EAN '92
30th Conference of Experimental Stress Analysis
30. konference o experimentální analýze napětí
2. - 5. 6. 1992 ČVUT Praha Czechoslovakia

RING-CORE METHOD FOR THE DETERMINATION OF RESIDUAL STRESSES DEMONSTRATED BY MEANS OF AN APPLICATION EXAMPLE

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The paper deals with the experimental determination of residual stress using the strain-gage based ring-core method. the method is carried out with a complete lmeasuring system which consists of strain-gage rosettes as sensors, a multipoint measuring unit and a computer running HBM's BEAM program.

Keywords : strain, residual stress, ring-core

1. INTRODUCTION

The ring-core method is one of many strain-gage based methods used for the determination of resdidual stresses. A feature common to all these methods is that changes of strain are measured from which the residual stress state must be calculated. Particularly the ring-core method entails a considerable degree of computation, which however recedes into the background if the user employs up-to-date techniques. The following shows by means of an actual industrial application example how residual stress determinations with the ring-core method can be carried out quite simply using an appropriate on-line measuring system and HBM's BEAM software.

2. THE RING-CORE METHOD

With the ring-core method a special ring-core rosette is bonded to the surface of the measurement object and a small annular-shaped groove is milled around it with special equipment. The ring-core rosette is a combination of three superimposed strain measuring grids, each angularly displaced by 45°. Figure 1 shows this rosette with views from above and below. The milling procedure leaves the upper part of the central core separated from the surrounding material. This separation causes the release of part of the residual stresses present in the core. The deformations occurring on the face side of the core are measured in three directions by the measuring grids of the strain-gage rosette and inferences can be made regarding the residual stress state before the groove was milled [1 to 3].

The ring-core method is able to provide information on the residual stresses in the layers situated below the component's surface. In order to achieve this, the technique requires the measurement of the changes in strain in relationship to the groove depth. The principle of the method is based on the step by step milling of the annular groove which releases residual stresses causing changes in strain on the upper face of the core. The changes in strain measured on the surface are dependent on the residual stress state about to be measured, but also on the core diameter, the shape of the groove bottom, the geometrical arrangement of the strain gage rosette and the groove depth. The groove depth is a supplementary measurement quantity for the technique and is monitored continuously.

The core diameter, groove depth and the strain gage arrangement influence the effect the release of residual stresses has on the change in strain on the surface. This influence must be determined in a calibration procedure using the original milling equipment and type of rosette before the actual measurements can be taken. With the calibration procedure a known uniaxial stress state is created using loading equipment in a bar in which the residual stresses have been eliminated as far as possible. The ring-core method is then applied using the equipment. The changes in strain which occur on the core during the milling of the groove are measured, in dependence of the groove depth, in the principal directions 1 and 2 of the loaded calibration sample. These strains measured on the core are compared with the actual principal strains which are given by the known current stress state and which would have occurred on the core had no groove been present. Relaxation factors are found from this comparison. These factors were expressed in the form of relaxation functions in relationship to the groove's depth. These relaxation functions were approximated to polynomials and included in the computer program used as software for the evaluation of the measured strains. A detailed explanation of the mathematical evaluation is given in [1].

3. PRACTICAL APPLICATION ON A LOW PRESSURE TURBINE DISK

The practical application of the method is demonstrated here by means of a typical example from the field of power plant engineering. Steam-turbine rotors for power stations up to about 1300 MW are often produced as a disk rotor, which usually consists of a spindle shaft onto which the circular disks are shrunk.

Compressive residual stresses in the disk near to the shrunk-on joint are an advantage in the component's design. By employing specific thermal treatment in the manufacture of the disks certain magnitudes and distributions of the residual stresses can be achieved in the disks. In order to optimize the treatment and to improve the quality control of the component, it is therefore important that the residual stresses in the disks are measured after heat treatment and before machining the final shape.

The practical application of the method is made with a mechanical device which enables centring of the milling tool over the ring-core rosette with the minimum of play and which can give fine increments in the cutter feed. The feed is measured electrically by an inductive displacement transducer. Its electrical output signal is passed, along with the output signals from the three strain-gage grids to the on-line measurement system.

Acquisition and processing of the output signals are carried out with the UPM 60 Multipoint Measuring Unit which operates on line with an Apple Macintosh Computer. Here, the measurements are transferred directly via the instrument's interface to the computer for evaluation using the BEAM program developed by HBM. Figure 2 shows the complete test equipment in operation on the raw turbine disk. The test procedure begins with the zero adjustment of the output signals of the strain gages and the displacement transducer. This procedure is carried out automatically by the on-line system. Then the milling process starts. With a core diameter of 14 mm, depth increments of 0.5 mm are used.

The computer receives the measurements directly from the multipoint measuring unit for each depth increment via its interface. All computations to evaluate the measured changes in strain during the milling process are carried out by the computer. The BEAM software program additionally offers a wide variety of options for graphical presentation of the test results. An example is given in Figure 3 which represents the screen image as generated during the test. The graph on the upper left shows the measured strains in relationship to the groove's depth. The lower graph on the left gives the stress components in the three measurement directions of the rosette's grids. The principal stresses of the residual stress state in the measurement object are given in the graph on the upper right and the orientation angle of the principal direction 1 related to the reference direction "a" of the rosette is plotted in the lower graph on the right-hand side. They represent the distribution of the residual stresses in the layers under the surface of the test sample down to a depth of 4.00 mm.

In order to obtain a complete image of the residual stress distribution along the disk's radius a row of measuring points is arranged on the surface of the disk. Figure 4 represents the distribution of the residual stress as determined at seven marked points along the contours of a cross-section of the disk. The tangential, axial and radial components of the residual stresses are plotted. Allowances for extra material were made on the raw forged disk so that the ring-core method can be applied without detriment to the finished disk. Once the ring-core tests have been concluded, the measuring points can be removed by machining, leaving the finished product free from any traces.

REFERENCES

[1] Wolf, H., W. Böhm: Das Ring-Kem-Verfahren zur Messung von Eigenspannungen und seine Anwendungen bei Turbinen- und Generatorwellen; Arch.f.d.Eisenhüttenwesen 42 (1971), pp. 195-200

[2] Wolf, H. W. Böhm: Entstehung, Messung und Beurteilung von Eigenspannungen in schweren Schmiedestücken für Turbinen und Generatoren; Arch.f.d.Eisenhütten-wesen 42 (1971), pp.509-513

[3] Wolf, H., E. Stücker, H.Nowack: Eigenspannungsuntersuchungen im Turbinen- und Generatorbau; Arch.f.d.Eisenhüttenwesen 48 (1977), pp. 173-178

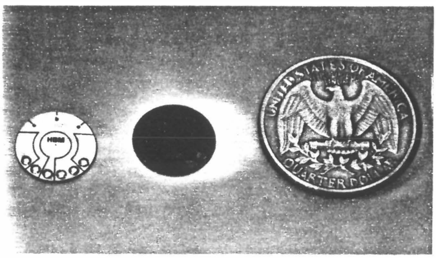

Fig. 1: RY 51 Ring-core Rosette viewed from above and below

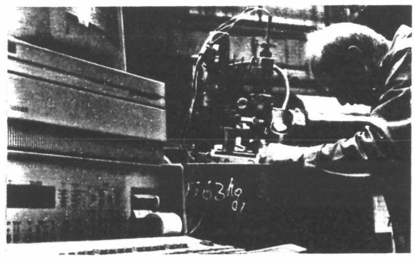

Fig. 2: The complete on line measurement system in application on the turbine disk

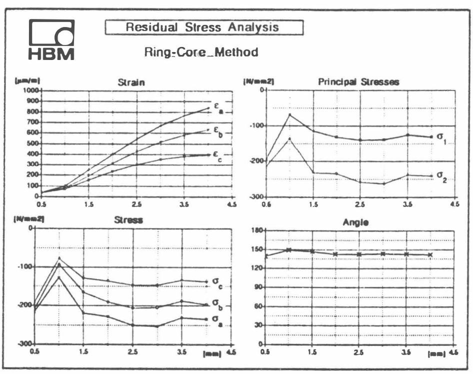

Fig. 3: Display of the results as given by the computer's monitor, represented as functions of the groove depth

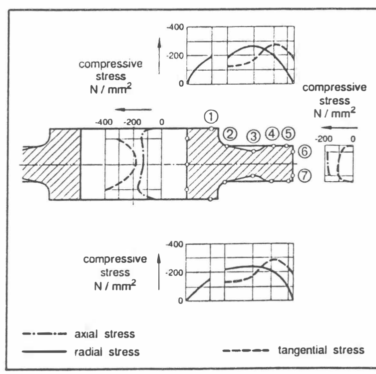

Fig. 4: Tangential, radial and axial components of the residual stress state as determined from seven measuring points

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