STRESS AND STRAIN ANALYSIS IN STEAM TURBINE OPERATION UPON
ROTOR STRAIGHTENING BY INDUCTION HEATING

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Abstract
Upon straightening of deformed steam turbine rotor by induction heating and stress relaxation, certain stresses are being remained. These stresses may cause new deformations in further operation of the steam turbine rotor. That is why it is necessary to determine minimum value of remained stresses that are not going to cause new rotor deformations. In this paper we have used simulation of the steam turbine operation by application of non-linear methods of finite elements, comparing obtained data with those that were measured and observed in thermo-electric power plant Tuzla.

1. INTRODUCTION
Companies that are being performed the steam turbine overhaul, adopted and successfully apply rotor axle straightening procedure based on correction of the creep phenomenon and stress relaxation by utilisation of the induction heating method. Substantially, by this method a straightening of the rotor and keeping of its shape stability is being performed. The essence of the method is as follows:
Relaxation steel characteristic is a ratio of the lowered stress value ($\Delta \sigma$) and initial stress ($\sigma_1$):

$$n = \frac{\Delta \sigma}{\sigma_1} \times 100 \%$$

In a case of total relaxation, final stress ($\sigma_2$) should be zero i.e. to disappear completely. What value of the remained stress is going to be, depends on the elastic deformation value and on the intensity of transition of elastic deformation into a plastic deformation. Straightening technology is based on the induction heating of the steam turbine rotor warping zone and its subjecting to external force that brings about elastic deformation. During such a process, under the action of external load and increased temperature in determined time interval, elastic limit is being decreased along with the change of the stress-strain ratio, and consequently one part of the elastic deformation is being transformed into a local plastic deformation. By keeping of this process at the temperature of relaxation and straightening, the material creeping phenomenon is being appearing that causes further plastic deformation along with a fall of the internal stresses. In this way straightening of the rotor axle and disappearing of internal stress is being brought about that provides the rotor axle shape stability independently on former warping.

The procedure of the turbine rotor axle straightening is very complex and expensive, and is possible to optimise by application of the appropriate model. Numerical modelling of thermo-technical phenomena, during the procedure of straightening of rotor of mean pressure turbine TK200-130 LMZ in power plant "Tuzla" was carried out by utilisation of the Finite Elements Method (FEM).
In numerical analyses of elastic-plastic deformations, type of analysis with large displacement, large rotations and small deformations was used along with linear or non-linear relation between stresses and deformations. Equations employed in model were derived and applied by means of ADINA program. Starting with Piola-Kirchof stress tensor and the Green-Lagrange deformation velocity tensor, as well as with Caushy stress tensor and Almansy deformation velocity tensor, constitutive equations, suitable for Total-Lagrange (T.L.) or Updates-Lagrange (U.L.) formulation. Cited modelling method by thermo-mechanical connection, ADINA-TMC, was tested by comparison with results obtained in practice at an example of the turbine rotor.

Figure 1. Rotor of the mean pressure turbine TK200-130 LMZ, object of modelling

2. MODELLING PRINCIPLES

2.1 Model Description
Research, described in this paper, was carried out during the straightening procedure at the rotor axle of mean pressure turbine TK200-130 LMZ in power plant "Tuzla" – Block 3.

Figure 2. Rotor model of the mean pressure turbine, 3D finite elements mesh

Total length of the rotor axle amounts 5800 mm.
Distance between the rotor axle support amounts 4280 mm.
Maximal rotor axle diameter amounts 640/160 mm.
Minimal rotor axle diameter amounts 350/160 mm.
Maximal rotor axle deflection upon break-down amounts 0.28 mm
Maximal rotor axle deflection after straightening by heating induction amounts 0.06 mm
Material rotor: 25HM
Rotors model is simplified and is presented without moving blades.

2.2 Description of Boundary Conditions
Mathematical model, employed for description of elastic-plastic deformations, is made of the equations of the momentum and angular momentum preservation, as well as constitutive equations for elastic-plastic body with initial and boundary conditions.
Operating steam temperature is 793 [K].
Rotor revolution number 3000 [min⁻¹].

2.3 Modelling Description
Upon the rotor axle straightening and the turbine block overhaul, the turbine was actuated and its exploitation was started again. During the turbine exploitation, values of the internal stresses and the rotor axle deflection were observed. The model was stopped at the moment when increased internal stresses appeared-raised, that caused renewed rotor axle warping. That had happened after 896 hours of operation.

3. INVESTIGATION RESULTS ANALYSIS
Distribution of remained stresses in the turbine rotor axle, after straightening procedure by induction full-annealing, is presented in the Figure 3.

**Figure 3.** Stresses in the rotor before exploitation (remained stresses)

**Figure 4.** Stresses in the critical moment of exploitation
In this modelling example, it is obvious that in the straightening procedure, internal stresses were not disappeared completely. During exploitation of the investigated rotor, stability of the rotor axle shape was disrupted. Remained internal stresses along with exploitation conditions: temperature, dynamic loading and time, had affected mentioned stability (Fig. 4 and 5.).

**Figure 5.** Stress and strain changes diagram during observed exploitation period of time

The rotor axle geometry upon straightening by means of induction full-annealing before exploitation and in a critical moment of exploitation after 896 hours of operation, is presented at Figure 6(b).

**Figure 6.** Rotor with vertical feed in the initial stage and in a critical moment of exploitation
Results obtained at the model show insignificant deviation from the results obtained in practical work.

4. CONCLUSION
Finite elements method applied in the ADINA program has shown as an effective method for solving of problems of thermal-elastic-plastic deformations confirming its efficiency at an example of the turbine rotor axle straightening by means of induction full-annealing and its behaviour during the exploitation.
This modelling is presented as an example of utilisation of high-sophisticated computers programs in practice.
Described modelling ensures an analysis of broad-spectrum real overhaul and production processes. By applying of the model in practice, it is possible to acquire considerable savings in time of the machine parts repair performance, as well as much better safety at work.

BIBLIOGRAPHY

a) a monographic publication

b) a paper printed in the conference proceedings