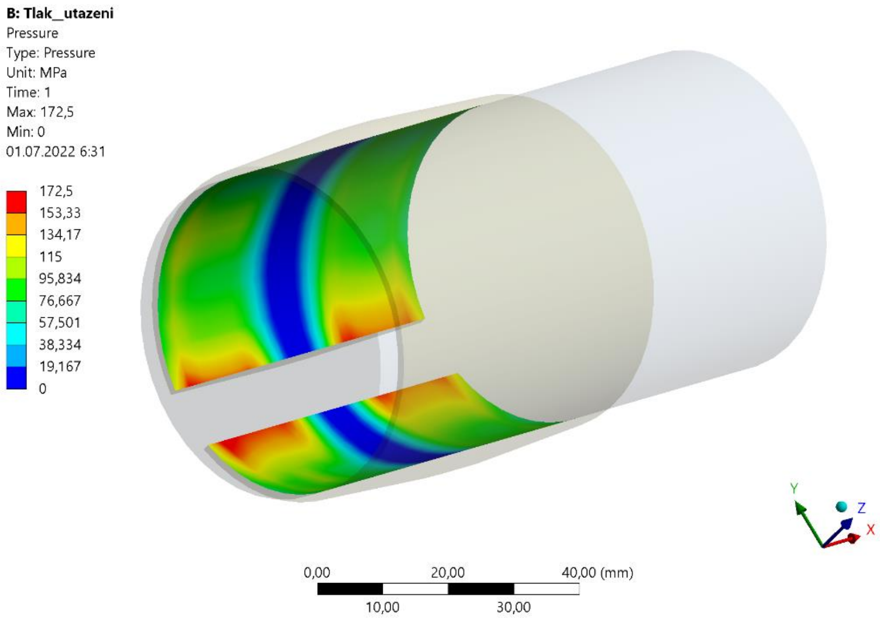

Fig. 5. Results of the FEM analysis

To compare the analytical calculation and the FEM model, the average pressure on the shaft was determined from the FEM model $p_{H\_FEM} = 71{,}6\ MPa$. The difference was very small, and it was assumed that the FEM model was set up correctly.

3.3 Measuring

The surface roughness was measured around the circumference of the shaft, in four areas (see Fig. 6.)

1. Area with original surface roughness.
2. The area under the first cone.
3. The area between the cones.
4. The area under the second cone.

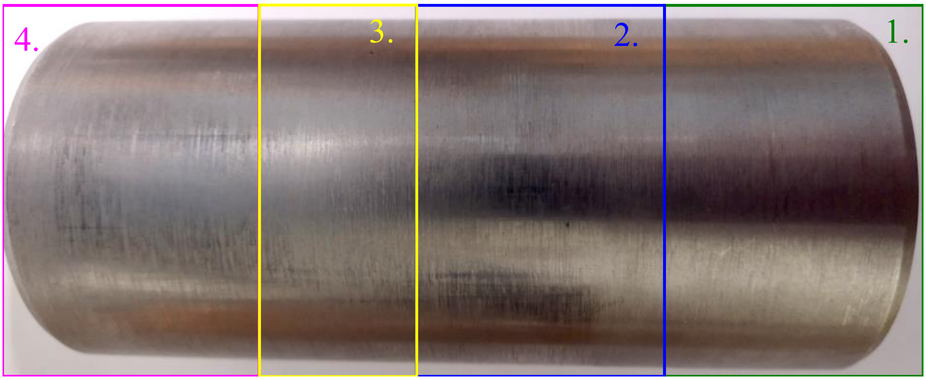

Fig. 6. Individual measurement areas of the shaft

The area with the original roughness is taken as a comparison for the decrease in roughness after the measurement. It is the area of the shaft that has not been fitted with a bushing. Under the cones there is the greatest pressure, and therefore there is an assumption of the greatest impact and therefore the greatest decrease in surface roughness. Between the cones there is again a reduction in pressure and the pressure here is not so great.

Table 1. Surface roughness values

	Ra [µm]	Rz [µm]	Rzmax [µm]	RSm [µm]
Original	2,9	15,6	17,7	162,5
Under the cone	2,1	10,1	12,7	167,6
Between the cones	2,9	14,3	16,9	155,5
Under the cone	2,8	12,5	15,6	157,6

The measured values are shown graphically in Fig. 7. The original roughness in the area unaffected by the sleeve corresponds to the maximum possible surface roughness Ra, which is determined by the manufacturer of the clamping bush.

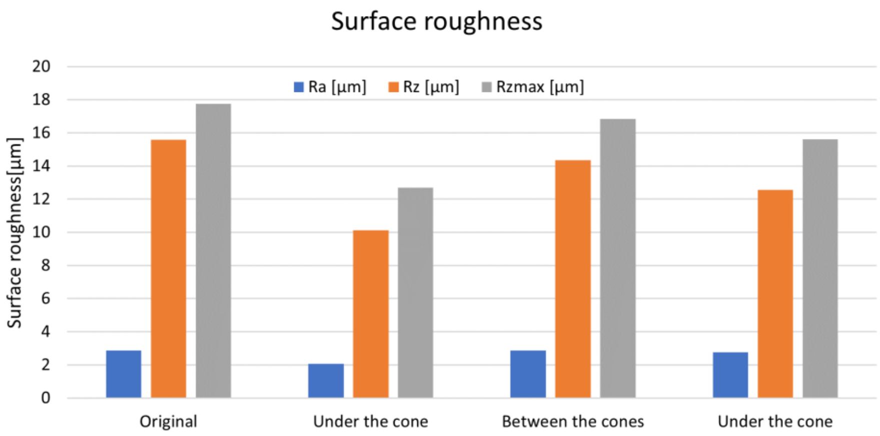

Fig. 7. Measuring data

It is also interesting to compare the decrease in roughness in percent with respect to the area unaffected by the clamping sleeve.

Table 2. Surface roughness values, decrease in percent

	Ra [%]	Rz [%]	Rzmax [%]	RSm [%]
Under the cone	71,6	64,9	71,5	103,1
Between the cones	100,3	91,9	94,9	95,7
Under the cone	96,4	80,5	87,9	97,0

The comparison can be seen very well in the form of a graph shown in Fig. 8.

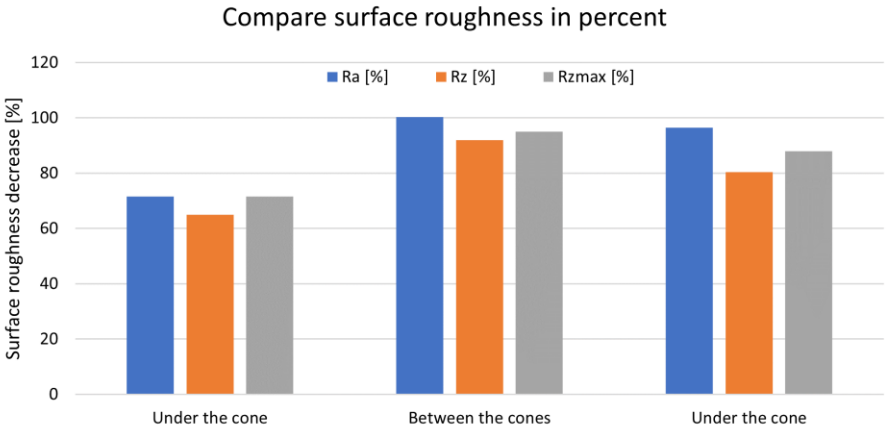

Fig. 8. Comparison of surface roughness in percentage

4 Conclusions

The roughness of the surface is crucial to the magnitude of the coefficient of shearing friction that makes the sleeve work. When choosing the surface roughness, however, we move between two options, if we use a higher surface roughness, we will achieve a higher coefficient of shear friction, which, however, may decrease due to multiple assembly and cause inaccuracy in the calculation. This was confirmed during the measurement of the axial force change in the clamping sleeve screws, when the surface roughness was at approximately 70% of the original value, even when the sleeve screws were tightened to a lower tightening torque, so the contact pressure was also lower. In the case of very frequent tightening of the clamping bush to the original and unreduced tightening torque of the screws, it is seen a very high risk in the gradual reduction of the surface roughness, thus also the coefficient of shear friction, which can lead to joint failure.

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