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Verification of the eccentric hole influence on accuracy of the residual stress determination by Hole-drilling strain gage method

Karel Vítek[1], Vojtěch Havlík [1]

Abstract: This paper represents procedure for how to determine accuracy of hole-drilling method for cases in which the drilled hole is not centric with the centre of the strain gage rosette. There are two simplifications implemented in this paper. The first one is, that the residual stress will be represented by uniaxial tensile stress, which do not vary with depth and the second one is, that the hole will be drilled through all the material.

Keywords: Hole-drilling method; Residual stress; Eccentric hole

1. Introduction

Hole-drilling strain gage method represents semi-destructive method which is able to measure residual stresses near the surface of isotropic linear-elastic material. It is based on relaxation of the residual stress in vicinity of the drilled hole. Relaxation of the residual stress relieves deformations which are measured with strain gage rosette. Whole method has been standardized in ASTM Standard Test Method E 837 [2]. This standard prescribes that the centre of drilled hole shall coincide with the centre of the strain gage rosette to within either ±0.004D or ±0.025mm, whichever is greater. However there are no coefficients or corrections parameters for cases, when eccentricity is greater than is allowed. That´s why bigger values of eccentricity between the hole and strain-gage centre can introduce significant errors into the measurement of residual stresses.

2. Basic theory for hole-drilling method

When thin plate (Fig. 1.) is loaded with uniaxial tension stress σ_x, then in each point P [R,α] with polar coordinates R and α, we can describe state of stress in radial direction Eq. (1) and tangential direction Eq. (2).

$$\sigma'_r = \frac{\sigma_x}{2}(1+\cos 2\alpha) \qquad (1) \qquad\qquad \sigma'_\theta = \frac{\sigma_x}{2}(1-\cos 2\alpha) \qquad (2)$$

[1] *Dr. Ing. Karel Vítek; Department of Mechanics, Biomechanics and Mechatronics, Faculty of Mechanical Engineering, CTU in Prague, Technicka 4, 16607 Prague 6, Czech Republic, karel.vitek@fs.cvut.cz*
[1] *Bc. Vojtěch Havlík;vojtech.havlik@fs.cvut.cz*

Using the Kirch's theory [1] we can also describe state of stress in radial direction Eq. (3) and tangent direction Eq. (4) in each point P [R,α] on the thin plate with through-hole. Plate (Fig. 2.) with through hole is again loaded with uniaxial tension stress $\sigma_x = 1MPa$.

$$\sigma_r'' = \frac{\sigma_x}{2}(1-\frac{1}{r^2}) + \frac{\sigma_x}{2}(1+\frac{3}{r^4}-\frac{4}{r^2})\cos 2\alpha \tag{3}$$

$$\sigma_\theta'' = \frac{\sigma_x}{2}(1+\frac{1}{r^2}) - \frac{\sigma_x}{2}(1+\frac{3}{r^4})\cos 2\alpha \tag{4}$$

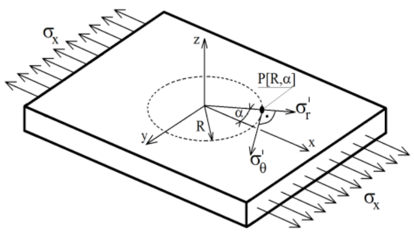

Fig. 1. Thin plate loaded with uniaxial tension stress

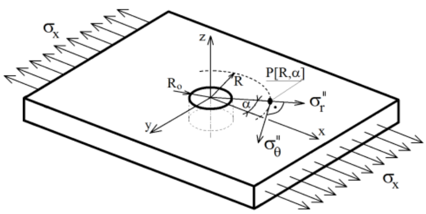

Fig. 2. Thin plate with through all hole loaded with uniaxial tension stress

Description of the state of stress for the plate with through-hole differs from description for the plate without hole. We can subtract equations Eq. (3) - Eq. (1) and Eq. (4) - Eq. (2) and the result which we obtain Eq. (5) and Eq. (6) represents change of the state of stress caused by presence of the drilled hole.

$$\sigma_r = \sigma_r'' - \sigma_r' = \frac{\sigma_x}{2}(-\frac{1}{r^2}) + \frac{\sigma_x}{2}(\frac{3}{r^4}-\frac{4}{r^2})\cos 2\alpha \tag{5}$$

$$\sigma_\theta = \sigma_\theta'' - \sigma_\theta' = \frac{\sigma_x}{2}(\frac{1}{r^2}) - \frac{\sigma_x}{2}(\frac{3}{r^4})\cos 2\alpha \tag{6}$$

Change of the state of stress after drilling the through-hole causes that strains in vicinity of the hole relieve. Thanks to the Hooke's law valid for isotropic material, we can write Eq. (7) for relieved strains ε_r and ε_θ.

$$\begin{bmatrix} \varepsilon_r \\ \varepsilon_\theta \end{bmatrix} = \frac{1}{E}\begin{bmatrix} 1 & -\nu \\ -\nu & 1 \end{bmatrix}\begin{bmatrix} \sigma_r \\ \sigma_\theta \end{bmatrix} = \frac{1}{E}\begin{bmatrix} 1 & -\nu \\ -\nu & 1 \end{bmatrix}\begin{bmatrix} \frac{\sigma_x}{2}(-\frac{1}{r^2}) + \frac{\sigma_x}{2}(\frac{3}{r^4}-\frac{4}{r^2})\cos 2\alpha \\ \frac{\sigma_x}{2}(\frac{1}{r^2}) - \frac{\sigma_x}{2}(\frac{3}{r^4})\cos 2\alpha \end{bmatrix} \tag{7}$$

Relieved radial and tangent strains which appear after drilling the hole are described by the equations Eq. (8) and Eq. (9) These equations have been solved in Matlab with variables values: hole radius R_0=1mm, E=200 000MPa, ν=0.3, $\sigma_x = 1MPa$ and r is defined as $r=R/R_0$. Results are displayed on the graphs (Fig. 3) and (Fig.4).

$$\varepsilon_r = \frac{\sigma_x \cdot (1+\nu)}{2E}\left[-\frac{1}{r^2}+\left(\frac{3}{r^4}-\frac{4}{(1+\nu)\cdot r^2}\right)\right]\cdot \cos 2\alpha \tag{8}$$

$$\varepsilon_\theta = \frac{\sigma_x \cdot (1+\nu)}{2E}\left[\frac{1}{r^2}-\left(\frac{3}{r^4}+\frac{4}{(1+\nu)\cdot r^2}\right)\right]\cdot \cos 2\alpha \tag{9}$$

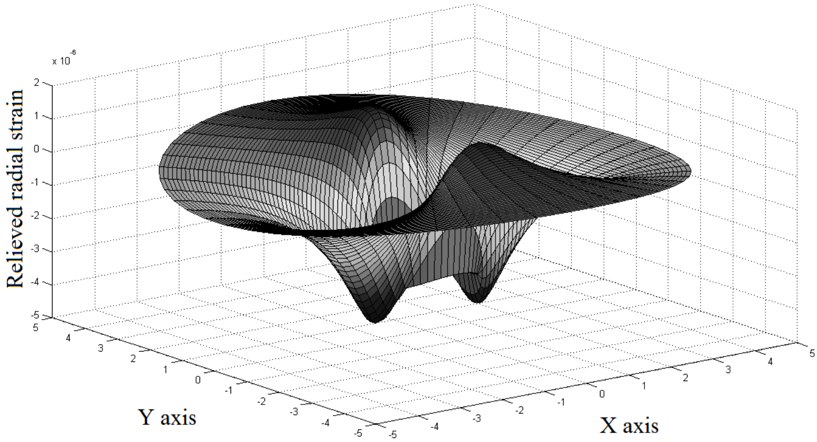

Fig. 3. Relieved radial strain

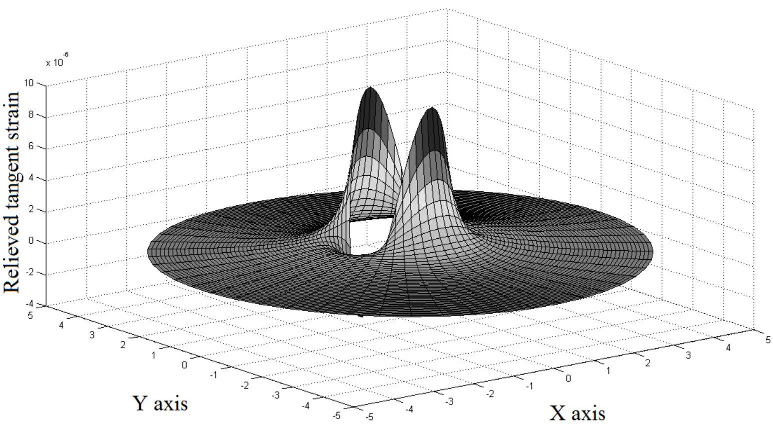

Fig. 4. Relieved tangential strain

3. Results from FEM simulation

The same plate with through-hole (Fig. 2) loaded with uniaxial tension stress $\sigma_x = 1MPa$ has been simulated and solved in FEM software Abaqus. Results of radial and tangential strain are displayed in the (Fig. 5.) and (Fig. 6.).

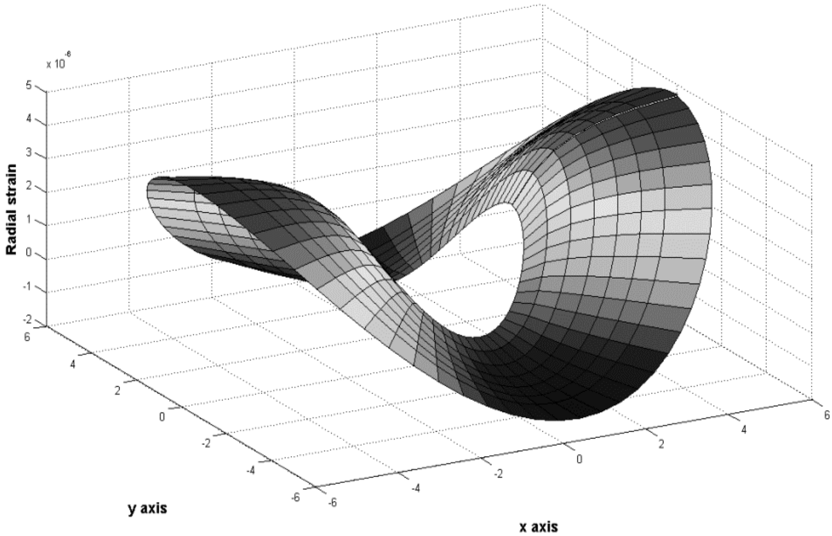

Fig. 5. Radial strain

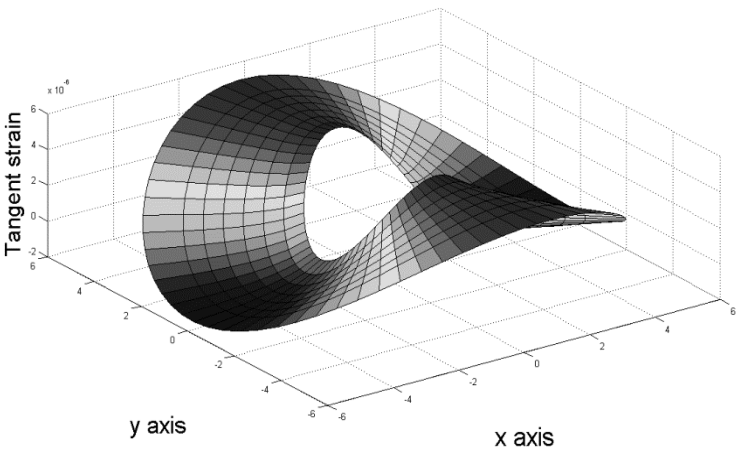

Fig. 6. Tangential strain

To determine the influence of eccentric hole there has been also simulated the model of the plate with relatively big eccentricity $0.1R_0$ in x axis direction. Then it´s possible to subtract both results for centric and eccentric hole and we obtain error which represents how does radial and tangential strain vary due to the eccentric hole.

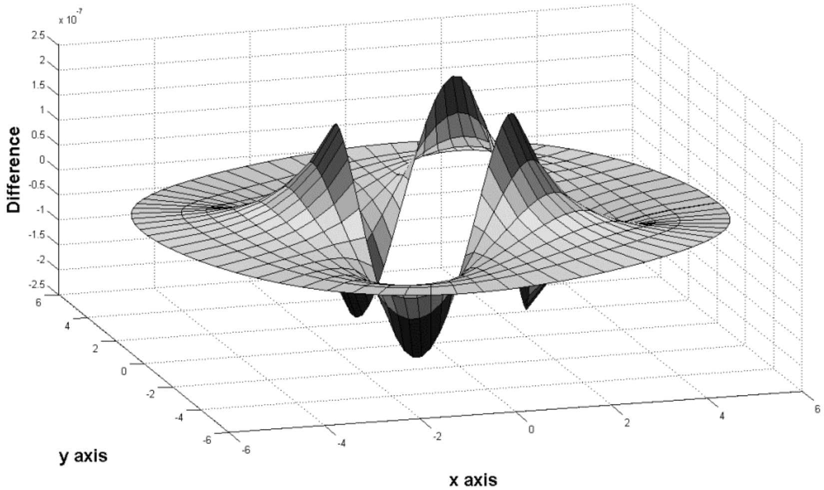

Fig. 7. Difference between radial strain of centric and eccentric hole

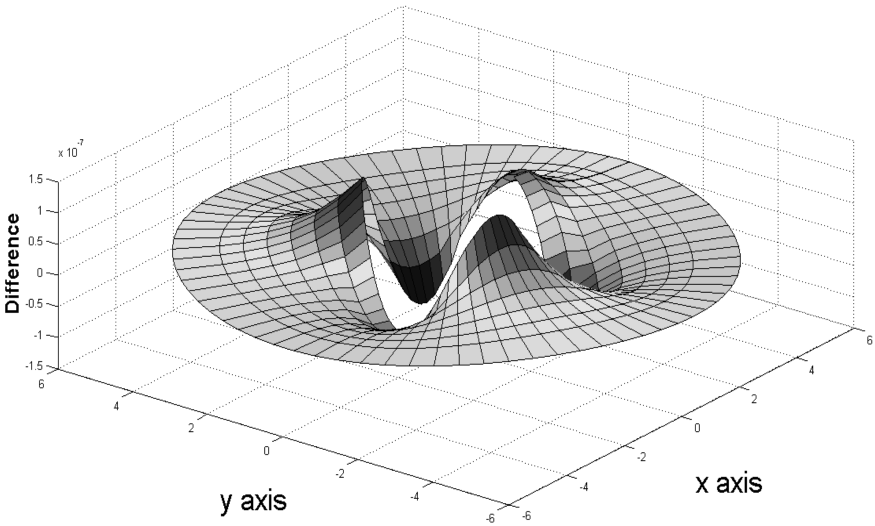

Fig. 8. Difference between tangential strain of centric and eccentric hole

4. Computation of relative errors

Relative error is here defined as difference between strains of centric and eccentric hole divided by the strain of centric hole. But first we have to modify the strain data. Values of relative errors are supposed to be zero in cases, when strains are smaller than the filter parameter. In the other way especially very small strains produce big relative errors. Next figures (Fig. 9 – Fig. 12) display relative error of both polar and tangential strains for two amounts of filter parameter (5e-7 and 1e-6)

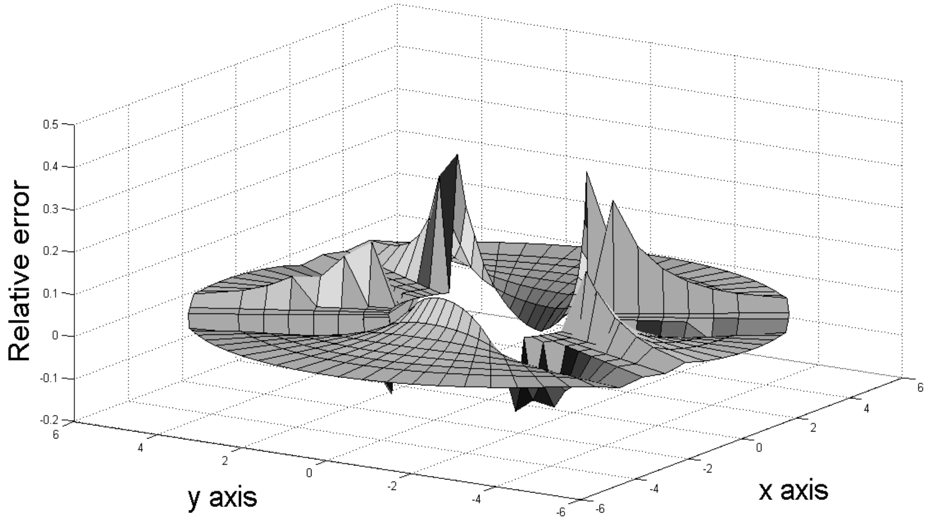

Fig. 9. Relative error of radial strain – filter 5e-7

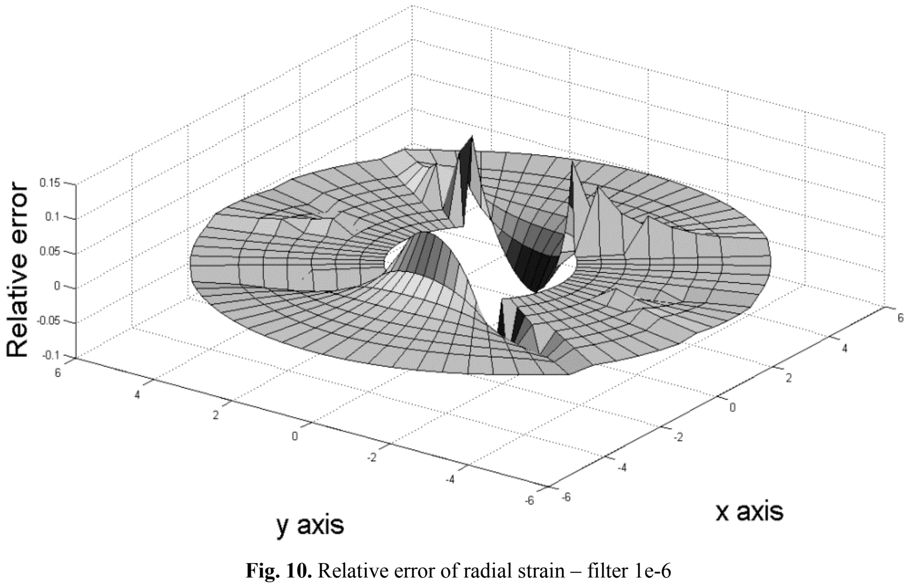

Fig. 10. Relative error of radial strain – filter 1e-6

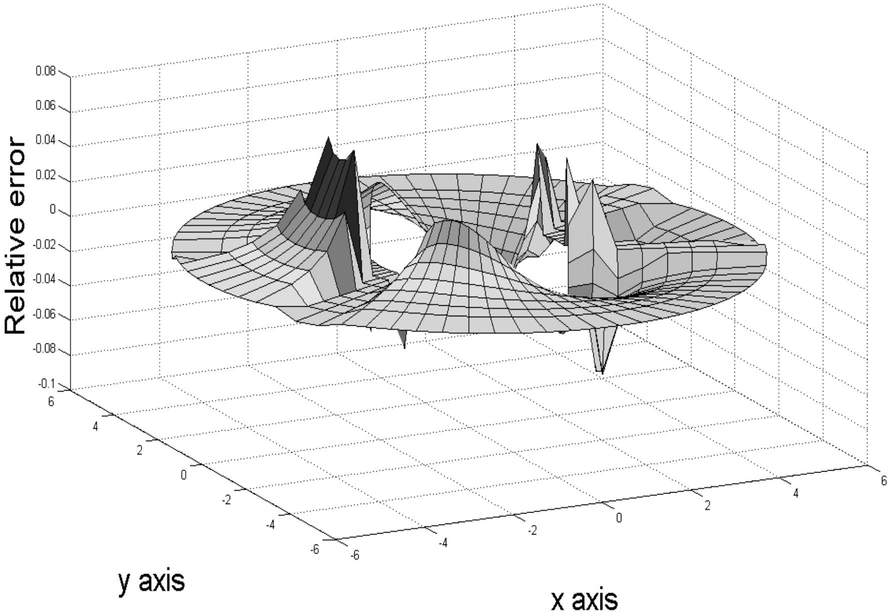

Fig. 11. Relative error of tangential strain – filter 5e-7

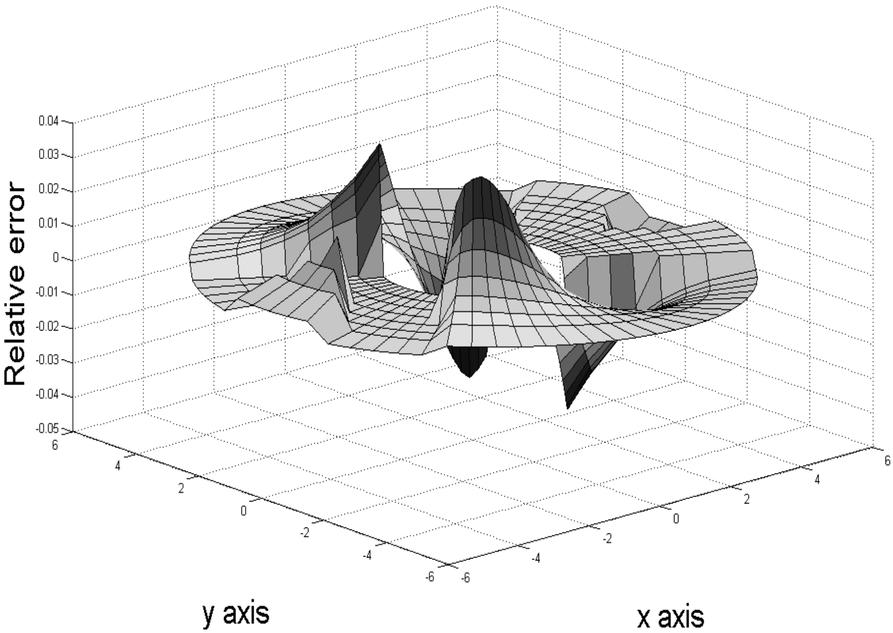

Fig.12. Relative error of tangenttial strain – filter 1e-6

5. Conclusion

The hole drilling method uses strain gage rosette with three strain gages which measure strains in vicinity of the drilled hole. Then residual stresses and angle between them are compute from these three values of strain. Eccentricity $0.1R_0$ can produce error in radial strains about 10% and in tangential strain even 30% as we can see on Fig. 9 - Fig. 12. These errors can significantly influence accuracy of compute residual stresses.

Acknowledgement

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References

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