Application of Notches in Machine Elements for Measurement Sensitivity Increase

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Abstract: This work is focused on the development of a method how to increase the sensitivity of measurement of machine elements using strain gauges. Many machine components are often intentionally designed as overdesigned therefore the surface deformation and the corresponding stress are difficult to measure with standard wire strain gauges. The research is carried out using mainly experimental work, the obtained results are compared with the FEM analysis.

Keywords: Strain Gauge; Notch; Stress Increase; Linearity

1 Introduction

Nowadays, measurements with strain gauges represent widespread and desired method for assessment of the stress state of machine elements because there is the possibility for the online measuring during the operation of a machine. However, there are many cases when the limitations of this method become dominant and the method cannot be used. Such case may be the measurement of machine components designed with high safety factor when the stress state during the operation is very low. Large industrial gearboxes are the examples of machine components that are designed with respect to the mechanical and economic efficiency. Application of strain gauge measurement gives information about the real efficiency of the operated machine to the customers. Moreover, service organization can get the information that helps them to improve the maintenance of the production equipment, and the producers receive important feedback for their development and production. It is also important to measure the efficiency of such large industrial gearboxes with high accuracy because for example the loss of 1 % of 6 MW gearbox is 60 kW.

Motivation of this article is to give the outline and insight how to use strain gauge measurement for such applications.

2 Theory

There are many possibilities how to increase the sensitivity of strain gauge measurement. For example the measuring equipment can be tailored. The sensitivity of equipment can be increased by usage of converter with higher bit width, or the application of semiconducting strain gauges that have 80 times higher sensitivity than wire strain gauges provides better results. Another possibility is to find the appropriate place for the strain gauge where the local increase in stress can be assumed. Also the increase of the measurement sensitivity can be expected proportionally to the local stress increase. Notches represent such places where the increase of stress arises.

From the theory of notch stress state follows that there is a small area near the notch where the increase of the stress is above the nominal value. Figure 1 shows the example of such notch created by a shaft shoulder where the stress flow is concentrated. The FEM analysis of the shaft with two shoulders, i.e. notches, and the course of shear stress along the shaft are shown in the figure 2. The increase of the stress near the notches is obvious.

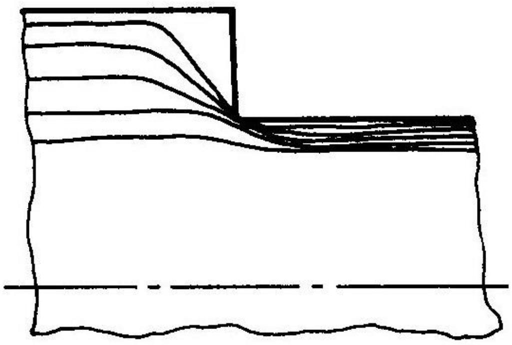

Fig. 1: Notch and the stress field

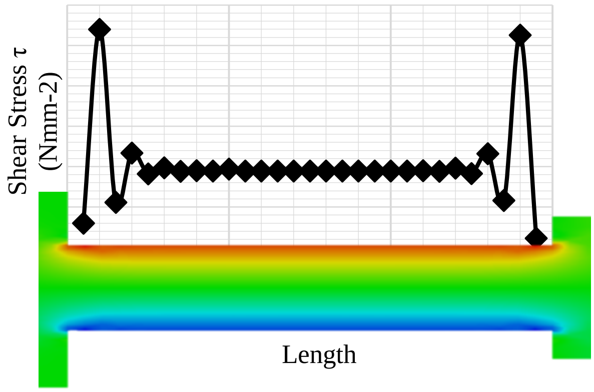

Fig. 2: Course of shear stress along the shaft

The value of the shear stress in the notch can be easily calculated from the known equation (1), where α is the stress concentration factor, τ_{nom} is the nominal shear stress and τ_{max} is the maximal value of the shear stress in the notch. Stress concentration factor α for the considered geometry can be found in known nomograms. Example of the nomogram for the shaft shoulder can be seen in the Figure 3 [2], where D and d are the shaft diameters and ρ is the notch radius.

$$\alpha = \frac{\tau_{\max}}{\tau_{nom}} \tag{1}$$

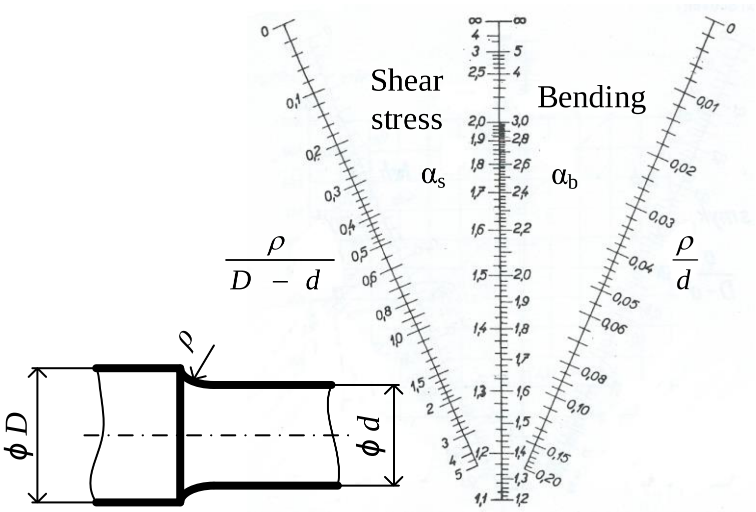

Fig. 3: Nomogram of the stress concentration factor α for the shaft shoulder

Using the stress concentration factor the value of the notch stress can be calculated, but in most cases it is not possible to place strain gauge directly to the notch. So there has to be found another place, where the stress is higher than the nominal value, which will guarantee an increase in sensitivity and where the strain gauge can be placed. To find this place a stress gradient γ can be used, which is calculated from the known equation (2).

$$\gamma = \frac{1}{\rho} + \frac{4}{D+d} \tag{2}$$

3 Experiment

The specimen of the shaft was created for the verification of the stress state in the real parts. On the shaft there were two notches/shaft shoulders. The measurement was obtained using 120hm strain gauges near the notches. The strain gauges were configured for measuring of the shear stress. The examples of measured results in both strain gauge positions can be seen in figure 4 and figure 5. The shear stress is linearly dependent proportional to the torque load.

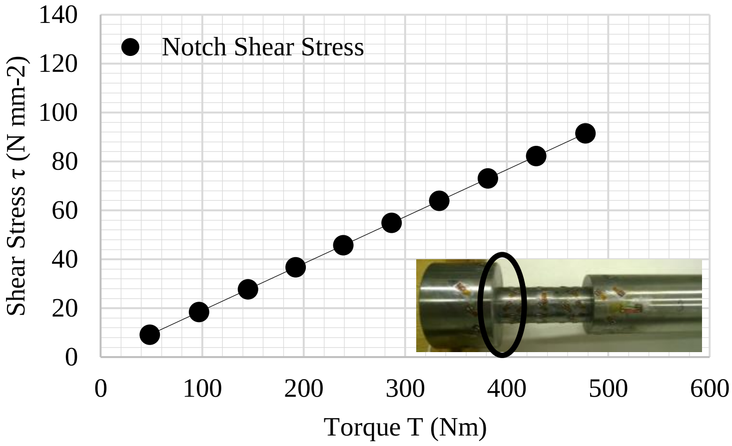

Fig. 4: Measurement of shear stress near the notch

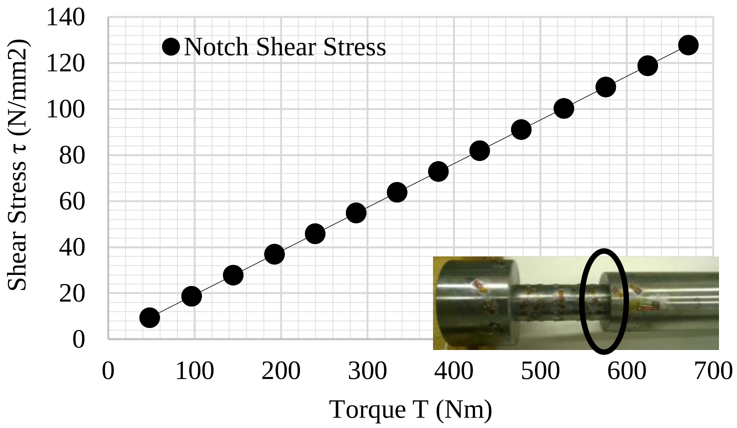

Fig. 5: Measurement of shear stress near the notch

4 Summary

The stress theory near the notch of the shaft loaded by torque was verified with help of experimental measurement and FEM analysis. It was confirmed that the increase of the stress near the notch is linearly proportional to the loading. Following research in this field is focused on the verification and application of other types of notches with respect to the increase in the sensitivity of the strain gauge measurement.

Acknowledgement

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