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Experimental Stress Analysis

The Application of Photostress Method for Experimental Stress Analysis of Plate Transducer

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Abstract: This article focus on an experimental stress analysis upon a dynamometric plate transducer. This kind of transducers is mostly used for rolling forces measurement under bearing housing of working or back-up rolls of rolling mills. Measurement was accomplished by means of a Photostress method. On the transducer side surface there was applied a Photostress coating and then isochromatic and isoclinic lines were photographed in reflected light during transducer nominal load. By means of a shear-difference method, main stresses courses and magnitudes as well as stress intensity values were found out. Obtained measurement results served as a support for further strain-gauge positioning and directing, in order to gain the maximal plate transducer sensitivity.

Keywords: Experimental stress analysis, Photostress, Transducer

1. Introduction

The cell transducers should not be overdesigned, because that leads to a significant reduction of sensitivity. That is why it is good to know transducer stress field during its nominal load and that is possible to find out by means of computing or experiment. In this case the experimental approach using the Photostress method was applied.

2. Measurement procedure and results

2.1. Applied optical method and materials

For the measurement itself the Photostress coating with thickness of 1.93 mm and made of material PS-1-B by VISHAY Company was used. It was applied on the plane side surface of the dynamometric shear plate transducer, see Fig. 1. There is necessary to know the mechanical and optical properties of the Photostress coating for quantitative evaluation of stress field on surface of the glued component. Optical properties of the Photostress coating material are characterized by dimensionless constant K, called a strain-optic coefficient of the photoelastic plastic. As far as components with plane surface are analyzed, usage of plane sheets by VISHAY is available. There are already provided with the strain-optic coefficient K by manufacturer. For analysis of curved surfaces the Photostress coating has to be cast first, shaped and also simultaneously calibrated. To measure the strain-optic coefficient K of cast coatings there can be use a calibration device Model 010-B made by VISHAY Company. The calibration procedure is described in references [1] and [2].

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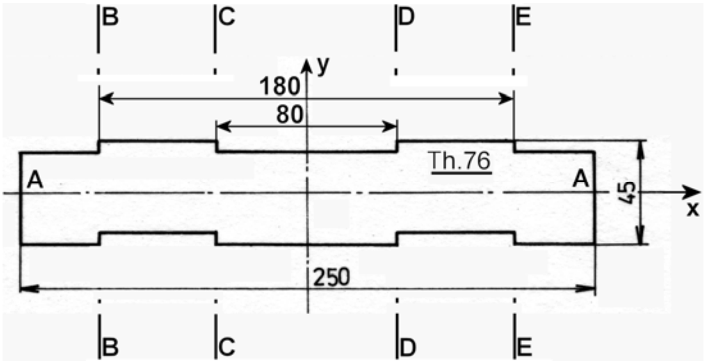

Fig. 1. The plate transducer

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

$$\delta = 2t(n_1 - n_2) = 2tK(\varepsilon_1 - \varepsilon_2) = m\lambda \tag{1}$$

Where δ means optical path difference of two polarized rays, caused by temporally 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. There is a constant 2 in the equation (1) because light ray echo passes through the photoelastic coating twice. The optical sensitivity of material K is then given by formula:

$$K = \frac{m \cdot \lambda}{2t(\varepsilon_1 - \varepsilon_2)} \tag{2}$$

Apart from the optical sensitivity K, which is non-dimensional and independent on cast thickness t of the photoelastic coating, practical measurement also uses another constant f called fringe value of the plastic coating that can be derived from previous equations:

$$(\varepsilon_1 - \varepsilon_2) = m\frac{\lambda}{2tK} = m \cdot f \tag{3}$$

$$f = \frac{\lambda}{2tK} \tag{4}$$

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

$$(\sigma_1 - \sigma_2) = \frac{E}{1+\mu}(\varepsilon_1 - \varepsilon_2) = \frac{E \cdot f}{1+\mu}m \tag{5}$$

According to the known fringe value f and measured order of isochromatic line can be by means of formula (3) computed difference of relative strains ratio (ε_1 - ε_2) in every single point of glued surface. The main stresses difference in examined points can be computed by formula (5).

Although the optical sensitivity K of used plain optically sensitive plate was given by manufacturer (K = 0.15), there was also carried out our own measurement by the calibration device mentioned above. The obtained measured result of the optical sensitivity was K = 0.152.

Attributes of used photoelastic coating PS-1-B are shown in Table 1:

Table 1. Attributes of photoelastic coating made from PS-1-B material

t	λ	μ	K	f
mm	nm	-	-	μm/m.order
1.93	575	0.33	0.15	993

2.2. Measurement procedure and evaluation

Shear plate transducer with glued photoelastic coating on was put into calibration press and loaded to its nominal force 800kN. There were in advance drawn grids on the photoelastic coating along estimated evaluation sections, more Fig. 2.

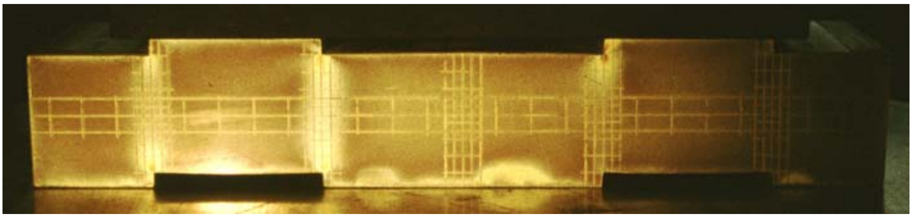

Fig. 2. Grids for the stress courses evaluation

Results of these measurements are determined courses of isoclinic and isochromatic lines, which serve as a basis for the following evaluation. Isoclinic lines join geometrical places of points, in which the directions of main stresses are constant and identical with the directions of crossing optical axes of polarizing filters in reflection polariscope. Isochromatic lines join geometrical places of points, which have difference of the main stresses constant.

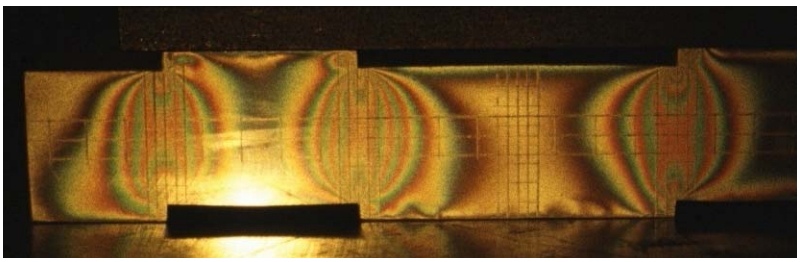

Fig. 3. Photo of isochromatic lines

Photo of developed courses of isochromatic lines on the photoelastic coating shows Fig. 3. Redrawn courses of the isochromatic lines with their order mark m are shown on Fig. 4.

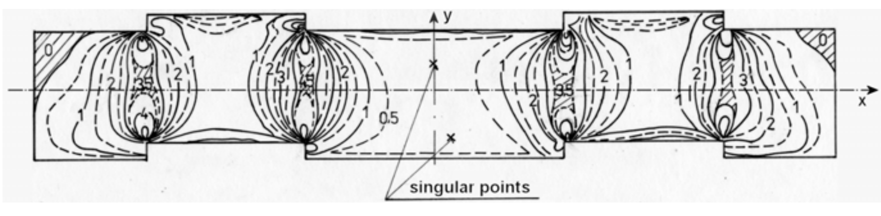

Fig. 4. Courses of the isochromatic lines

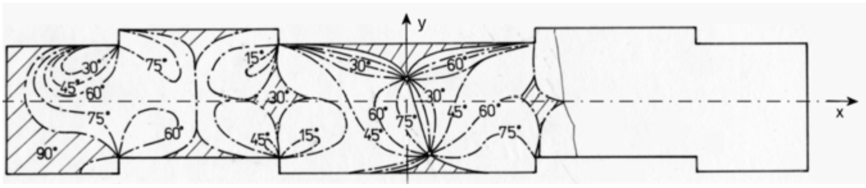

Fig. 5. Courses of the isoclinic lines

Detected course of isoclinic lines is redrawn on Fig. 5. From obtained projection of isoclines there was by means of graphic construction drawn the course of isostatic lines shown on Fig. 6.

Tangents and perpendiculars toward isostatic lines determine action of the main stresses directions. Image of isoclines shows significant singular points, where all isoclines pass through and both main stresses have the same magnitude. Asymmetric placement of these points shows asymmetric transducer load or transducer inaccurate production.

Measurement results are detected directions and difference in magnitudes of the main stresses, but it is not sufficient enough for the main stresses separation. That is why, there is necessary to perform other additional measurements or separate the main stresses numerically. The additional measurement can be accomplished for instance by oblique-incidence method, separation strain-gauge Photostress or using groove (Slitting method) [4].

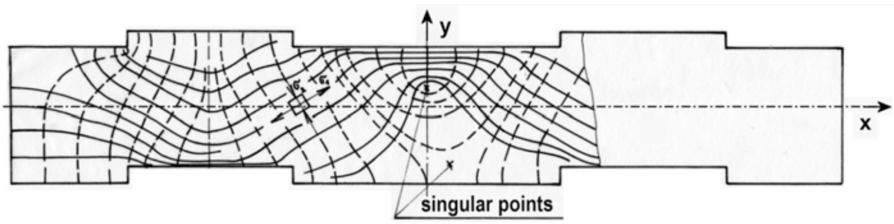

Fig. 6. Courses of the isostatic lines

In this case the main stresses separation was accomplished numerically by a shear stress difference method [5]. This method is based on a numerical solution of the static conditions for equilibrium for plain state stress on transducer surface by means of partial differential equations:

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} = 0; \quad \frac{\partial \tau_{yx}}{\partial x} + \frac{\partial \sigma_y}{\partial y} = 0 \tag{6}$$

Stress intensity values were then calculated by means of the obtained main stresses according to formula:

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

2.3. Measurement results

Measurement results are displayed by a form of evaluated main stresses courses along one horizontal and four vertical cross-sections on a side surface of the shear dynamometric transducer. Location of the chosen horizontal cross-section A – A and the vertical cross-sections B – B to E – E is shown on Fig. 1.

Evaluated courses of the main stresses and stress intensity along horizontal cross-section A – A are displayed on Fig. 7. The horizontal cross-section A – A as well as two auxiliary cross-sections a and b were divided by 25 points on a coordinate grid. In node points of this grid were out of isoclinic image evaluated directions of the main stresses and by means of digital compensator the main stress differences were measured. Evaluation of the stress field was initiated in the end point A by means of shear stress difference method. There is one main stress σ_1 in the vertical direction toward the transducer surface zero. The second main stress σ_2 can be easily calculated, based on measured order of isochromates m in this point and formula (5). The main stress σ_1 is tensile along whole cross-section, the main stress σ_2 mostly compressive with significant maxima in the locations of vertical cross-sections over notches.

Fig. 8 shows evaluated courses of the main stresses along vertical cross-sections B – B up to E – E. In those cross-sections the points 4, 9, 17 and 22 of horizontal section A - A were chosen as initiation points of an integration of static conditions for equilibrium, more Fig. 7. In those points there are all stress tensor components known, based on the previous evaluation along section A – A. As we can be seen from Fig. 8, every evaluated vertical section has main stress σ_1 tensile and main stress σ_2 compressive. The compressive main stresses σ_2 reach relative high values and also computed stress intensity in the notch neighbourhood reaches values up to 700 MPa.

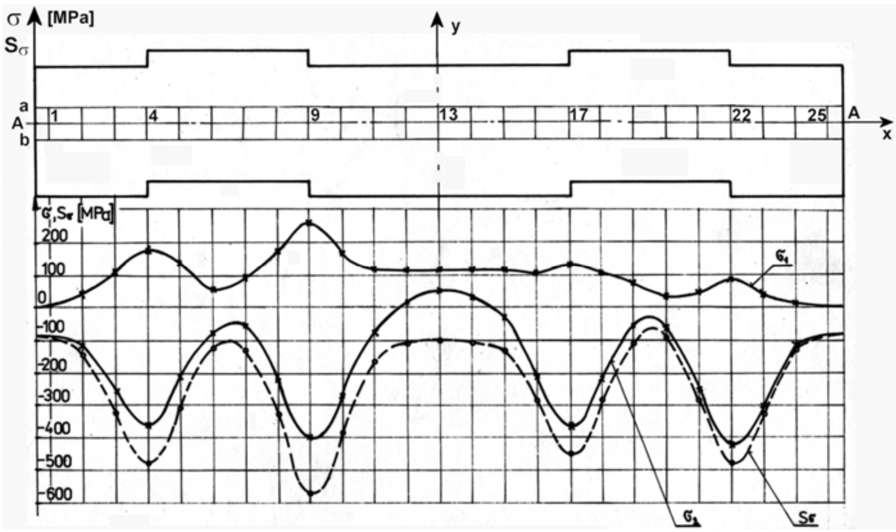

Fig. 7. Courses of the main stresses and stress intensity along the cross-section A - A

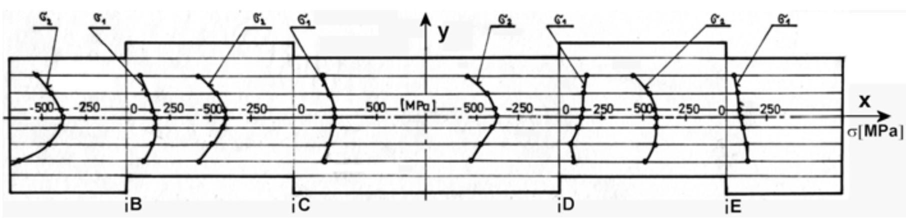

Fig. 8. Courses of the main stresses along the vertical cross-section through the notches

Fig. 9 shows detailed stress analysis in the most loaded point 9 of cross-section A – A, see Fig. 7. The evaluated isoclines courses by Fig. 5 show that the main stresses don't occur in

45° and 135° directions toward the horizontal axis x, as would happen during simple shear state of stress in this point. The real main stress directions are active in -30° and 60° as the Mohr's circle shows on Fig. 9. In order to achieve maximal transducer sensitivity, the strain-gauge should not be glued under 45 degree toward the horizontal axis x, but in the directions of the main stresses occurrence. Applying this, the transducer sensitivity can be increased up to 12%.

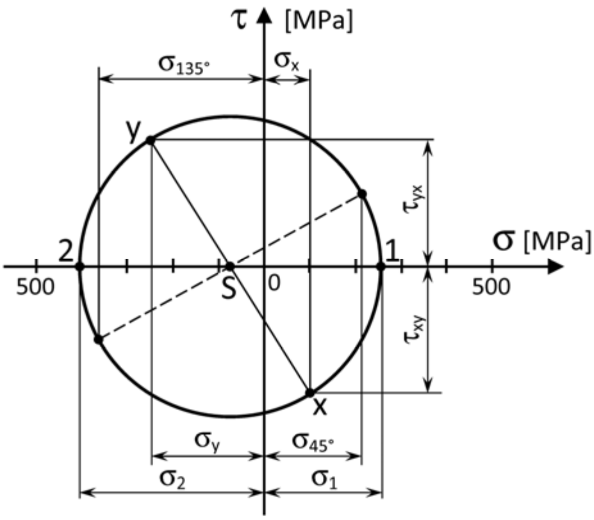

Fig. 9. Mohr's circle of stresses at point 9

From the evaluated courses of the main stresses and stress intensity according to Figs. 7 and 8 can be seen transducer non-uniform loading, its left side was loaded more. The photography from Fig. 2 was taken just after measurement and transducer unloading, the transducer shows obvious signs of overloading and locations of the vertical cross-sections reached permanent plastic deformations.

3. Conclusion

This paper briefly shows stress field measurement results of the shear dynamometric plate transducer. For the measurement itself optical experimental stress analysis method called PhotoStress was applied. The measured results showed non optimized transducer dimension design considering its nominal loading and undersized design of the transducer. Based on obtained measurement results, the transducer dimensions were redesigned and transducer was optimized.

References

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