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CHARACTERISTICS OF NON-STATIONARY THERMAL STRESSES IN STEAM TURBINE ROTOR

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ABSTRACT

The paper «Modelling Non-stationary Thermal Stresses in Steam Turbine Rotor» presented at TMT 2004 shows the algorithm and the results of numerical modelling of non-stationary temperature fields, and the respective thermal deformations and stresses, caused by the steam turbine exit pressure change. From the presented general distributions of temperatures, deformations and stresses along the domain of complete rotor the general image about influence of the change of the exit pressure value on its thermal-stressed state is obtained. Simultaneously, some characteristic regions of rotor thermal-stressed state have been indicated which demand additional analysis: a) the central rotor bore; b) the rotor low pressure part; c) the disc of last turbine stage; d) the rear-end labyrinth gland. It is in this work that the results of detailed analysis by means of parametric curves for cited regions for five values of the exit pressure are presented.

Key words: steam turbine rotor, non-stationary thermal stresses, numerical modelling

1. INTRODUCTION

In paper [1] it is shown that today the non-stationary thermal-stressed state of the steam turbine rotor can be effectively determined by numerical modelling by means of sophisticated users′ software, with the accuracy of calculations which satisfy the engineering applications. By setting valid thermal and mechanical boundary conditions the obtained results enable reliable analyses of thermal stressed state in rotor in these off-design working regimes. The general distributions of non-stationary temperature fields along the domain of complete rotor of the back-pressure steam turbine of 30 MW power, caused by the exit pressure change, and the respective distributions of thermal deformations and stresses are obtained by numerical modelling by means of sophisticated users′ software based on finite elements method for five characteristic working regimes, for on-design value of the exit pressure 0.03 MPa and for four off-design values: 0.055; 0.085; 0.115; 0.14 MPa.

The analysis of the calculated non-stationary temperature fields has shown that the maximal temperatures in rotor have appeared at the disc of the controlling stage (influence of steam high temperature on turbine inlet) and in the region of the rear-end labyrinth gland (influence of high temperature of superheated steam for sealing). For all values of the exit pressure the temperature fields in the rotor region from the left rotor sleeve to disc of the 9th turbine stage are quantitatively equal, which means that here the change of the exit pressure has no influence. The turbine exit pressure change depends on the temperature distribution only in the region of low pressure rotor part, i.e. from the 9th turbine stage to the starting-point of the rear-end labyrinth gland, so that isoterms of higher temperature with the exit pressure increase have been displaced downstream.

The calculated thermal deformations are qualitatively equal for all values of the exit pressure and they increase with the exit pressure increase since higher average rotor temperature corresponds to the higher exit pressure. Significant thermal deformations are in the region of the rear-end labyrinth gland, left rotor sleeve and the disc of the controlling stage.

The calculated non-stationary equivalent von Mises thermal stresses are qualitatively equal for all the values of the exit pressure. Due to the previously cited reasons in the rotor region from left sleeve to disc of the 9th turbine stage the stresses are quantitatively equal. In the region of ″sensitivity″ of the thermal-stressed rotor state to the exit pressure, the equivalent stresses decrease with the exit pressure increase, because with the exit pressure increase the rotor average temperature increases and the temperature gradients decrease. The highest temperature gradients at the rear-end labyrinth gland are the cause of significant values of stresses in this region.

The analysis of the general distributions of non-stationary temperature fields and the respective thermal deformations and stresses presented in [1] have indicated the places at rotor which are characteristic by thermal-stressed state. Therefore, in work [2] the one-dimensional analysis by means of parametric curves is also performed for the cited values of the exit pressure along the rotor central bore, for the low pressure part of the rotor, for disc of the last turbine stage and for the rear-end labyrinth gland, the results of which have been presented in this work.

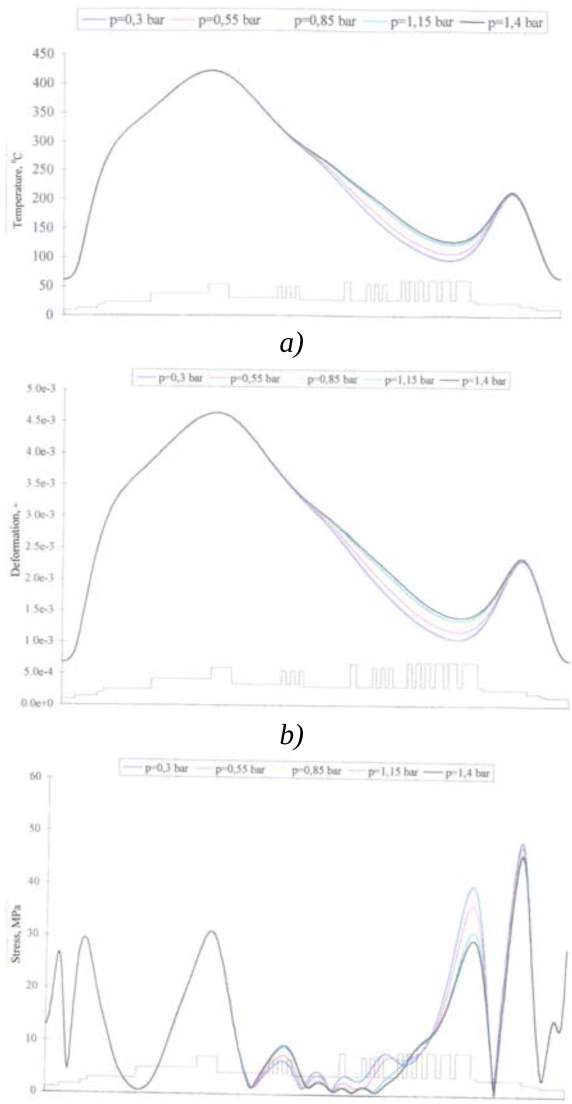
2. ANALYSIS OF THERMAL-STRESSED STATE OF CHARACTERISTIC PLACES IN TURBINE ROTOR

2.1 The rotor central bore

The rotor central bore has been performed because of the possibility of investigating and controlling the rotor material state during the turbine useful life. The today used modern methods of the material state measurement without destruction decline the need for realization of the rotor central bore. The temperature distributions along the rotor central bore are presented in Fig. 1.a. The highest temperature on 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 coincided from left rotor sleeve to place of disc of the 9th stage. Evidently, this region does not feature any more the upstream influence of 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 9th stage occurs the separation of the temperature distributions 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 bearing the temperature distributions are again identical. It is the influence of introducing the superheated steam of high temperature in labyrinth gland thus overcoming the influence of the steam temperature change in the low pressure turbine part (which depends on the exit pressure change). Fig. 1.b shows the distributions of thermal deformations which have the same character as the temperature distributions, and Fig. 1.c shows the equivalent von Mises thermal stresses along bore. With the increase of the exit pressure from 0.3 bar to 1.4 bar at the level of the disc of last stage differences in stresses values are approximately 10 MPa.

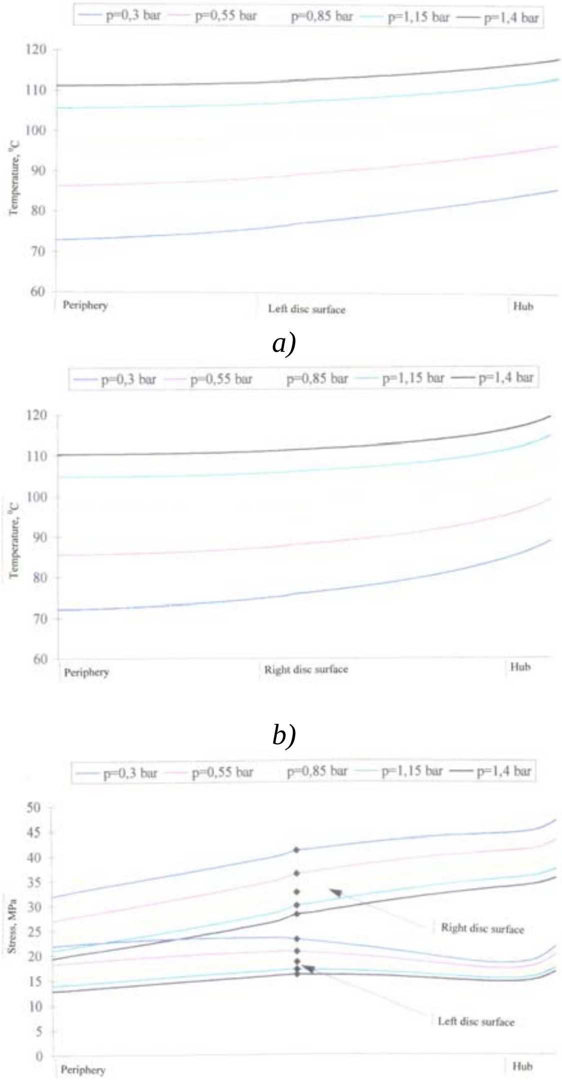
2.2 The low pressure part of rotor

The analysis along the rotor bore has shown that thermal-stressed state depends most significantly on the exit pressure in low pressure part of turbine rotor after the 9th stage. Due to the analysis of low pressure part of rotor (from 12th to 21st stage) is performed in ten sections, and the results are presented for 1st, 6th and 10th sections. In all sections the temperature increases with the exit pressure increase. Here, in each of these sections the temperature increases from rotor periphery toward the central bore, which is the result of better heat rejection in the region of interstage labyrinth gland than in the inside rotor closer to the bore. In the steam flow direction per given sections the temperature values decrease, since by expansion through flow part its temperature also decreases. Generally for all sections holds that with the exit pressure increase the average rotor temperature increases and also the deformations are bigger. In the 1st section the equivalent von Mises stresses are the biggest in the region of the rotor periphery, while they are considerably lower near the bore; in the 6th section their increase in the region of the rotor bore has been observed, while stresses on the periphery remain high; in the 10th section the stresses distribution is approximately the same as in the 6th section, but further increase of the equivalent von Mises stresses at the rotor bore occurs. Generally, the values of equivalent von Mises stresses in the region of low pressure part of the turbine rotor increase downstream per each cross section.



c)

Figure 1. The distributions of temperatures (a), thermal deformations (b) and equivalent von Mises stresses (c) along the rotor central bore



c)

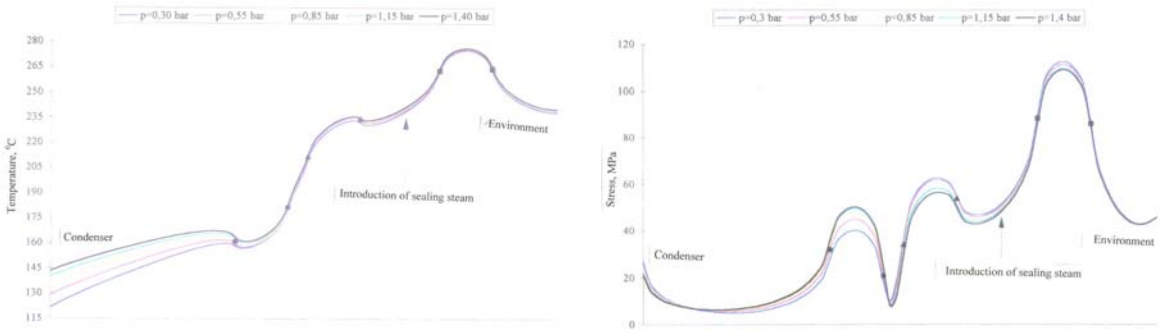
Figure 2. The distributions of temperatures on left (a) and right disc surface (b) of last turbine stage, and the distributions of equivalent von Mises stresses for both disc surfaces (c)

2.3 The disc of last turbine stage

The influence of the exit pressure change on thermal stressed state of the turbine rotor is most evident on the disc of the turbine last stage, since all changes on the turbine exit are manifested first on its work. Figs. 2.a,b show the temperature distributions on the left and right disc surface in dependence on the exit pressure. There is a slight increase of the surface temperature from periphery to the disc hub, which is the consequence both of the heat transfer coefficients decrease on the surfaces of the rotating disc from periphery to hub and partially of the thermal state in the region of labyrinth gland. The deformations have similar tendency of temperate increase from periphery to hub. The equivalent von Mises stresses on left and right disc surface are presented in Fig. 2.c. The increased stress on the right disc surface with regard to the left one is evident, as well as the “deformity” of stresses pattern in the region of the disc hub on both surfaces.

2.4 The rear-end labyrinth gland

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 with high temperature for sealing and wet steam with low temperature after the last turbine stage. The temperature distributions are presented in Fig. 3.a. The highest temperature has been established in the region of the outer gland segment, which is explained by the fact that the heat rejection on its outer side is very poor. The second local temperature maximum has been established on the inlet in the first inner gland segment, and then temperature starts to decrease towards the values which are determined by the thermodynamic state in the condenser. On the ambient side the temperature also decreases since the influence of the outer gland segment is decreasing. In the region of the sealing steam introduction the temperature distribution is established which is the result of the states on the boundaries of the outer and the first inner gland segment. With the exit pressure change, only the values of the thermal deformation change, and not the laws of distribution. Generally the thermal deformations increase with the exit pressure increase. Distributions of the equivalent von Mises stresses are presented in Fig. 3.b. 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 [3].



a) *b)*

Figure 3. The distributions of temperatures (a) and equivalent von Mises stresses (b) along the region of the rear-end labyrinth gland

3. CONCLUSION

The conclusion about good design solution of the rotor of the analysed turbine from the standpoint of the analysed variable thermal-stressed state due to pressure change in the turbine exit, obtained on the basis of the uniformity of general distributions of stress in the greatest part of the rotor, are additionally confirmed by the analyses at characteristics places. With the exception of the rear-end labyrinth gland the values of analysed stresses at characteristic places are acceptable. 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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