Complement of Calibration of Measuring Element Using FEA

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Abstract: This paper focuses on complement of calibration of measuring element directly integrated into industry machine using finite elements method analysis. It describes a method to convert calibrated load by concentrated force into real industry load by pressure. It is based on similarity and comparison of curves of deformation for both these cases of load.

Keywords: Calibration; Strain Gauge; FEM analysis.

1 Introduction

In industry, there are lot of requests to measure stress, deformation, pressure, force, velocity, etc. For the experimental measurement are often used special sensors with strain gauges. The sensors are often directly integrated into industry machines, e.g. [1, 2].

In this case, there was a request to calibrate measuring element with given geometry, where strain gauges are used. The measuring element is directly integrated into industry machine, so there was no possibility to change the geometry. The measuring element is loaded with constant pressure in the industry machine, but there was no way to precisely simulate constant pressure during the calibration.

Hence, a method has been devised how to convert calibrated load by concentrated force into load by pressure using FEA. This method is based on defining curves of deformation for both cases of loads and their comparison. This will allow us to obtain a constant of transformation of load by concentrated force to load by pressure.

2 The Geometry of the Measuring Element

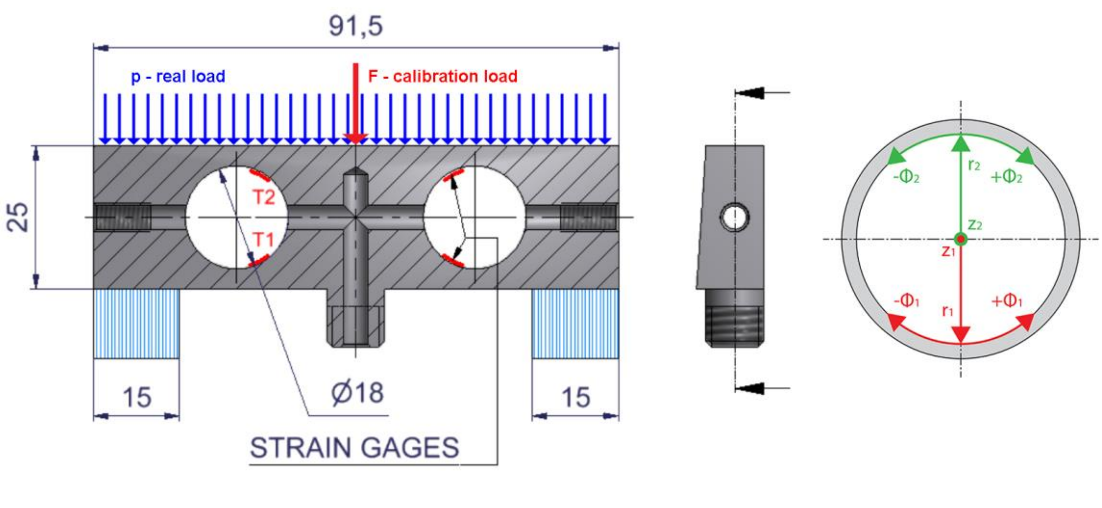

Fig. 1: The geometry of the measuring element with illustrated load, boundary conditions, position of strain gauges and definition of local cylindrical coordinate systems.

The two defined local cylindrical coordinate systems on measuring element are shown in Fig. 1, named C_1 (r_1, Φ_1, z_1) and C_2 (r_2, Φ_2, z_2). Results of FEA are shown just in these coordinate systems which corresponds to deformation of strain gauges placed on circumference of circular holes.

3 Defining Curves of Deformation Using FEA

A very fine mesh in the area of strain gauges was designed using C3D8R elements in Abaqus software [3]. The mesh is shown in Fig. 2. There are 16 elements in the 'z' axis direction and 148 elements in the 'Φ' axis direction. Nodes are numbered in the (i, j) coordinate system, where i = {1, 2, …, 149} and j = {1, 2, …, 17}. After analysing the data, the values of relative deformation of circumference of the hole for both cases of load, in every node N(i, j), were found.

The results were constant by the 'z_1' and 'z_2' axis in C_1 and C_2 systems. Hence, an average of the results was taken. The average was taken only in strain gauge area, which is located between nodes j = 6 and j = 12. Averaged result by the 'i' axis then corresponds to the result by the 'Φ' axis. This is described in Eq. (1) and shown in Fig. 2, where the surface of the hole is developed. The result is a function of one variable and can be shown in 2D graph. This is how the curves of deformation are defined.

$$\varepsilon_{(\Phi_1,\Phi_2)} \approx \varepsilon_{(i)} = \sum_{j=6}^{j=12} \bar{\varepsilon}_{(i,j)} \tag{1}$$

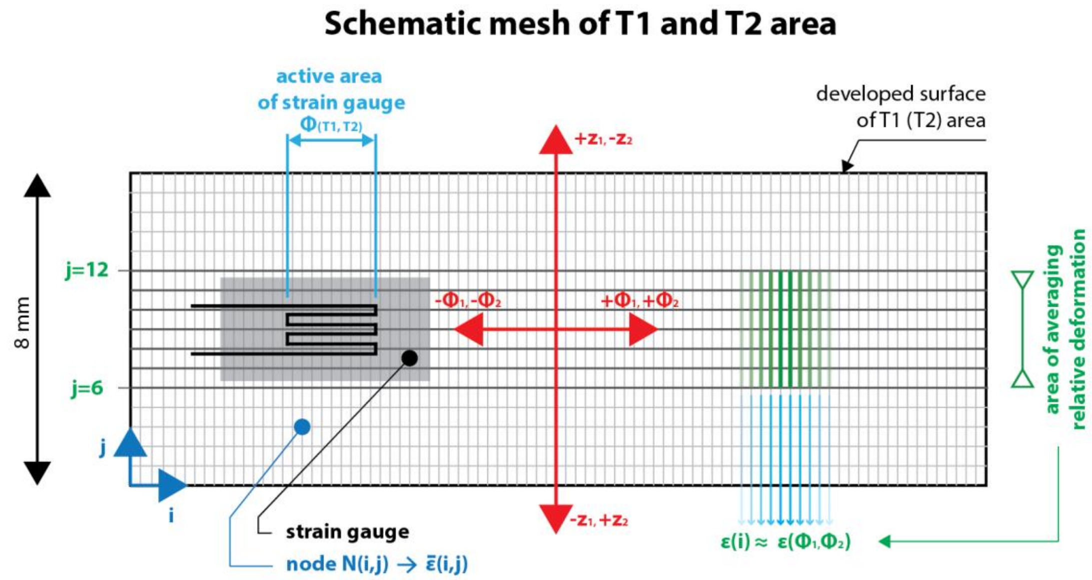

Fig. 2: The mesh of T1 and T2 area, where the strain gauges are located.

The exact position of strain gauges was measured using the optical method. The averaging of the curve of deformation in the zone of measured real position of active area of the strain gauge should be theoretically equal to the value measured by the strain gauge. These relations are shown mathematically in Eq. (2) and Eq. (3).

$$\varepsilon_{(T1,T2)}^{force} = \frac{1}{\Phi_{(T1,T2)}} \cdot \int_{(T1,T2)} \varepsilon_{(\Phi_1,\Phi_2)}^{force} \cdot d\Phi \tag{2}$$

$$\varepsilon_{(T1,T2)}^{pressure} = \frac{1}{\Phi_{(T1,T2)}} \cdot \int_{(T1,T2)} \varepsilon_{(\Phi_1,\Phi_2)}^{pressure} \cdot d\Phi \tag{3}$$

$$R = \frac{\varepsilon_{(T1,T2)}^{pressure}}{\varepsilon_{(T1,T2)}^{force}} \tag{4}$$

Based on the similarity of these curves of deformation for both cases of load, the ratio R between the integrated values of the curves of deformation for both loads is the constant that should be used while converting calibrated load into real industry load. This relation is shown mathematically in Eq. (4).

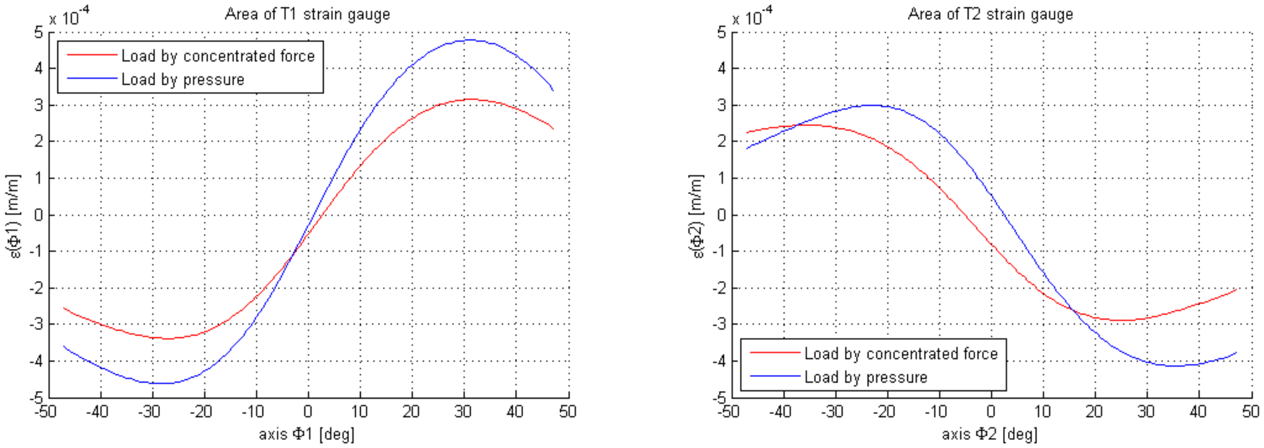

Fig. 3: The curves of deformation in T1 and T2 area for load by concentrated force and load by pressure.

4 Converting loads

The analysis was divided into 10 equal steps, given in Tab. 1. The load by concentrated force from 0 to 3.0 kN with step 0.3 kN was used during calibration. For load by pressure the values from 0 to 10 MPa with step 1 MPa were used. Graphs of curves of deformation are always shown for the loads in the same step only. The ratio between them does not change for any step. It is because of linearity of the model. For example, in Fig. 3 curves made by loads from step 10 are shown.

Tab. 1: Table of conversion of loads for FEA divided by the steps.

step [-]	1	2	3	4	5	6	7	8	9	10
load by force [kN]	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0
load by pressure [MPa]	1	2	3	4	5	6	7	8	9	10

The ratio between values of loads in Tab. 1 for every step is fixed and its value is 0.3. The relation of conversion from load by concentrated force to load by pressure can be set with knowledge of Tab. 1. The ratio R obtained from the analysis will also be used. This is mathematically described in Eq. (5).

$$p_{meassured}\ [MPa] \approx \frac{1}{0.3} \cdot R \cdot F_{calibrated}\ [kN] \tag{5}$$

5 Strain gauges

Linear HBM strain gauges type 1-LY11-1.5/120 were used. In total 4 pieces were used, 2 for every circular hole of measuring element. This theory is given only for one half of the measuring element. This is the reason why only two areas of strain gauges T1 and T2 are mentioned.

This theory can also be analogically used for the second half of the measuring element because all the model is symmetric by the plane where the concentrated force is applied.

Every strain gauge is connected in quarter-bridge circuit, so the data from each strain gauge is taken separately.

6 Conclusion

The proposed method for calibration of the given measuring element takes advantage of the simplicity of the loading by a concentrated force during the calibration. The FEA based on the similarity of curves of deformation in strain gauges areas and their comparison gives the sufficient method how to link the calibration and the real measurement of the pressure load.

References

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