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Petr BOHDAN*, Stanislav HOLÝ, Jiří JANKOVEC***, Petr JAROŠ****, Jaroslav VÁCLAVÍK*****, Otakar WEINBERG******

RESIDUAL STRESS MEASUREMENT USING RING-CORE METHOD

MĚŘENÍ ZBYTKOVÝCH NAPĚTÍ METODOU ODVRTÁNÍ MEZIKRUŽÍ

Abstract

The method for measuring residual stresses using ring-core method is described. Basic relations are given for residual stress measurement along the specimen depth and simplified method is described for average residual stress estimation in the drilled layer for known principal stress directions. The estimation of calculated coefficients is made using FEM. Comparison of method sensitivity is made with hole drilling method. The device for method application is described and an initial experiment is introduced.

Abstrakt

Je popsána metoda pro měření zbytkových napětí metodou odvrtání mezikruží. Jsou uvedeny základní vztahy pro výpočet zbytkového napětí po hloubce a je uvedena zjednodušená metoda pro odhad napětí v odvrtané vrstvě při známém směru hlavních napětí. Odhad výpočtových koeficientů je proveden pomocí MKP. Je uvedeno porovnání citlivosti metody s metodou odvrtání otvoru. Je popsáno zařízení pro aplikaci metody a je uveden úvodní experiment.

1 INTRODUCTION

Identification of residual stresses in the structure is very important for estimation of the structure service or residual service life. In some cases the determination of residual stresses is used for controlling the manufacture process indirectly, which is the case of checking the core residual stresses of large forgings induced by heat treatment process through measuring the surface residual stresses. However, the surface residual stresses are always influenced by stresses, induced due to rough turning, as there is difficult to apply the hole-drilling method to the rough structure of the non-machined shaft. The influenced depth by turning is approximately 1 mm, so there is the effort to measure the stress at least 2 mm below the surface. The allowable limit of residual stress is about 60 MPa in a lot of mentioned cases. The most widely used method for measuring residual stresses, the hole-drilling method, is sometimes used for this type of investigations. Procedures, sensitive to non-linear stress field, have to be used for measured data evaluation, which may be among others power series method [1], integral method [2] or method, using derivatives of relieved strains [3]. But

* Ing., Dynamic Testing Laboratory, ŠKODA VÝZKUM s.r.o., Tylova 1/57, 316 00 Plzeň, tel. (+420) 37 818 2143, e-mail petr.bohdan@skodavyzkum.cz
** Prof.Ing.CSc., Institute of Mechanics, Mechanical Faculty, Technical University in Prague, Technická 4,, tel. (+420) 22 435 2510, e-mail stanislav.holy@fs.cvut.cz
*** Ph.D.Ing., Computational Modelling, ŠKODA VÝZKUM s.r.o., Tylova 1/57, 316 00 Plzeň, tel. (+420) 37 818 2203, e-mail jiri.jankovec@skodavyzkum.cz
**** Ing, Techlab Ltd., Sokolovská 207, 190 00 Praha, (+420) 28 389 0583, e-mail techlab@czn.cz
***** Ing., Dynamic Testing Laboratory, ŠKODA VÝZKUM s.r.o., Tylova 1/57, 316 00 Plzeň, tel. (+420) 37 818 2162, e-mail jaroslav.vaclavik@skodavyzkum.cz
****** Ing., Dynamic Testing Laboratory, ŠKODA VÝZKUM s.r.o., Tylova 1/57, 316 00 Plzeň, tel. (+420) 37 818 2123, e-mail otakar.weinberg@skodavyzkum.cz

these methods are not sensitive enough at required depths, to give the stresses with satisfactory accuracy using conventionally produced strain gauge rosette diameters. This is the reason; the ring-core method was implemented in the ŠKODA VÝZKUM s.r.o. [4]. This method allows measurements up to 6 mm depth, enables evaluation of stress profile along the depth and provides full relaxation of the stresses without undesirable stress concentration effects.

2 THEORY OF RING-CORE METHOD

In the ring-core method, an annular grove is machined in the surface of the structural part with a crown-milling cutter. The method utilizes the relaxation effect in the core to measure the macroscopic inherent stresses. The relieved strains are measured at the face of the core using three-element rectangular rosette at common direction *a*, *b* and *c* and the residual stresses are calculated using derivatives of these strains with respect to the depth *z* with the help of relaxation coefficients K_1, K_2, derived for uniaxial stress $\sigma_{1,\,cal}$ experimentally or with the help of FEM (1). The residual stresses in direction *a, b, c* are first calculated (2) to (4) and the principal stresses and their directions are obtained from them as usual (5). The evaluation method is the same as used in [3] for hole-drilling method.

$$K_1 = \frac{E}{\sigma_{1,cal}} \cdot \frac{d\varepsilon_{1,cal}}{dz}, \qquad K_2 = \frac{E}{\nu \cdot \sigma_{1,cal}} \cdot \frac{d\varepsilon_{2,cal}}{dz} \tag{1}$$

$$\sigma_a = \frac{E}{K_1^2 - \nu^2 \cdot K_2^2} \cdot \left(K_1 \cdot \frac{d\varepsilon_a}{dz} - \nu \cdot K_2 \cdot \frac{d\varepsilon_c}{dz} \right) \tag{2}$$

$$\sigma_b = \frac{E}{K_1^2 - \nu^2 \cdot K_2^2} \cdot \left[K_1 \cdot \frac{d\varepsilon_b}{dz} - \nu \cdot K_2 \cdot \left(\frac{d\varepsilon_a}{dz} - \frac{d\varepsilon_a}{dz} + \frac{d\varepsilon_c}{dz} \right) \right] \tag{3}$$

$$\sigma_a = \frac{E}{K_1^2 - \nu^2 \cdot K_2^2} \cdot \left(K_1 \cdot \frac{d\varepsilon_c}{dz} - \nu \cdot K_2 \cdot \frac{d\varepsilon_a}{dz} \right) \tag{4}$$

$$\sigma_{1,2} = \frac{\sigma_a + \sigma_c}{2} \pm \frac{1}{\sqrt{2}} \cdot \sqrt{(\sigma_b - \sigma_a)^2 - (\sigma_b - \sigma_c)^2}, \; \varphi = \frac{1}{2} \arctan \frac{2 \cdot \sigma_b - \sigma_a - \sigma_c}{\sigma_a - \sigma_c} \tag{5}$$

To performed production tests, where the principal directions are known, as there is on large shafts, the simplified differential method is suitable. This method is based on the fact, that the residual stress may be assumed constant within the drilled layer. The principal stresses σ_1 and σ_2 in two perpendicular rosette directions *a* and *c* are calculated in the layer between the drilled depth *z* and $2 \cdot z$ using measured strains differences at these directions between these drilling steps $\Delta\varepsilon_a$, $\Delta\varepsilon_b$. The relaxation coefficients *A* and *B*, according (8) for this depth difference are used for stress calculation according relation (9)

$$\Delta\varepsilon_{a,cal} = \varepsilon_{a,2z} - \varepsilon_{a,z}, \qquad \Delta\varepsilon_{b,cal} = \varepsilon_{b,2z} - \varepsilon_{b,z} \tag{6}$$

$$\Delta\varepsilon^*_{a,cal} = \frac{\Delta\varepsilon_{a,cal}}{\varepsilon_{1,cal}} \qquad \Delta\varepsilon^*_{b,cal} = \frac{\Delta\varepsilon_{b,cal}}{\nu \cdot \varepsilon_{1,cal}} \tag{7}$$

$$A = \frac{E \cdot \Delta\varepsilon^*_{a,cal}}{\left(\Delta\varepsilon^*_{a,cal}\right)^2 - \left(\nu \cdot \Delta\varepsilon^*_{b,cal}\right)^2} \qquad B = \frac{E \cdot \Delta\varepsilon^*_{b,cal}}{\left(\Delta\varepsilon^*_{a,cal}\right)^2 - \left(\nu \cdot \Delta\varepsilon^*_{b,cal}\right)^2} \tag{8}$$

$$\sigma_1 = A \cdot \Delta\varepsilon_a - B \cdot \Delta \cdot \varepsilon_b , \qquad \sigma_2 = A \cdot \Delta\varepsilon_b - B \cdot \Delta \cdot \varepsilon_a \tag{9}$$

3 COMPARISON OF RING-CORE WITH HOLE DRILLING METHOD

Comparison of absolute relieved strains for both ring-core (Ø14/Ø18 mm) and hole-drilling (RY21, Ø 4 and Ø 6 mm, RY61, hole Ø1.5) methods for uniform uniaxial stress 60 MPa, is made in Fig. 1 a) and curve derivatives are given in Fig. 1 b). Derived coefficients *K1* and *K2* according (1) are shown in Fig. 2. and simplified coefficients *A* and *B* are expressed in Fig. 3. The most sensitive depth for hole drilling method is 0,5 mm for small and 1 mm for large rosettes, where the derivatives have the maximum. The depth of this peak does not changed with increasing the hole diameter. The highest sensitivity of ring-core method is over 2 mm depths. This fact is visible also from Fig. 3, where the lowest value of *A*, *B* gives the highest sensitivity of the method. Ring-core method is the best solution for residual stress measurement in the layer 2÷4 mm, but for the layer 1÷2 mm the rosette RY21 with the hole Ø 6 mm also can be recommended. Manually applied large rosette on mean diameter *D* around the ring-core hole d =, with the same *d/D* ratio as RY21, Ø 6 mm, gives unexpected low sensitivity, comparable with RY21, Ø 6 mm rosette. All charts are based on FEM calculations.

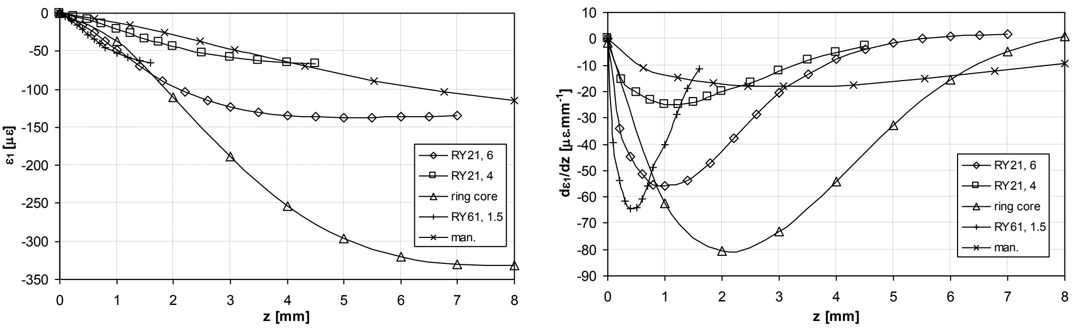

Fig. 1 Comparison of relieved strains and their derivatives for uniaxial stress σ_1 = 60 MPa

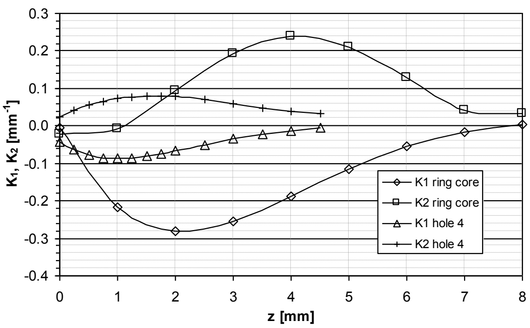

Fig. 2 Calculated relaxation constants K_1, K_2

	A ring	B ring	A RY21,6	B RY21,6	A RY21,4	B RY21,4	A man.	B man.
0.5-1 mm			-2.2783	0.4386	-5.2464	1.2171		
1-2 mm	-0.8216	0.0291	-1.3418	0.3477	-2.8920	0.8579	-2.9035	0.5280
2-4 mm	-0.4444	0.1074	-2.0368	0.9575	-3.6742	1.7686	-1.9299	0.4249
3-6 mm	-0.5814	0.2669					-1.1644	0.3113

Fig. 3 Calculated relaxation constants *A*, *B*

4 APPLICATION OF THE METHOD

The ring-core equipment consists of a base section and a drive section. After the base section is placed on the object and fastened with three magnetic foots, the measuring circle is marked out with the help of a guide plate. Special strain gauge rosette FR-5-11 TML with integrated leading wires in three-wire connection is applied in the centre of the circle. Then the drive section of the equipment is placed on its lifting rod and the leads are threaded through the hollow spindle to the static measuring amplifier TC-31K, TML. The annular groove Ø14/Ø18 mm is machined with special tubular milling cutter in steps of 0,5 mm, the depth is controlled via dial gauge.

An introductory investigation of the described equipment was made on the thin plate under four point bending. The principal upper surface stress was about 120 MPa, verification of neutral axes position and the loading symmetry was performed using additional four strain gauges. In Fig. 4., ring core drilling device (a) and detail of drilled core (b) are shown.

a)

b)

Fig. 4 Device for ring-core drilling (a) and detail of drilled ring (b)

5 CONCLUSION

The ring core method was implemented in ŠKODA VÝZKUM s.r.o. It is suitable for measurement of under-surface stresses, where the standard hole-drilling method is less sensitive. An improvement of mathematical model, experimental determination of calibrated coefficients, more detailed sensitivity and reliability analysis of ring-core method is the object of prepared project, which should be solved during next years.

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Reviewer: prof. MSc. Pavel MACURA, DrSc., VŠB - Technical University of Ostrava