12th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2008, Istanbul, Turkey, 26-30 August 2008

CHARACTERISTICS OF NON-STATIONARY THERMAL STRESSES IN STEAM TURBINE ROTOR ALONG CENTRAL BORE

Zvonimir Guzović, Stanislav Sviderek, Tihomir Mihalić
Faculty of Mechanical Engineering and Naval Architecture
Ivana Lučića 5, 10000 Zagreb
Croatia

ABSTRACT
In the paper "Modelling of Non-stationary Thermal Stresses in Steam Turbine Rotors" [1] presented on TMT 2004, the algorithm and the results of non-stationary thermal stresses modelling in steam turbine rotor by means of the users software package are shown. Non-stationary thermal stresses are stipulated by pressure change on turbine exit. The results of non-stationary thermal stresses calculations (i.e. of modelling) show on several characteristic regions of the rotor thermal stressed state: a) the rotor central bore; b) the low-pressure rotor; c) disc of the last turbine stage, and d) the rear-end labyrinth gland. Due to in the paper "Characteristics of Non-Stationary Thermal Stresses in Steam Turbine Rotors" [2] presented on TMT 2006, these characteristic regions are additionally analysed. As along the rotor central bore the specific distributions of thermal and mechanical quantities (temperature, heat flux, deformation, stress) are determined, so this region of rotor is analysed in detail. In this paper the results of this analyse are presented.
Key words: steam turbine rotor, non-stationary thermal stresses, numerical modelling

1. INTRODUCTION
The rotor central bore has been performed in order to investigate and control the rotor material state during the steam turbine life cycle, Fig. 1 [3]. The different measurements and investigations on single longitudinal sections of bore have been performed. The today used modern non-destructive methods of the material state measurements eliminate the need for making the rotor central bore. Since the analysed rotor has been designed with a bore, the thermal and mechanical quantities distributions on the bore surface along the rotor from left to right sleeve have been analyzed [4]. For easier understanding of the results, every distribution is accompanied by the sketch of the steam turbine rotor, which makes it possible to identify with sufficient precision the place along the rotor and to determine the respective values of thermal and mechanical quantities from parametric curves for individual working regime.

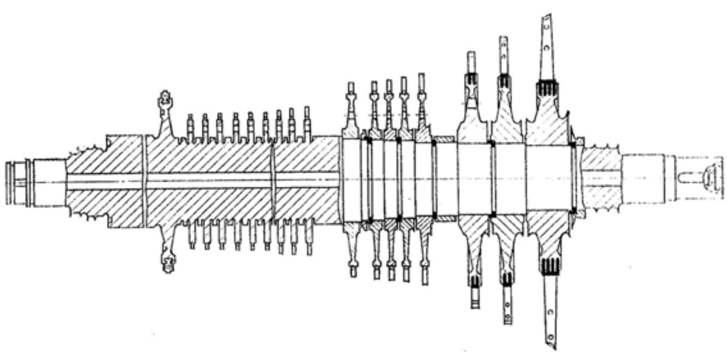


Figure 1. Steam turbine rotor with central bore

2. ANALYSIS OF THERMAL-STRESSED STATE IN TURBINE ROTOR ALONG CENTRAL BORE

The temperature distributions for different turbine exit pressures along the rotor central bore are presented in Fig. 2. The highest temperature on the surface of the central bore appeared on the place of the highest steam temperature, i.e. at the controlling stage. Downstream from this place the temperature decreases because the temperature of steam which expands has decreased. The temperature distributions for different values of the steam exit pressure have coincide from the left rotor sleeve to place of disc of the 9^{th} stage. Evidently, this region does not feature any more the upstream influence of the change of steam thermo-dynamical quantities and aero-dynamical characteristics of the stages of the low pressure turbine part which are result of the exit temperature change. Downstream from the 9^{th} stage, the separation of the temperature distributions occurs on the surface of the bore, in such a manner that higher temperatures correspond to higher exit pressure. With the exit pressure increase the steam temperature increases, which is the cooling fluid of turbine rotor in the low pressure turbine part, and this is reflected on the temperature of the bore surface. Also, from place at level with the rear-end labyrinth gland to the right rotor sleeve the temperature distributions are again identical. It is the influence of introducing the superheated steam of high temperature in rear-end labyrinth gland thus overcoming the influence of the steam temperature change in the low pressure turbine part which depends on the exit pressure change.

The obtained axial heat flux is for an order of magnitude greater than the radial heat flux, the value of which is negligibly low. Small contribution of the radial heat flux to the resultant value of heat flux is the best seen in Fig. 3, where the resultant heat flux is just equal to the absolute value of the axial heat flux, and therefore further only the results of axial heat flux distributions are analysed.

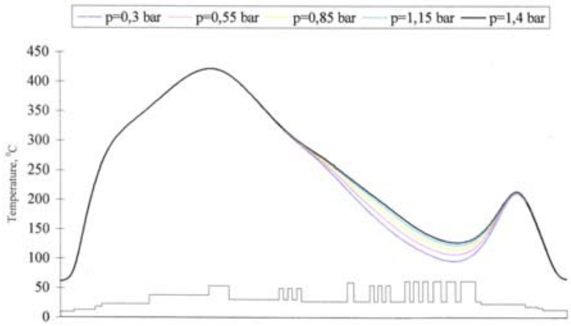


Figure 2. Distributions of temperatures along the rotor central bore for different turbine exit pressures

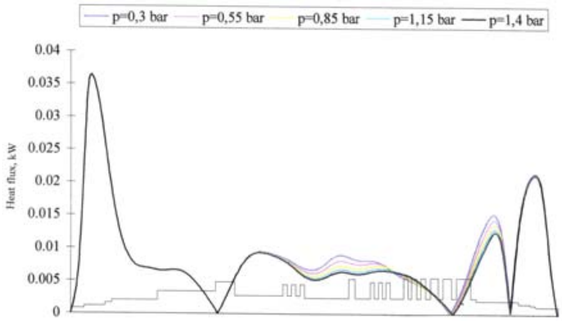
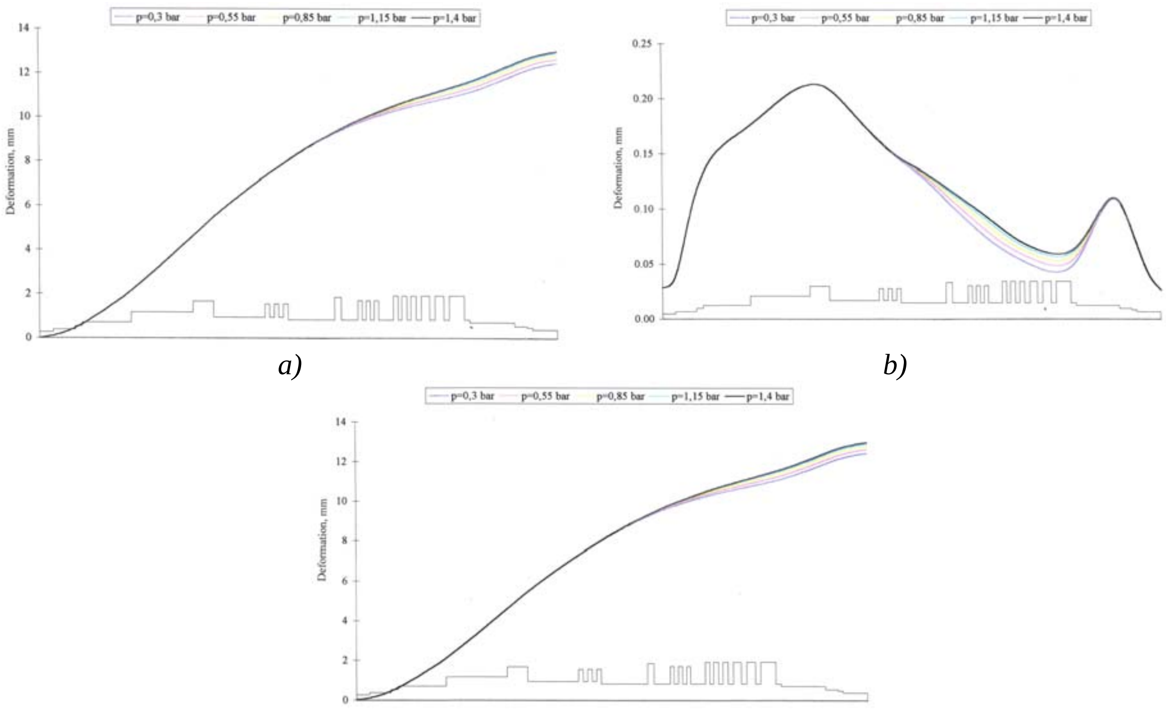


Figure 3. Distributions of resultant heat fluxes along the rotor central bore for different turbine exit pressures

Axial thermal deformations (Fig. 4.a) are absolute regarding the fixed point of model at thrust bearing on the left side of the rotor. The values of axial thermal deformations do not change in the previously mentioned two regions of «insensitivity», and this is generally valid for all the other mechanical values along the turbine rotor central bore. Axial deformations are greater for higher exit pressure. Radial deformations are presented in Fig. 4.b. Dependence on temperature distribution is evident. All said about temperature dependence on the exit pressure holds also for thermal deformations, because radial thermal deformations are directly dependent on temperature distribution. The radial thermal deformations are fairly smaller from deformations in axial direction, therefore the values of deformation resultants are approximately equal to absolute values of axial deformations (Fig. 4.c).

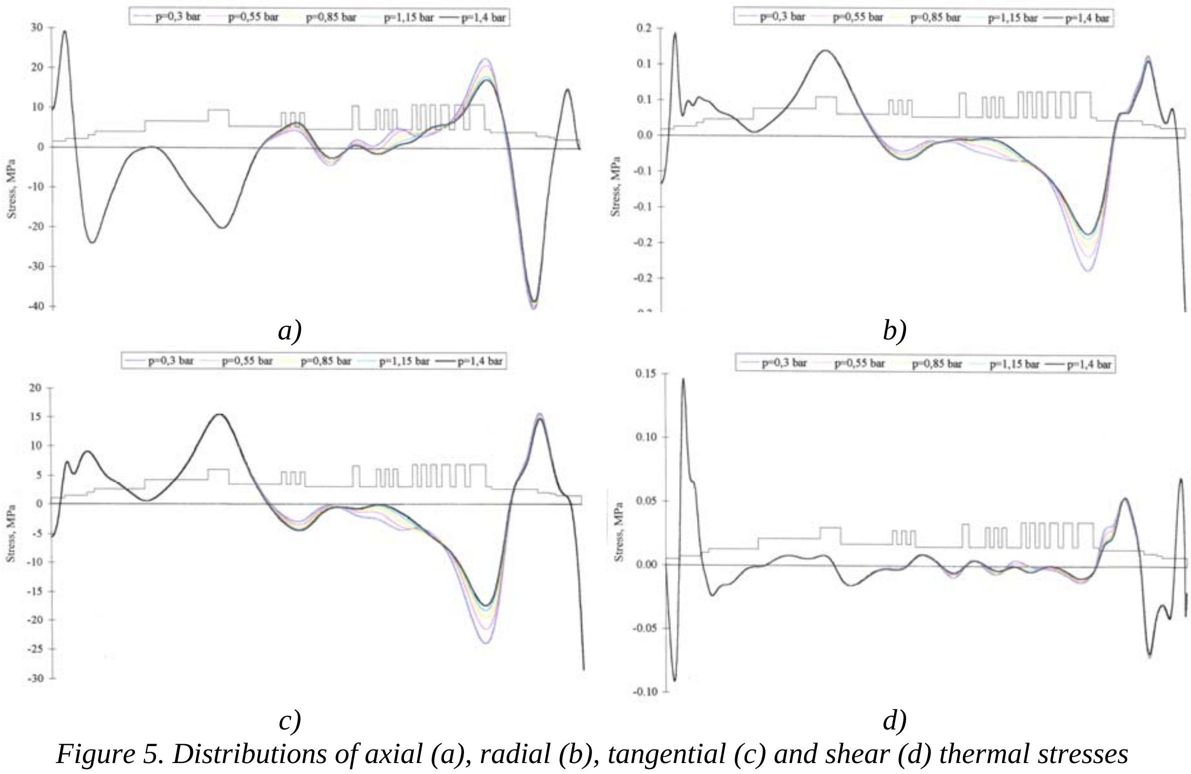
Distributions of thermal stresses due to temperature distributions are presented in Figs. 5.a - 5.d. Comparing Figs. 5.a – 5.d it is obvious that regarding values the axial and tangential stresses are dominant, while the radial and shear stresses are much smaller. For axial stresses, presented in Fig. 5.a, some regions of increased values of stresses are characteristic. These are first of all the place of turbine controlling stage and the region of rear-end labyrinth gland, because here the local temperature gradients are the biggest. The distribution of axial stresses is stipulated by the determined distribution of thermal deformations (Figs. 4.a – 4.c).



a) *b)*

c)

Figure 4. Distributions of axial (a), radial (b) and resultant (c) thermal deformations along the rotor central bore for different turbine exit pressures



a) *b)*

c) *d)*

Figure 5. Distributions of axial (a), radial (b), tangential (c) and shear (d) thermal stresses along the rotor central bore for different turbine exit pressures

The distributions of radial stresses along the rotor central bore obtained by user's software based on Finite Elements Method (FEM) do not correspond to the real state of stresses because on the surface of the rotor central bore these equal zero. The obtained distributions presented in Fig. 5.b are the result of the fact that the used software calculates the radial stresses in nodes which lie on the surface of the rotor central bore in the manner that the stress values are determined from approximate

functions of finite elements near the bore surface including the nodes inside the rotor in which the stress in radial direction really exists [4]. This generates an error in the obtained results of radial stress distributions along the surface of the rotor central bore, and this is confirmed by the negligibly small values of radial stresses presented in Fig. 5.b. Tangential thermal stresses (Fig. 5.c) along the rotor central bore show tendency of increasing at the same places as axial thermal stresses, and causes of this are identical to those in the analysis of axial stresses. Shear stresses (Fig. 5.d) are result of local temperature distribution and the corresponding geometry of the deformed rotor state. Regarding values they are negligibly low and therefore they are not included in further analysis.
The influence of turbine exit pressure change is not reflected in any significant extent on the stress values along the rotor central bore, but only on the character and law of their distribution. With change of exit pressure the locations of local change of stress character are displaced upstream or downstream along the bore, but they continue to be negligibly small regarding values.
Fig. 6 presents the equivalent von Mises thermal stresses along the rotor central bore. With the increase in the exit pressure from 0.3 bar to 1.4 bar at the level of the disc of last turbine stage, the differences in equivalent stress values are approximately 10 MPa.

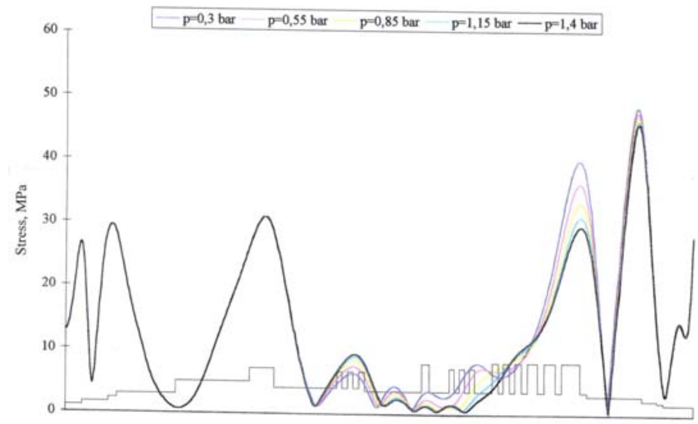


Figure 6. Distributions of equivalent von Mises thermal stresses along the rotor central bore for different turbine exit pressures

3. CONCLUSION

The thermal-stressed state along the central bore of the steam turbine rotor is characterised by three regions:

- two regions of «insensitivity» of thermal and mechanical quantities (temperature, heat flux, thermal deformations and stresses) on the change of turbine exit pressure (from the left rotor sleeve to disc of the 9th turbine stage and from the rear-end labyrinth gland to the right rotor sleeve), and
- the central region between these two regions of «insensitivity» where thermal and mechanical values depend on the change of the turbine exit pressure.

On the basis of the obtained thermal and mechanical values it is possible to conclude that the thermal-stressed state of the analysed rotor of the steam turbine in the region of the central bore is acceptable: maximal equivalent von Mises thermal stress is 50 MPa.

4. REFERENCES

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