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STRAIGHTENING PROCESS MODELLING OF STEAM TURBINE ROTORS APPLYING TENSION RELAXATION METHOD

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1. Introduction

It is often to face a problem in practice , related to appearance of rotating machine (pumps , turbines , compressors) rotor axles bending . Technology of rotor axles straightening depends on bending characteristics, type of rotating machine , dimensions, constructive details , material quality, overhaul-capacities etc. Classical straightening method of steam turbine rotors consists of several basic phases:

1. rotor axle full-annealing for the purpose of stresses relaxation,
2. rotor axle full-annealing for the purpose of straightening (once or with several repetitions),
3. rotor axle full-annealing aiming to stresses relaxation.

In one of the leading overhaul-institute WIBREM, Repairs-services Enterprise Ltd. Wroclav, a method of the steam turbine rotor axles straightening was improved, based on creation of the stresses relaxation and material creeping by induction heating, without moving blades removal, and with adequate protection of heating. By this method, some of the straightening operations are being carrying out simultaneously, using the fact that processes of the stress relaxation and material creeping develop at the approximately same temperature. By this it is possible to carry out the rotor straightening on the spot at the power plant facilities, and the process of repair is being reduced for more than 8 days comparing to the standard straightening method.

This method was used for the steam turbine rotor straightening in a power plant in Tuzla after damage in 1992.

Procedure of the steam turbine rotor straightening is very complex and expensive , and is possible to optimise it through application of the appropriate models.

In this paper finite elements method (FEM) was employed for numerical modelling of thermomechanical phenomenon in an example of the straightening of mean pressure turbine rotor TK 200-130 LMZ in the power plant Tuzla.

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.

2. Model Description

The most frequent cause of the rotor axle bending is a condensate influx into the turbine housing. That is why unfavourable temperature changes appear at the rotor axle creating internal stresses that superimpose with working load stresses so the total stresses in some part of the rotor exceed the elasticity limit causing permanent plastic deformations and bending.

Technology of the rotor axle straightening is based on local heating of the bending zone and action of external force to the axle. In such a condition, relaxation processes and paterial creeping develop. These two processes progress at the same temperatures and stresses.

In order to shorten the straightening process it is possible to join two stages of straightening into one : full annealing providing the stresses relaxation and straightening under the action of efternal forces.

Besides a decrease of elasticity limit , stress-strain ratio changes due to heating too , and some part of elastic deformation transforms into the plastic deformation.

Keeping the rotor at the stresses relaxation temperature, creeping of material develops causing further plastic deformation followed by continual drop of the stresses. This is a way of the rotor axle straightening and internal stresses disappearing , ensuring shaft shape stability independently on magnitude of former bending.

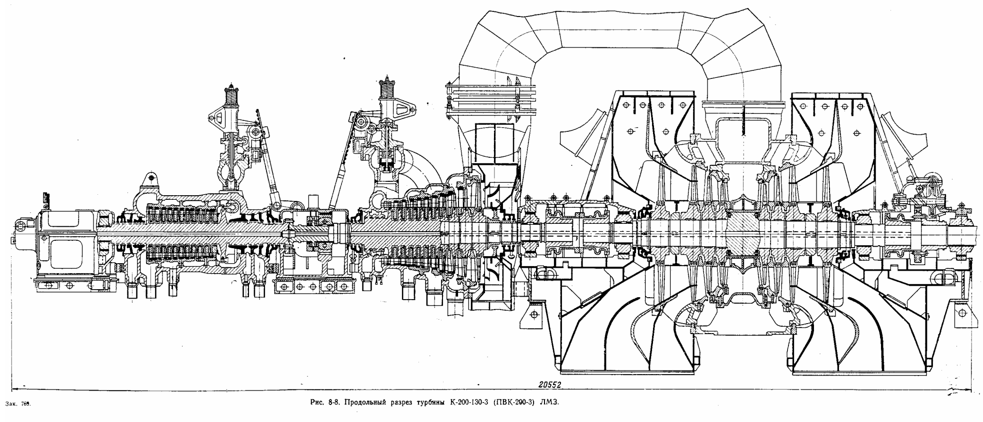

Figure 1. Turbine K-200-130 LMZ cross section

3. Modelling

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.

3.1 Thermo-mechanical Analysis

The heat transfer and temperature analysis of a finite element model performed by ADINA-T can be used to generate temperatures for a displacement and stress analysis with ADINA.

The solution of fully coupled thermo-machanical problems can be performed with ADINA-TMC.

In this class of problems, the thermal solution can affect the structural solution and the structural solution can affect the thermal solution.

The thermo-mechanical problems can include the following effects:

- Internal heat generation due to plastic deformations of the material,
- Heat transfer between contacting bodies, and
- Surface heat generation due to friction the contact surfaces.

The internal heat generated due to plastic deformations in a unit volume Q_M is computed as

$$Q_M = w\bar{\tau} \cdot \overline{D}^p \tag{1}$$

where $\bar{t}$ is the Caushy stress tensor and $\overline{D}^{p}$ is the plastic velocity strain tensor. The overbar denotes "corresponding to the intermediate configuration". w is a parameter, *0 £ w ³ 1*, to account for possible losses.

Contact heat transfer is governed by an equation similar to that used for convection boundary conditions: the heat entering contacting body *I* is

$$q_c^I = \hat{h}(\Theta^J - \Theta^I) \tag{2}$$

where $\hat{h}$ is the contact heat transfer coefficient and Q^{I} and Q^{J} are the surface temperatures of the contacting bodies.

Coupled diffusion-stress analysis problems can be solved with the ADINA system. Such is the phenomena of soil consolidation, in which a soil under load settles due to the dissipation of excess internal fluid pressure.

The linear consolidation theory provides a macroscopic description of soil response, based on the following assumptions:

- The soil skeleton behaviour is linear elastic isotropic.
- The fluid is incompressible.
- The fluid flows through the porous soil according to Darcy`s law:

$$v = -k \cdot \nabla p \tag{3}$$

where v = fluid velocity vector, k = soil permeability matrix, p = fluid pressure.

Consolidating only small strains in the soil and small velocities in the fluid, a linear stress-strain relation can be derived:

$$s = Ce - ap1 \tag{4}$$

where s = macroscopic stress tensor, e = macroscopic strain tensor, C = macroscopic stress-strain law matrix of the soil skeleton, l = first soil consolidation parameter, 1= Kronecker delta vector.

It is also assumed that the fluid content q varies linearly with the fluid pressure and the soil volumetric strain, i.e.

$$q = a \cdot e_v + bp \tag{5}$$

where e_v = soil skeleton volumetric strain, b = second soil consolidation parameter.

The general equations governing transient soil consolidation can then be established. First, the macroscopic stresses defined in equation (4) must satisfy the equilibrium condition:

$$\nabla \cdot s + f^{b} = 0 \tag{6}$$

where f^{b} are body forces.

Second, the continuity condition for incompressible fluid flows:

$$\frac{\partial q}{\partial t} - q^{b} = -\nabla \cdot v \tag{7}$$

where q^{b} is the internal fluid flow generation, used together with Darcy`s equation (3), and with equation (5), yield the diffusion equation controlling the variation of the fluid pressure:

$$\nabla \cdot (k \cdot \nabla p) = a \frac{\partial e_v}{\partial t} + b \frac{\partial p}{\partial t} - q^b \quad (8)$$

We can now see that the stress equation (6) and the diffusion equation (8)constitute a coupled diffusion-stress equation system.
For a finite element discretization, equations (6) and (8) yield the following equation:

$$\begin{bmatrix} 0 & 0 \\ K_{pu}^T & M \end{bmatrix} \begin{bmatrix} \frac{\partial u}{\partial t} \\ \frac{\partial p}{\partial t} \end{bmatrix} + \begin{bmatrix} K_u & K_{up} \\ 0 & K_p \end{bmatrix} \begin{bmatrix} u \\ p \end{bmatrix} = \begin{bmatrix} f \\ q \end{bmatrix} \quad (9)$$

where $K_u = \int B_u^T C B_u dv$; $K_{up} = -\int_V B_u^T a H dv$; $K_{pu}^T = -\int_V H^T l B_u dv$; $K_p = \int_V B_p^T k B_p dv$; $M = \int_V H^T b H dv$; f, q = load vectors (forces, fluid flows), H = interpolation matrix, B_u, B_p = gradient matrices for the displacements U and pressure p.
Equation (9) can be written as follows:

$$K_u u = f - K_{up} p \quad (10)$$

$$M \frac{\partial p}{\partial t} + K_p p = q - K_{pu}^T \frac{\partial u}{\partial t} \quad (11)$$

An iterative procedure can therefore be used to solve this equation system. Within ADINA models are solved alternately until convergence is reached for both the structural equation (10) and the diffusion equation (11).

3.2 Material Models

Theoretical solution of the rotor axle straightening for a case of stiff-plastic material , was carried out by FEM analysis The user-supplied material model be employed in 3-D condition elements.

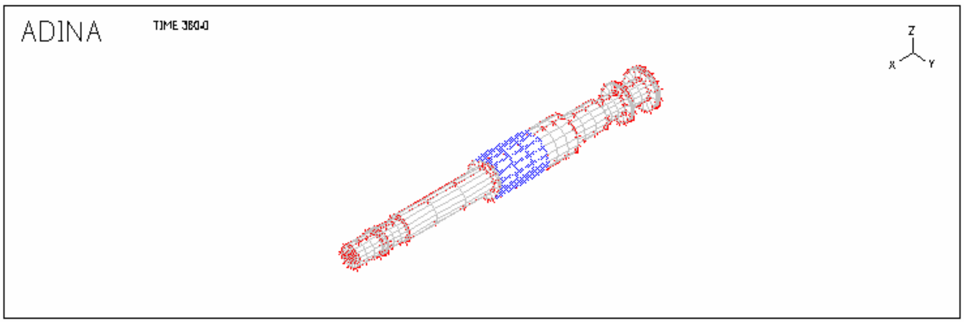

Figure 2. Material rotor models

4. Model Testing

Mechanical damages at the rotor axle were not registered after deformation and at the end of the straightening process This fact was confirmed by theoretical solution at the established model too. During full annealing of the rotor axle , moving blades impeller are protected against heating , and that is why there are no moving blades impeller at the model. The rotor axle is of high-alloyed steel 25HM (GOST).

4.1 Straightening Process

Maximal bending of the rotor axle 5850 mm long upon damage was 0.28 mm . Permissible bending of the rotor axle is 0.06 mm. Process of the rotor axle straightening consists of the operations as follows:

1. Preparation for straightening (control measurements and the rotor inspection , placement of the straightening equipment)
2. Full annealing of the rotor axle aiming at the stress relaxation and straightening .
3. Control measurements and the rotor inspections.
4. Equipment dismantling , rotor balancing , the rotor mounting and functional trial.

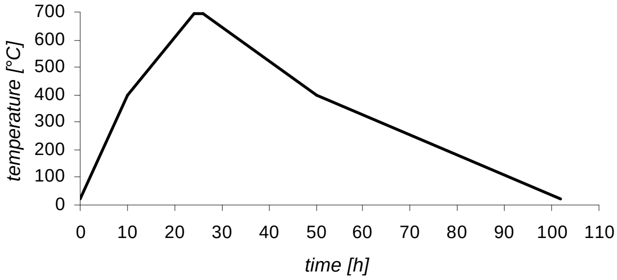

Figure 3. Diagram of thermal straightening of the rotor

4.2 Heat transfer analysis

At the Figure 4 , pattern of temperature field in the rotor axle in the full-annealing phase aiming the stresses relaxation, is presented.

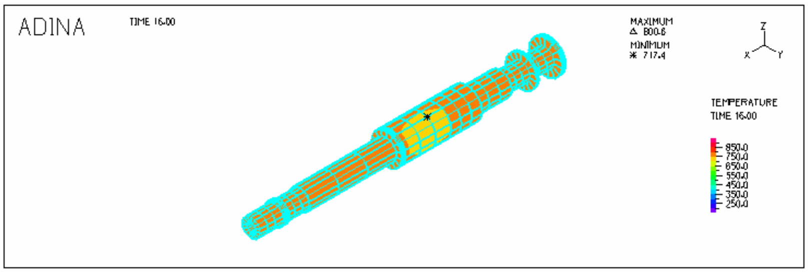

Figure 4. Temperature disposition in the rotor axle

4.3 Stress analysis

Figure 5 presents a pattern of the effective stresses after straightening by means of induction full-annealing.

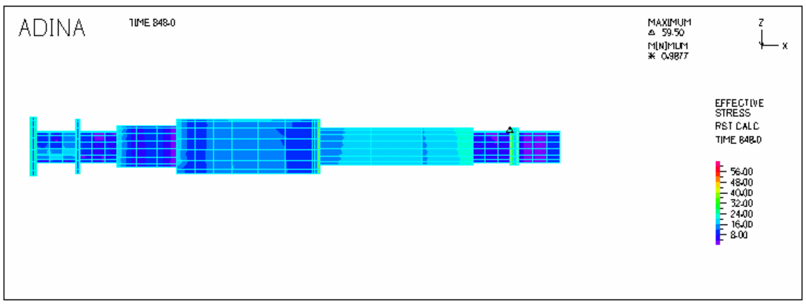

Figure 5. Effective stresses pattern – final stage

At the set straight rotor internal stresses are partly disappeared as a result of 85% material relaxation. By correction of the diagrams of thermal straightening it is possible to get better results of material relaxation.

4.4 Deformation analysis

The rotor axle geometry before and after straightening by induction full-annealing is presented at the Figures 6 and 7 . Results obtained at the model show insignificant deviation from the results obtained in practical work.

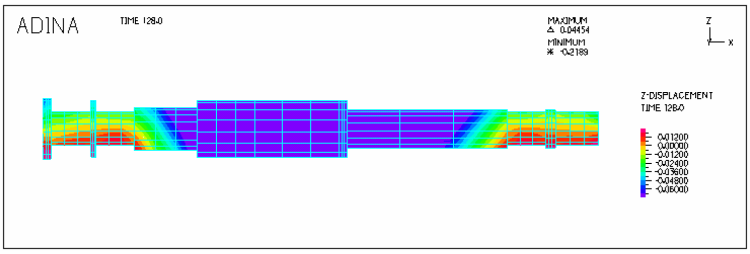

Figure 6. Pattern of vertical displacement before straightening

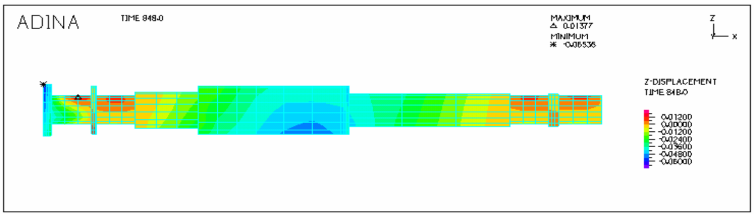

Figure 7. Pattern of vertical displacement after straightening

5. 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 effectivness at an example of the turbine rotor axle straightening by means of induction full-annealing.

Results of maximal displacement calculations compared with the measurement data in the initial and the final straightening phase were within the limits of 5 % .

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.

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