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CHARACTERISTICS OF NON-STATIONARY THERMAL STRESSES IN STEAM TURBINE ROTOR AT REAR-END LABYRINTH GLAND

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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 at the rear-end labyrinth gland the high gradients 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 will be presented.
Key words: steam turbine rotor, non-stationary thermal stresses, numerical modelling

1. INTRODUCTION

The region of the rear-end labyrinth gland is interesting due to the presence of high gradients of thermal and mechanical quantities, since, on a relatively small distance there comes to the interaction of superheated steam of high temperature for sealing, and wet steam of low temperature after the last turbine stage. Thermodynamic state of wet steam at the turbine exit is determined by the pressure in the condenser. Therefore, in work [3] the detailed analysis for the rotor at region of the rear-end labyrinth gland is performed by means of parametric curves for five different values of the exit pressure, the results of which have been presented in this work.

All graphic presentations from this analysis refer to the outside boundary rotor surface in the region of the rear-end labyrinth gland of analysed steam turbine, which is marked with thick line in Fig. 1. In graphic presentations for easier orientation, the start and end of each labyrinth gland segment are marked by symbols ●, ▲ and ■, thus: a) the outside sealing segment, region ●-●; b) the 1st inner sealing segment, region ▲-▲, and c) the 2nd inner sealing segment, region ■-■.

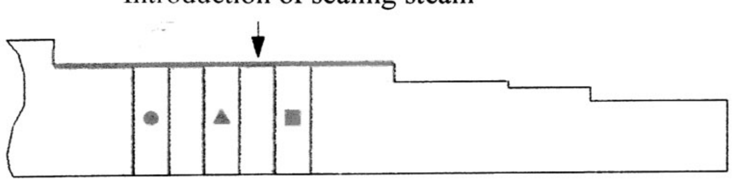


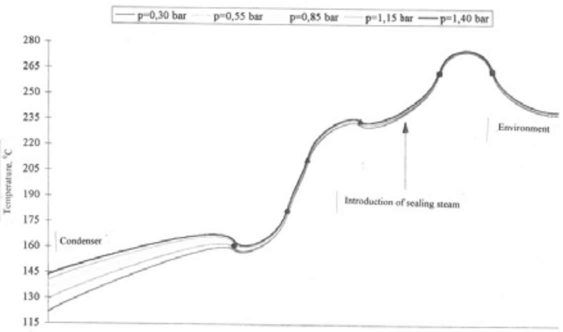
Figure 1. The region of the rear-end labyrinth gland

The length of abscissa of the graphic presentations in corresponding measure corresponds to the developed outside rotor surface where the rear-end labyrinth gland is placed (thick line in Fig. 1). Due to more complete understanding of one-dimensional graphic presentations, the paper also presents the distributions of thermal and mechanical quantities in rotor in the region of the rear-end labyrinth gland (dark region in Fig. 1), obtained by numerical modelling by means of user software package.

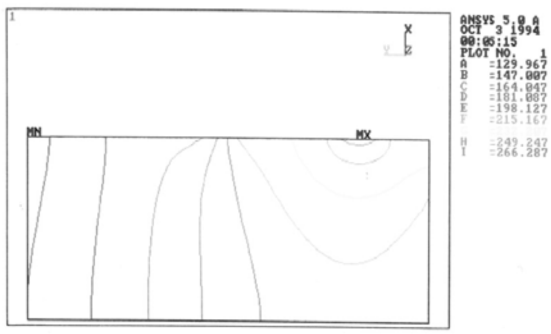
2. ANALYSIS OF THERMAL-STRESSED STATE IN TURBINE ROTOR AT REAR-END LABYRINTH GLAND

Fig. 2.a shows distributions of temperatures along outside rotor surface for different pressures in condenser, while Fig. 2.b shows temperature field in rotor in the region of the rear-end labyrinth gland. The highest temperature has been established in the region of outside sealing segment of the rear-end labyrinth gland, because the conduction of heat from its outer side is very poor. The local temperature maximum reaches up to 276^0C, while the temperature differences within this outside sealing segment are about 14^0C per 40 mm of the segment width. The second local temperature maximum has been established at the entrance into the first sealing segment, while after this the temperature starts to decrease towards the value which is determined by the thermodynamic state in condenser. Major mutual discrepancy of temperature distributions dependent on the pressure in condenser starts only at the second inner sealing segment. Here, higher temperatures correspond to higher pressure of wet steam.

On the environment side the temperature also decreases because the influence of the outside sealing segment is getting weaker. In the region of introduction of sealing steam the temperature distribution has been established which results from the states on the boundaries of the external and the first inner sealing segment. This is the region of perpendicular streaming of steam on the turbine rotor, for which there are no adequate correlations for determining of thermal boundary condition in available literature. Therefore, the obtained distributions of temperatures in the region of introducing the sealing steam have questionable reliability. However, this is only of local character and it is not reflected on the general pattern in the region of the rear-end labyrinth gland.



a)



b)

Figure 2. Distributions of temperatures along outside rotor surface for different pressures (a) and temperature field in rotor (b) in the region of the rear-end labyrinth gland

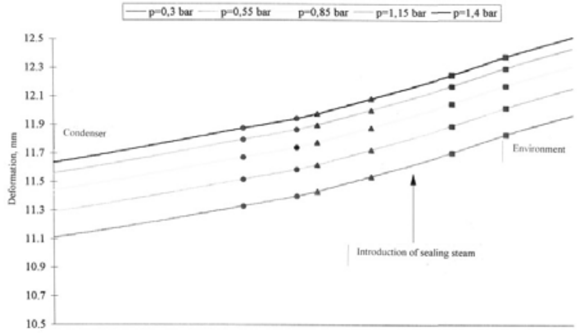


Figure 3. Distributions of axial thermal deformations for different pressures

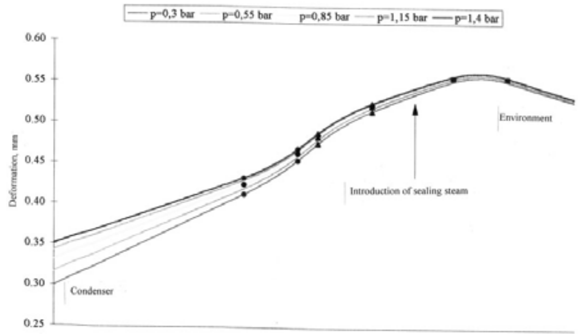
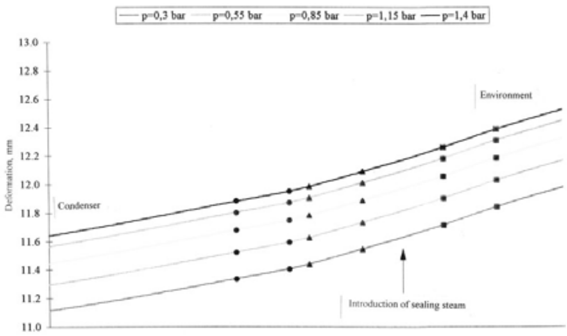


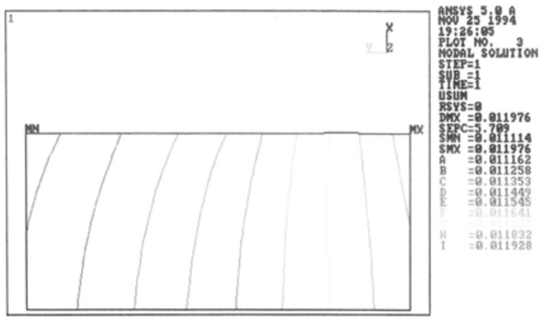
Figure 4. Distributions of radial thermal deformations for different pressures

The distributions of axial and radial thermal deformations for different pressures in the condenser are presented in Figs. 3 and 4. With pressure change, only the value of axial thermal deformation along

the external rotor surface has changed, and not the law of the distribution (Fig. 3). Axial thermal deformations of rotor are higher for higher pressure in condenser. In case of radial thermal deformations, the change of deformations gradients in dependence of pressure in condenser has been observed for the part of rotor closer to the condenser (Fig. 4). The gradient of radial thermal deformations is higher for the lower pressure in condenser. On this part of rotor closer to sealing segments the influence of radial thermal deformations on the pressure in condenser has been decreased because high temperature of sealing steam makes this region insensitive to thermal state in condenser.
Fig. 5.a and Fig.5.b present distributions of resultant thermal deformations along outside surface of rotor i.e. in rotor in the region of the rear-end labyrinth gland.



a)



b)

Figure 5. Distributions of resultant thermal deformations along outside surface of rotor for different pressures (a) and in rotor (b) in the region of the rear-end labyrinth gland

From distributions of the axial thermal stresses, Fig. 6, it is obviously that the highest value has been established in the region of the outer sealing segment. Along the region of the two inner sealing segments the axial stresses decrease, and at the end of the second inner sealing segment the symbol changes, i.e. from tensile they change to compressive. Further towards the condenser compressive stress increases, and on the left end of rotor sleeve it reaches -22,8 to -28,7 MPa. In the regions of sealing segments the axial thermal stresses increase to their maximum of approximately 34.7 MPa, and then towards the end of sleeve end decrease to zero.
Radial thermal stresses (Fig. 7) very pulsating, change the value and the symbol, which is the result of complex mutual dependence between deformations and stresses, and high gradients of thermal and mechanical quantities on a small distance. Due to their negligible values, these stresses do not represent any danger for safe work of steam turbine.

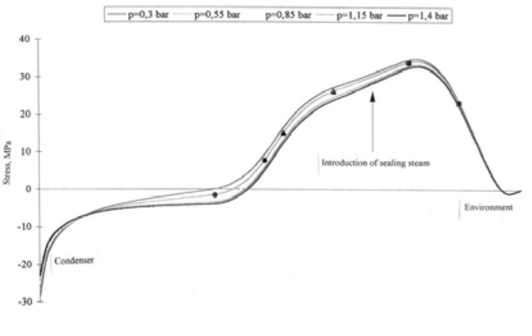


Figure 6. Distributions of the axial stresses

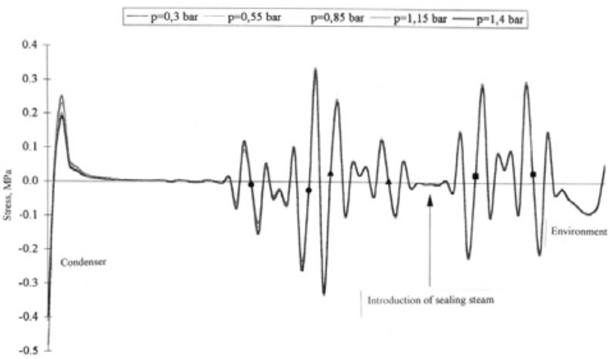


Figure 7. Distributions of the radial stresses

Tangential thermal stresses with their values are dominant (Fig. 8). In the region of the second inner sealing segment they are tensile and in the regions of the first inner sealing segment and outer sealing segment they are compressive. Tangential stresses are the result of deformations in tangential direction, and therefore, their distribution has been determined by distributions of thermal deformations.
Shear stresses are negligibly low (Fig. 9). The values of shear stresses are somewhat more significant only in the region closer to the condenser, in the region of transition from one cross section to another,

but fully negligible with regard to safe work of steam turbine rotor. In the rest of the rotor, in the field of rear-end labyrinth gland, shear stresses similar to radial stresses have pulsating character, with the same frequency and places of appearance, but with smaller amplitudes.

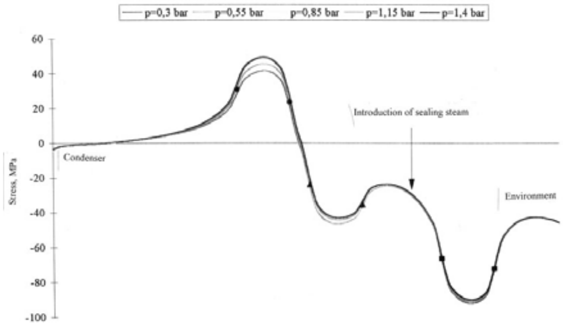


Figure 8. Distributions of the tangential stresses

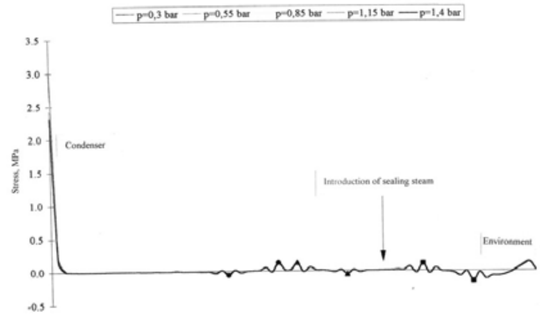
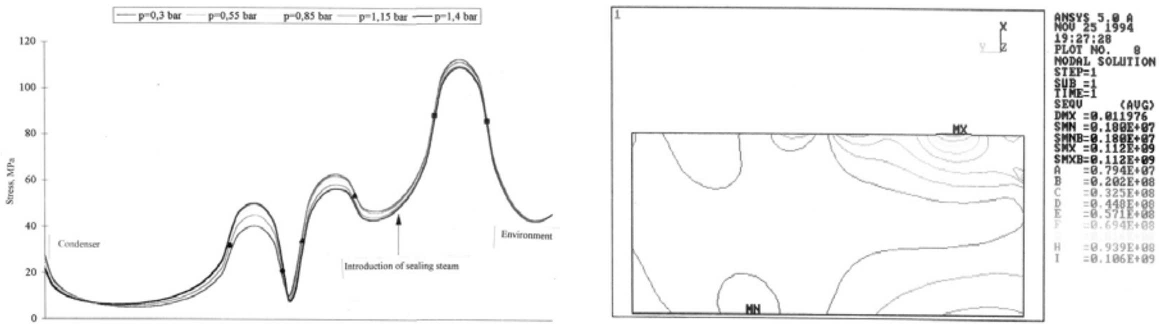


Figure 9. Distributions of the shear stresses

All previously analysed single stresses with regard to values are acceptable. However, with their calculation by means of energy theory of equivalent stresses, stresses state obtains a new dimension. Fig. 10.a and Fig.10.b present the distributions of equivalent von Mises stresses along the outside surface of rotor i.e. in the rotor in the region of the rear-end labyrinth gland. The maximal value of equivalent von Mises stresses is 112 MPa.



a) *b)*

Figure 10. Distributions of equivalent von Mises stresses along the outside surface of rotor for different pressures (a) and in the rotor (b) in the region of the rear-end labyrinth gland

3. CONCLUSION

The character of the equivalent von Mises stresses in the region of the rear-end labyrinth gland and maximal stress from 112 MPa demand particular attention in choosing the parameters and the design of the rear-end labyrinth gland. Otherwise, it can come to undesirable effects. The high values of the equivalent stresses in the region of the rear-end labyrinth gland are specific for the majority of steam turbines due to the nature of the thermal state and conditions which exist in this region [4]. However, the values of equivalent stresses in the region of rear-end labyrinth gland are not the result of variable working regime of the analysed steam turbine but rather of the existing thermal state in this region. They have appeared at the place of change of the rotor cross section and are partly result of geometrical simplification of the roundness radius.

4. REFERENCES

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