14th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2010, Mediterranean Cruise, 11-18 September 2010

CHARACTERISTICS OF NON-STATIONARY THERMAL STRESSES IN THE DISC OF THE LAST TURBINE STAGE

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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) the 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 in the disc of the last turbine stage 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 are presented.
Key words: steam turbine disc, non-stationary thermal stresses, numerical modelling

1. INTRODUCTION

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. Therefore, in this paper thermal stressed state in the disc of the last turbine stage (marked as 21^{st} on the cross section of steam turbine of 30 MW power in Figure 1) is analysed. The moving blades from the 2^{nd} to 8^{th} stage are located on a drum-type rotor, while all the remaining moving blades of other stages (1^{st}, 9^{th} to 21^{st}) are located on discs which have been forged together with the shaft. Therefore the rotor of the analysed steam turbine has been designed as a mono-block (of a single piece) with the central bore.

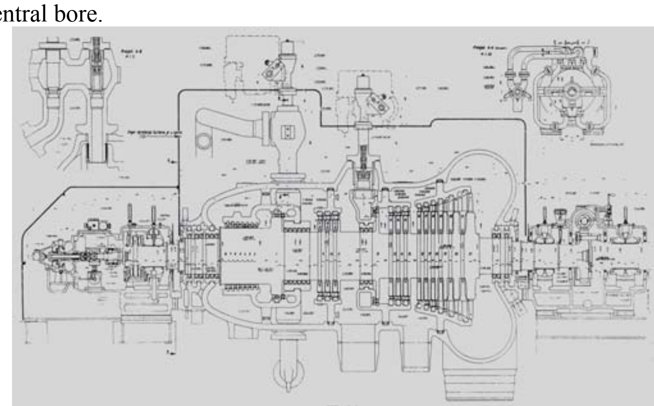

Figure 1. Cross section of steam turbine of 30 MW power

The calculations of non-stationary temperature fields, and the respective thermal deformations and stresses have been carried out 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. One-dimensional graphical representations are given parametrically depending on the turbine exit pressure and relate to the left and right boundary surface of the 21st stage disc. Abscissa of the diagram is developed surface of the disc from the periphery to the disc hub.

2. ANALYSIS OF THERMAL-STRESSED STATE IN THE DISC OF THE LAST TURBINE STAGE

Figures 2 and 3 show the temperature distributions along the boundary surfaces of the disc of 21st stage using the parametric curves, depending on the pressure in the condenser. A slight increase in the surface temperature from the periphery to the disc hub has been observed, which is a result of the heat transfer coefficient decrease on the boundary surfaces of the rotating disc from the periphery towards the disc hub, and partly of the thermal state in the region of the labyrinth gland, which affects on the disc surface temperature in the hub region [3].

The conditions of the heat transfer in the region close to the disc hub are worse than in the region closer to the periphery [3]. That is the reason of the higher temperatures for both boundary surfaces at the disc hub than at its periphery. But this temperature is still higher than the temperature of the working fluid (of wet steam), which therefore cools the boundary surfaces of the disc, i.e., working fluid takes the heat that is conducted through the rotor shaft to the 21st stage disc. Similarly, with the increase of pressure in the condenser the working fluid temperature also increases, so the boundary surfaces of the disc are less cooled, i.e. their temperature also increases. This increase is of degresive type, which means that with the increasing in the exit pressure, the temperature of the boundary surface of the disc increases more slowly, i.e. it has a smaller increase gradient.

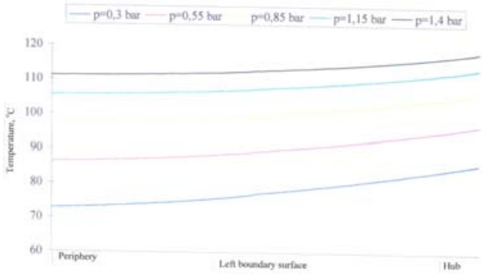

Figure 2. Temperature distributions along the left boundary surface

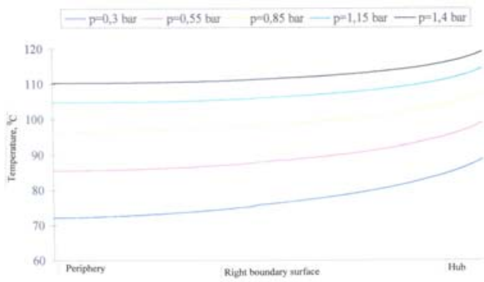

Figure 3. Temperature distributions along the right boundary surface

The distributions of the heat fluxes along the boundary surfaces are formed as the balance of overall heat fluxes in the body of the disc which are in equilibrium with the internal and external resistances to heat transfer. The heat fluxes in the body of the disc are relatively small compared to the same ones in the region of the labyrinth gland in the turbine stage and rear-end labyrinth gland, and already a little change in the thermodynamic state of wet vapor (of working fluid) leads to local changes in the heat flow both regarding the direction and the value [4]. The general conclusion that arises is that the values of heat fluxes on the boundary surfaces of the disc (their absolute values) decrease with the increasing exit pressure (Figure 4), as a result of temperature rise of wet steam, which is seen here as the cooling fluid of the disc, so the amount of heat taken by wet steam is decreased.

The discontinuity of the heat fluxes on the left and right sides of the disc appears on the place of the geometry changes of the disc profile, from a conical disc to a disc of equal thickness, which changes the conditions of heat conduction through the body of the disc and heat transfer on the boundary surfaces of the disc. A certain influence on the discontinuity has simplification of the boundary surface geometry of the 21st stage disc (neglected radius of curvature).

The heat flux on the sloping surfaces of the disc are becoming more pronounced in the axial direction than in the radial direction, regardless of that the absolute value of the heat flux vector also decreases with the increasing pressure in the condenser [4].

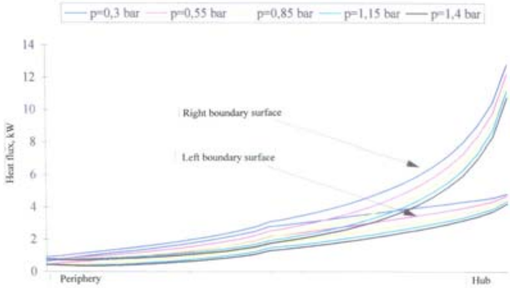

Figure 4. Distributions of resultant heat flux along left and right boundary surface

With the exit pressure increase the resultant deformation increases degresively [4]. This gives the same conclusions that are derived from the dependence of the temperature distribution on the pressure in the condenser.

The obtained distributions of axial stresses along the boundary surfaces are a result of numerical error of the used users' software program [4]. The actual axial stresses on the boundary surfaces of the disc equal zero, and the obtained distributions are a result of calculating of stresses in the nodes of finite elements that belong to the boundary surfaces of the disc on the basis of the remaining nodes in the interior of the disc for each finite element along the boundary surfaces. About the changes of axial stresses, however, it is possible to conclude that they are determined by free axial dilatations of the disc region closer to the periphery, and related axial dilatations in the region of the disc hub, which are in interaction with the axial dilatations of the rotor sleeve near the disc of the 21^{st} stage.

Figures 5 and 6 show the stress distributions in the radial direction along the left and right boundary surfaces of the disc of 21^{st} stage. It is clear that these are compressive stresses, for which there is a simple explanation. The temperature decreases from hub to the periphery, and so the external cooler part of the disc does not allow the hoter inner part to dilate appropriately. In other words, the radial stresses on the boundary surfaces of the disc, due to radial deformations, in a certain radial section of the disc on radius r_0 are the result of resistance to deformation of the peripheral layers of the disc, at radius $r > r_0$. This resistance to radial deformation of outer layers of the disc is the cause to compressive stress of internal layer of the disc (for $r \leq r_0$).

An excessive stress increase near the hub is a result of high stresses in the rotor shaft. The discontinuities, denoted with symbol ♦ indicate the places on the disc boundary surfaces where there is a change of the disc cross section due to which the value of stresses changes locally.

Figure 7 shows the tangential stress distributions for both disc surfaces. It is characteristic that the values of the tangential stresses decrease from the periphery to the disc hub, as result of the increasing tangential deformations (they are cumulatively summed from the hub to the top of the disc). The inflection points (denoted with symbol♦) in the region of geometry change of the disc cross section are the result of previously mentioned manner of the disc geometry modelling and do not correspond to the actual distribution. It is observable that on the disc left boundary surface in the region near the hub compressive stresses appear, while on the right boundary surface the stresses have tensile character as a result of bending of the disc around its radial axis in the direction of the disc left boundary surface.

The shear stresses on both sides of the disc to the place of the geometry change of the cross section of the disc are negligibly small and approximately equal to zero [4]. In the region of the conical cross section of the disc the shear stresses increase more and more towards the disc hub.

Figure 8 shows the distributions of the equivalent von Mises stresses for both boundary surfaces of the disc. And here the stress increase is visible along the right boundary surface of the disc relative to the left one, and the distortion of the stress distributions in the region of the disc hub on both boundary surfaces.

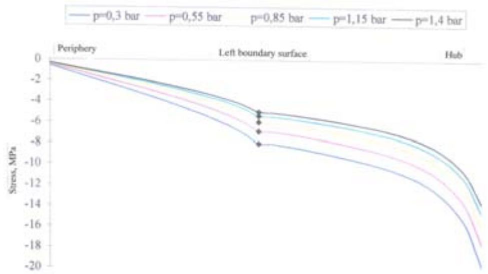

Figure 5. Distributions of radial stresses along left boundary surface

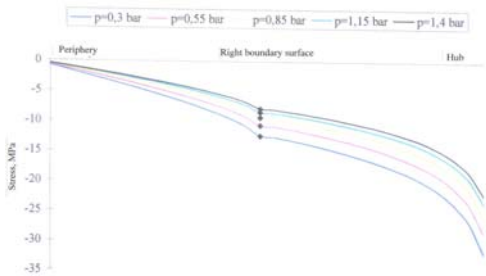

Figure 6. Distributions of radial stresses along right boundary surface

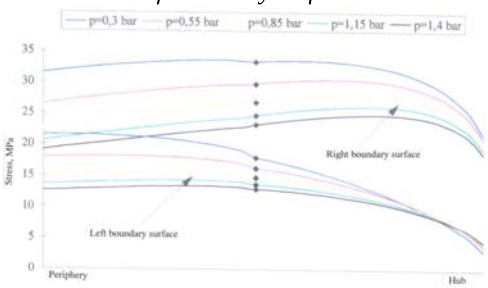

Figure 7. Distributions of tangential stresses along left and right boundary surfaces

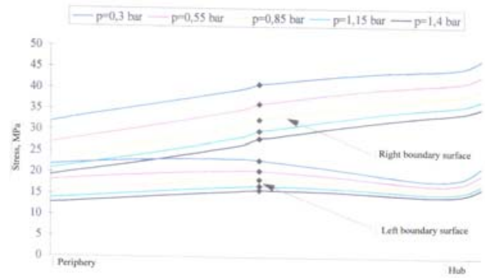

Figure 8. Distributions of equivalent von Mises stresses along left and right boundary surfaces

3. CONCLUSION

For the thermal-stressed state in the disc of the last turbine stage is characteristically:

- the temperature of the boundary surfaces increases with the increase of the exit pressure;
- the values of heat fluxes along the boundary surfaces (their absolute values) decrease with the increase of the exit pressure;
- the resultant deformation increases degresively with the exit pressure increase;
- the obtained distributions of axial stresses along the boundary surfaces are a result of numerical error;
- an excessive radial stress increase near the hub is a result of high stresses in the rotor shaft;
- the values of the tangential stresses decrease from the periphery to the disc hub;
- the shear stresses are negligibly small and approximately equal to zero;
- the equivalent von Mises stresses along the right boundary surface are larger than along the left boundary surface.

Generally, on the basis of the obtained thermal and mechanical values it is possible to conclude that the thermal-stressed state of the analysed 21st stage disc of the steam turbine is acceptable: maximal equivalent von Mises stress is below 50 MPa.

4. REFERENCES

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