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Experimental Stress Analysis of Transducers by Means of PhotoStress Method

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BIOGRAPHICAL NOTES

prof. Ing. Pavel Macura, DrSc (born in 13.9.1940) is a professor at the VŠB - TU Ostrava, Faculty of Mechanical Engineering, department of Mechanics of Materials. Prof. Macura graduated at VŠB - TU Ostrava, Faculty of Mechanical Engineering in 1962, in the branch of metallurgical works machinery with specialization in rolling mills. Between 1961 and 1965 he worked as a designer of rolling mills at Machine Works and Foundry in Žďár nad Sázavou (ŽDAS), from 1965 to 1972 as an assistant professor at VŠB - TU Ostrava, Faculty of Mechanical Engineering, department of Mechanics of Materials and 1972 - 1996 as a research and scientific worker at the Iron and Steel Research Institute in Dobrá at Frýdek - Místek. Since 1996 he has been working at his current position as a professor. Professional specialization is a computational and especially experimental stress analysis in the field of elastic and plastic deformations by means of strain gage, photoelasticity and photoplasticity methods and also measurements of residual stresses, design and investigation of transducers and metal forming optimization. He is a member of the national committee for Experimental Mechanics in the Czech Society for Mechanics. He is an author of many lecture notes about experimental methods in the field of elasticity and plasticity, contributions about using tensor calculus in the theory of elasticity and forming and other 160 conferences and periodical papers.

KEY WORDS

PhotoStress Method, Reflection Polariscope, Photoelastic Coating, Transducer

ABSTRACT

This article deals with some experimental stress analysis issues by means of the PhotoStress method. The method was used in order to find out directions and magnitudes of the main stresses at specific cells of the pressure transducers. Since the experimental analysis has been carried out on the curved surfaces of the transducers, the photoelastic coatings had to be cast, shaped, glued on and calibrated before the measurement itself. First of all the article shortly describes calibration process of the cast photoelastic coating made of PL 8 material. Then the measurement procedure and results of courses for the main stresses magnitudes and their directions, computed by means of a shear stresses difference method, are introduced. The measurement results serve as the basis of the strain gauges placement and directions, in order to assure maximal sensitivity of the transducers.

INTRODUCTION

The pressure transducers should not be oversized, since they would provide low sensitivity. That's why there is essential to know magnitudes and directions of the main stresses during the transducers nominal load. During measurements of pressure forces, those forces are transmitted over relatively large contact areas, which might influence the right choice of boundary conditions at numerical computing. Thereby, the results obtained directly on the real parts, by means of experimental methods during their nominal load, are very valuable. One of the suitable experimental methods is PhotoStress, which enables an experimental analysis of directions and magnitudes of the stresses on the whole accessible surfaces of the loaded elements. The presented article shows the usage of this method for directions and places determination of the maximal main stresses on the specific cell of the transducer. Hence gluing strain-gauges on those places in their right directions there is achieved maximal sensitivity of the designed transducer.

MEASUREMENT PROCEDURE

Measurement was carried out on the three types of specific cells of the pressure transducers. The first type was a shear ring transducer as Fig. 1 shows.

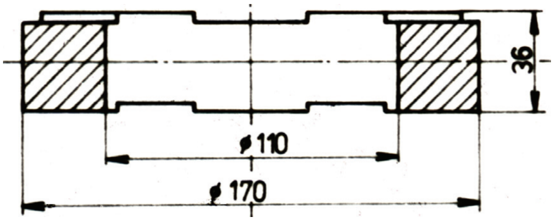

Fig. 1 *Shear ring transducer*

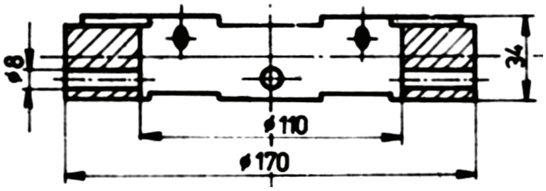

Fig. 2 *Shear ring transducer with added holes*

Figure 2 shows the same but redesigned transducer with added holes, which serve for purpose of leading electrical wires and connection of glued strain gauges into Wheatstone bridge. There was studied an influence of those holes on the state of stress of the given specific cell. The third measured specific cell was shear plate transducer according to Fig. 3. The article is going to show only measurement results of the specific cell from Fig. 1.

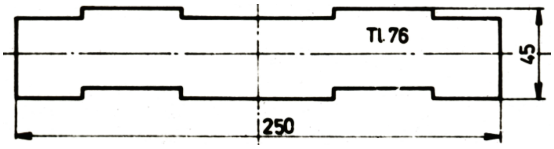

Fig. 3 *Shear plate transducer*

There was supposed to glue strain-gauges on available cylindrical surfaces of the specific cell. Since those surfaces aren't planes, there was not possible to use already manufactured photoelastic coating in form of thin plates, but the photoelastic coating had to be cast first, shaped and then glued on instead. A test specimen was taken from the photoelastic coating before its shaping, for the optical sensitivity determination purpose of the cast material.

OPTICAL SENSITIVITY MEASUREMENT

There was used an epoxy resin PL8 by American company VISHAY for the measurement. The cast coating was 2,3 mm thick and glued on a beam of calibration device Model 010 - B by VISHAY company as well. Principle of the calibration process shows Fig. 4. Testing specimen taken from the photoelastic coating glued on the top of calibration beam of a rectangular cross section was attached by the first end into a frame and the second end was loaded by a simple force executed by turning micrometer screw. By means of a reflection polariscope Model 030 and digital compensator Model 632, orders of isochromatic lines **m** in interval **x**, from the place of beam fixation during different deflection values were measured. Isochromatic lines join geometrical places of points, which have difference of the main strains ($\varepsilon_1 - \varepsilon_2$) or the main stresses difference ($\sigma_1 - \sigma_2$) constant.

Magnitude determination of the maximal bending stress in place **x** is given by:

$$\sigma_o = \frac{3Eh(l-x)}{2l^3} y_F \qquad (1)$$

Dependence between stresses and strains at plain state of stress on surface of an element is given by relation:

$$(\sigma_1-\sigma_2)=\frac{E}{1+\mu}(\varepsilon_1-\varepsilon_2) \qquad (2)$$

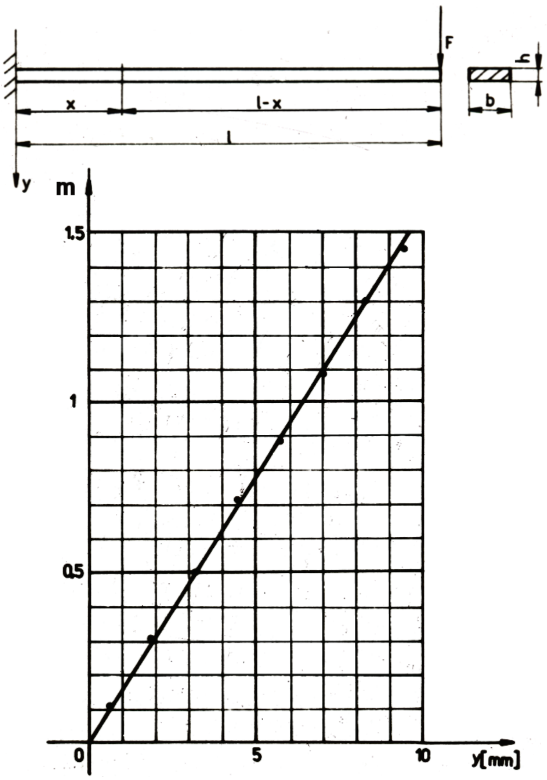

Fig. 4 *Optical sensitivity measurement*

For uniaxial stress on the beam surface in place **x** according to Fig. 4 then there is valid:

$$(\varepsilon_1-\varepsilon_2)=\frac{1+\mu}{E}\sigma_o=\frac{3(1+\mu)\,h\,(l-x)}{2l^3}y_F \qquad (3)$$

Dependence between optical and mechanical quantities during load of optically active temporarily double refraction material is given by Wertheim's law [2], which says that ellipsoid of refractive indexes **n** and strains ellipsoid ε are similar and coaxial:

$$\delta=2t(n_1-n_2)=2tK(\varepsilon_1-\varepsilon_2)=m\lambda \qquad (4)$$

Where δ means optical path difference of two polarized rays, caused by temporarily double refraction in photoelastic coating, which can be expressed as **m** - multiple of wavelength λ of light passing through. Quantity **m** determines fringe orders of isochromatic lines, **t** is the coating thickness. There is constant 2 in equation (4) because of light ray echo passes through photoelastic coating twice. For measuring of strain-optic coefficient **K**, then from equation (3) and (4) there is a consequence correlation:

$$K=\frac{m\cdot\lambda}{2t(\varepsilon_1-\varepsilon_2)}=\frac{\lambda l^3}{3th(1+\mu)(l-x)}\cdot\frac{m}{y_F} \qquad (5)$$

Beside the strain-optic coefficient **K**, which is non-dimensional and independent on coating thickness **t**, during practical measurement there is also used other constant **f** called fringe value of the plastic coating that can be derived from previous equations:

$$(\varepsilon_1-\varepsilon_2)=m\frac{\lambda}{2tK}=m\cdot f$$
$$f=\frac{\lambda}{2tK}=\frac{3h\,(1+\mu)(l-x)}{2l^3}\cdot\frac{y_F}{m} \qquad (6)$$

Derived relations are valid supposing that rigidity of calibration beam is not influenced by glued photoelastic coating. In fact, dependence on the thickness ratio of **t** and **h**, might this rigidity influence quite significantly and hence there is a need to correct the obtained results. Correction of the used calibration device can be achieved by nomogram, developed by its manufacturer [3] and showed on Fig. 5.

Measurement procedure, calibration and correction are following. By means of a compensator there are measured fringe orders of isochromates **m** in a distance of **x** from fixed end of beam at different values of measured deflection y_F, the distance is marked by line on the calibrator frame. Measured results are drawn into a chart, as the Fig. 4 presents below. From the chart, there is analyzed direction of acquired line $\Delta m/\Delta y$ and for measured thickness **t** of glued photoelastic coating, nomogram from Fig. 5 is used to read strain-optic coefficient **K** and fringe value **f**.

The measured results of the cast material PL 8 are introduced in Tab. 1.

l	mm	254	λ	Å	5766
x	mm	63,5	μ	-	0,33
b	mm	25,4	$\frac{\Delta m}{\Delta y}$	$\frac{orders}{mm}$	0,158
h	mm	6,35	K	-	0,11
t	mm	2,3	f	$\frac{\mu m}{m\cdot order}$	1100

Tab. 1 *Calibration values and results of PL 8 material*

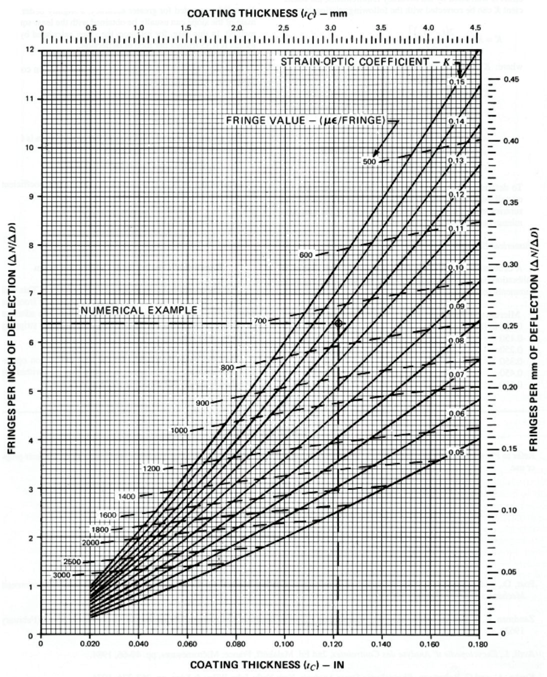

Fig. 5 *Nomogram for corrections of strain-optic coefficient K and fringe value f*

Comparison of computed values f according to equation (6) and corrected ones in Table 1 shows difference of 18%, which means that glued photoelastic coating increases rigidity of the calibration beam quite significantly.

MEASUREMENT RESULTS

Measured transducers with glued photoelastic coating on were gradually put into calibration press and loaded up to their nominal forces, whole process shows Fig. 6, 7 and 8.

Fig. 6 *Isochromatic lines on ring transducer*

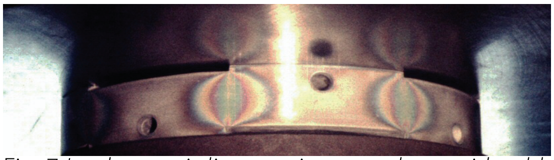

Fig. 7 *Isochromatic lines on ring transducer with added holes*

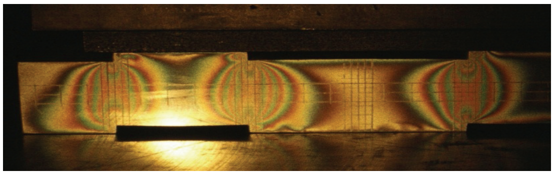

Fig. 8 *Isochromatic lines on plate transducer*

Photographs were taken from the raised interference effects in the photoelastic coatings and serve as a basis of the main stresses directions and magnitudes evaluation in any places of glued surface of the specific cell. Results of the measurement are obtained courses for two kinds of interference lines. Isochromates already defined above, and isoclinic lines that join geometrical places of points, where the directions of main stresses are constant and identical with the directions of crossing optical axes of polarizing filters in reflection polariscope.
Detected course of isochromatic lines of the first transducer type, during its nominal load 2 000 kN describes Fig. 9.

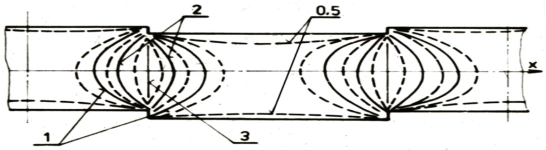

Fig. 9 *Courses of the isochromatic lines*

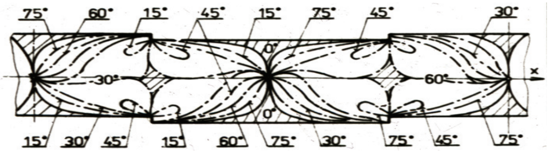

Fig. 10 *Courses of the isoclinic lines*

Fig. 11 *Courses of the isostatic lines*

Figure 10 shows detected course of isoclines. There is obvious position of singular points, which are points where all isoclines passing through and they all have difference of their main stresses zero. That means that in those points the main stresses are of the same size, Mohr's circle in those places is reduced into a single point and isochromates have zero fringe order here. The detected isoclinic lines courses serve to find out courses of the isostatic lines by means of graphical construction [2]. Isostatic lines join geometrical places of points, where tangents and perpendiculars determine directions of the main stresses in investigated points. Detected course of isostates is drawn on Fig. 11, this figure also shows the state of stress at a point, where the designation, direction and sense of the main stresses at point P of vertical cross section between notches of specific cell are obvious. Those places are supposed to serve for strain gauges placement and hence there is essential to find out directions of the main stresses here, in order to glue them on in the optimal directions. The isoclines and isostates image shows that direction of the main stress σ_1 is 30 degrees and the second main stress σ_2 has direction of 120 degrees toward horizontal axis. Assuming simple shear in those sections, the directions of the main stresses would be 45 and 135 degrees and gluing on strain gauges in those directions would not be optimal.

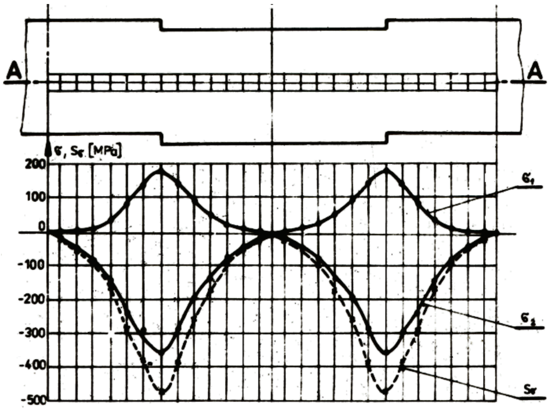

Fig. 12 *The courses of main stresses and stress intensity along cross section A - A*

The main stresses separation was done with a numerical solution of static conditions for equilibrium by shear stress difference method [1], [2], [4]. Evaluated courses of the main stresses along horizontal cross section A – A are drawn on Fig. 12. The picture also shows course of stress intensity S_σ, which value is identical with the size of reduced stress σ_{red} by HMH hypothesis and it was calculated according to equation:

$$S_\sigma = \sigma_{red} = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_2\sigma_1} \qquad (7)$$

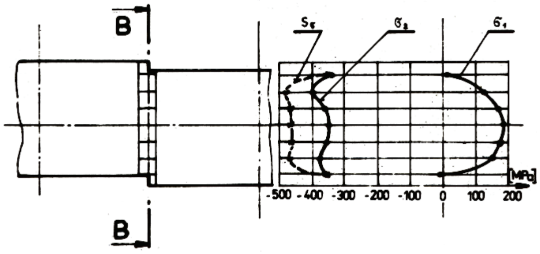

Fig. 13 *The courses of main stresses and stress intensity along cross section B - B*

Fig. 13 then shows evaluated courses of the main stresses and stress intensity along vertical cross section between notches B – B. The first main stress is tensile, the second compressive, but their values are not of the same size, as would correspond to a simple shear in this cross section.

CONCLUSION

The article describes results of detailed experimental stress analysis for shear specific cell of pressure ring transducer. Experimental analysis was carried out by means of the optical PhotoStress method and introduction above shows procedure at the necessary calibration of a photoelastic coating, if the coating is cast for the measurement of curved surfaces of a measured part. There were experimentally found out courses of isoclinic and isochromatic lines and by a shear stress difference method, courses of the main stresses and stress intensity in chosen cross sections were evaluated. Directions and magnitudes of main stress were localized for the following strain gauges gluing onto. The goal of this measurement was to achieve a maximal sensitivity of the designed dynamometrical transducer. During its nominal load the stress intensity magnitude in places of strain gauges gluing showed 470 MPa. Directions of the main stresses do not have in those places 45 degrees considering horizontal or longitudinal axis of the specific cell but 30 or 60 degrees depending on shape of the notch. Gluing on strain gauges into those places transducer's sensitivity increases by about 11,4% against traditional way of gluing them in 45 degrees angle, as Mohr's circle stress analysis would suggest. Measurement results serve as a valuable basis for dynamometric transducers design.

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