MODERNISATION OF STEAM TURBINE CONSTRUCTION AT REGENERATIVE STEAM EXTRACTION POINT

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Abstract: The paper presents a methodology which has led to improvement of the turbine stage performance in the regenerative steam extraction chamber area by introducing a ring which collects the leakage flow from the gaps over unshrouded rotor blade tips and directs it to the extraction chamber. A comparison is made between the results obtained for the initial design (without a ring) and the design with the ring mounted. The results obtained for the construction were calibrated using the data measured on a real turbine in a Polish power plant.

Keywords: modernization, turbine stage, extraction point, leakage

1. Introduction

In turbine stages, gaps over rotor blades are necessary to allow the rotor to rotate. The steam flowing through these gaps has higher energy and a different direction than the main stream. All this is a source of losses generated in this area, as the leakage steam not only flows through the rotor without work, but also generates intensive mixing processes which unfavourably affect the overall stage efficiency. The fact that the leakage steam leaves the gap with high velocity is particularly unfavourable in the regenerative steam extraction areas where it disturbs the extraction process, as was observed by the authors in the steam flow measurements done in the low-pressure part of the 200MW turbine.

A detailed analysis of the phenomena taking place in the steam extraction area provided opportunities for working out a new stage design, a general concept of which is shown in Figure 1 [1].

The aim of the new design was to reduce losses and other unfavourable effects generated by the leakage flow. It was done by introducing a special ring downstream of the rotor in the vicinity of the gap to direct the leakage flow to the regenerative chamber. The ring was fixed to the stator disc by special supports.

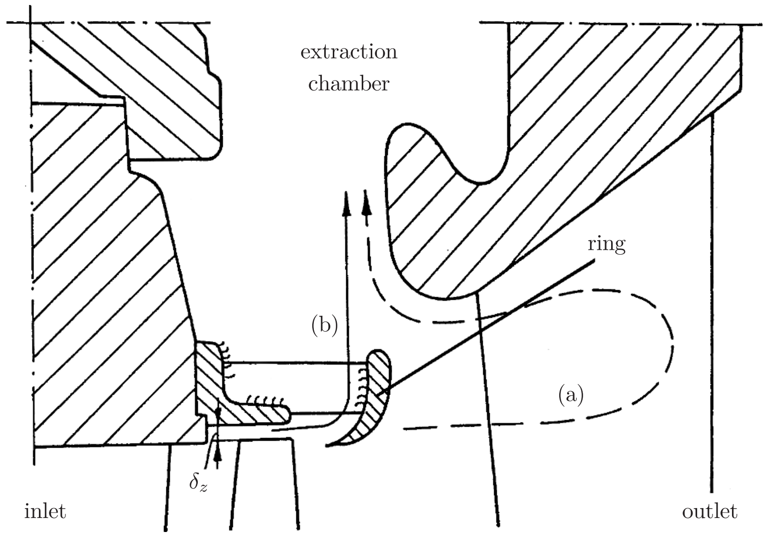

Figure 1. Turbine stage design in steam extraction area. The arrows indicate the leakage flow direction before (a) and after (b) modernisation

2. Geometry and calculation grid

The numerical calculations, performed to compare the modernised turbine construction with the initial design in the area of the 200MW LP turbine extraction chamber were limited to the diffuser between stages 3 and 4. The calculations were performed using the code Fluent [2], geometric data for which were obtained from the technical documentation available in the archives of the Turbine Aerodynamics Department, IMP PAN Gdansk.

The axial symmetry of the turbine geometry justified reducing the three-dimensional task of the axially symmetrical flow with a whirl to a two-dimensional model. This simplification did not reduce the generality and accuracy of the obtained results, but it considerably shortened the calculation time, which in turn made it possible to increase the resolution of the grid used in the calculations.

Two variants of turbine geometry were prepared for the comparison. The initial variant, without a ring, is given in Figure 2, while Figure 3 shows the variant with the installed ring.

For both the variants a structural grid was generated after dividing the entire domain into over ten blocks. The total number of finite volumes was equal to 18 000 in the first variant and 25 000 in the second variant. The dimension of the smallest cell within the boundary layer area corresponded to y^+ approximately equal to 1.

The extraction chamber outlet which in the real turbine has the form of a connector pipe situated at the extraction chamber side, is modelled in the 2D calculations as an opening uniformly distributed around the top wall of the extraction chamber, see the thick line in Figure 2. The total areas of the real and model outlets are identical.

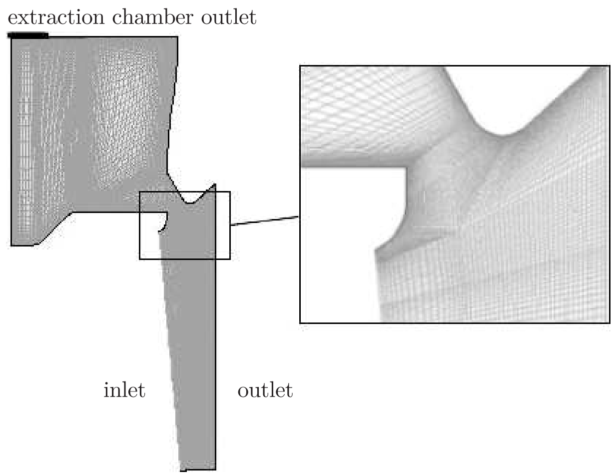

Figure 2. Geometry of interstage diffuser with extraction chamber, and calculation grid (variant without separation ring)

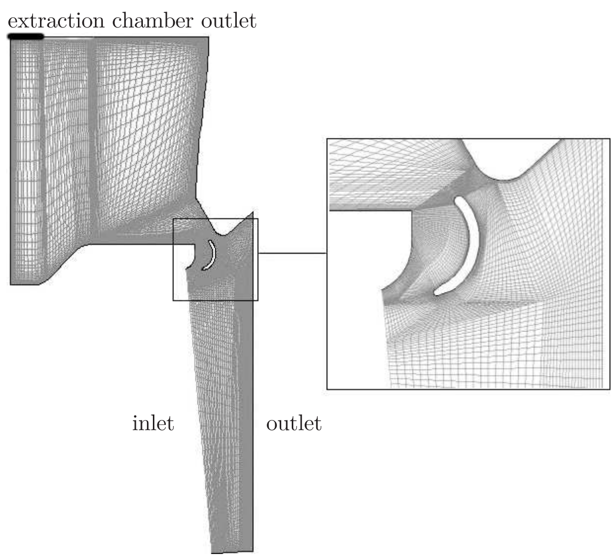

Figure 3. Geometry of interstage diffuser with extraction chamber, and calculation grid (variant with separation ring)

3. Thermodynamic parameters

The thermodynamic parameters to be used for the calculations were generated from the protocols of steam flow measurements in the 13K-225LP turbine in operation in Block 8, Polaniec Power Plant [3]. From among all the measurement series recorded for the nominal load 220MW, was selected as representative for the turbine operation. The measurement was done, using specially designed probes, in the area where the ring was to be installed, which made it possible to determine the distributions of such parameters as static and total pressure, absolute velocity and its axial component, total temperature, flow inlet angles, as a function of the turbine passage height. These quantities made the basis, after relevant scaling, for determining the inlet and outlet boundary conditions for interstage diffuser calculations.

The boundary conditions for the steam flow were assumed identical for the variant with and without a ring. The radial distributions of the diffuser inlet parameters, which were total and static pressures, temperatures, and flow angles in the area situated downstream of the stage 3 rotor blades were set based on their values measured in the real turbine, assuming their uniformity in the circumferential direction. At the same time the static pressure, required at the diffuser outlet, was determined in an iterative way from the mass flow rate measured in the main flow. This outlet pressure was changed along the blade span according to the radial equilibrium equation.

The calculations were performed for a model of compressible and viscous fluid, and using a two-equation turbulence k-ω model. The thermodynamic state of the steam was modelled by the equations valid for perfect gas. The thermodynamic constants, determined for conditions corresponding to a wet steam flow, were equal to: $R = 437.5\,\mathrm{J/kg}\,k$ and $k = 1.13$.

Comparing the calculated radial distributions of pressure, velocity and temperature with those measured along the probe traversing line confirmed the correctness and physical reliability of the assumed boundary conditions at the diffuser inlet, Figures 4–6.

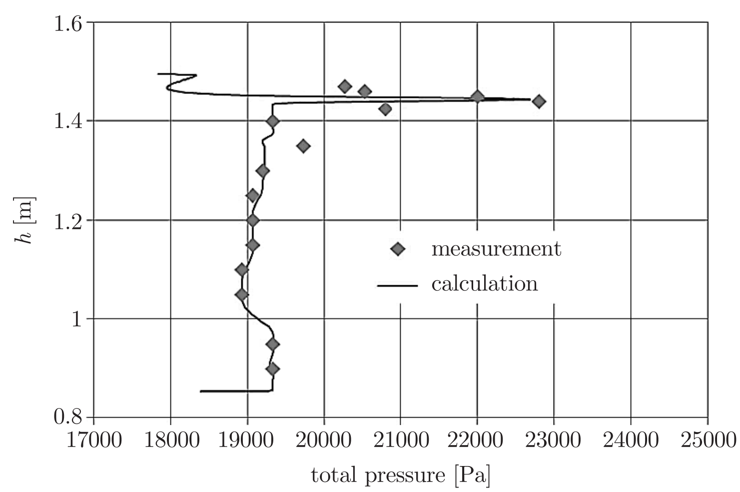

Figure 4. Comparing calculated radial distributions of total pressure with those measured in real turbine

The experimental data making the basis for determining the boundary conditions for the flow through the interstage diffuser were recorded inside the diffuser, along the traversing line approximately situated in the middle between the diffuser inlet and outlet. For these measurements, diffuser inlet and outlet

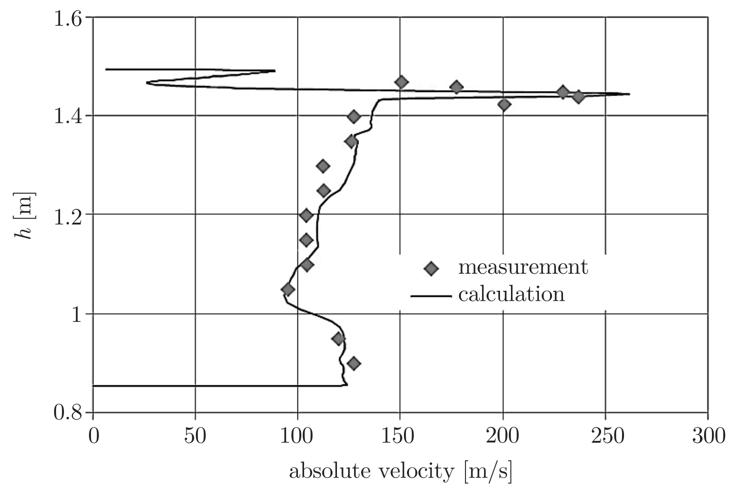

Figure 5. Comparing the calculated radial distributions of absolute velocity with those measured in a real turbine

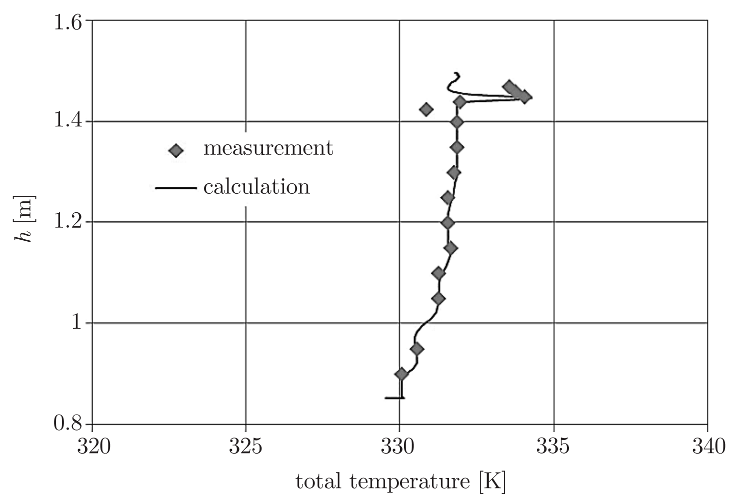

Figure 6. Comparing calculated radial distributions of total temperature with those measured in real turbine

parameters were to be selected in such a way, using an iterative procedure, that the resultant distributions calculated along the traversing line were the closest to those measured. Figures 4–6 compare pairs of corresponding distributions calculated and measured along the traversing line. The presented diagrams show that the boundary conditions for the diffuser flow calculations were selected correctly.

The presented diagrams reveal a remarkable effect of the stage 3 rotor tip leakage flow on the distributions of thermodynamic parameters in the diffuser. This effect manifests itself, *inter alia*, in incorrect flow inlet angles when the flow approaches stage 4 stator blades.

4. Results of CFD calculations

The performed steam flow calculations gave the distributions of flow parameters in the examined area. The first calculation series referred to the flow variant without a ring. It was performed for the conditions taken from measurement which were close to the nominal turbine operation: $N \sim 220\,\mathrm{MW}$; $G \sim 62.5\,\mathrm{kg/s}$, $G_{\mathrm{ex}} \sim 1\,\mathrm{kg/s}$ [3].

It is clear from Figure 7 that in the initial construction the steam flow to the extraction chamber is blocked by the stage 3 rotor tip leakage flow [4]. This tendency was confirmed by observations done in a real turbine in which salt deposits were seen on the last stage stator blades [5]. It is noteworthy that in the examined case the mass flow rate of the steam entering the extraction chamber is equal to about 1kg/s, *i.e.* less than 2% of the main flow mass flow rate. Such a small volume of the extracted steam is an effect of the activity of the leakage jet which almost totally blocks the entrance to the extraction chamber.

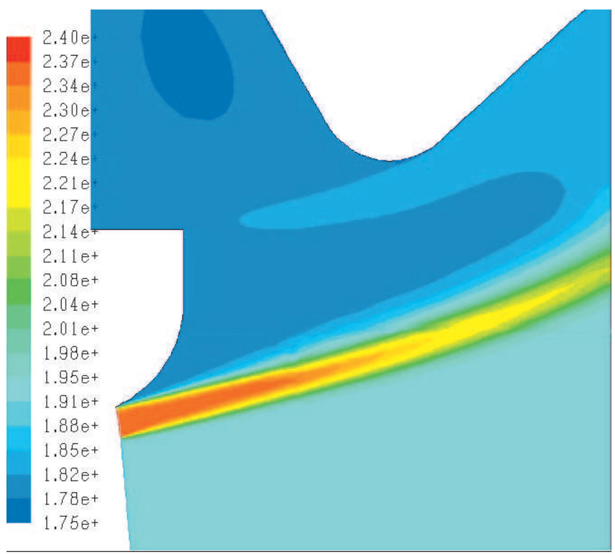

Figure 7. Total pressure distributions in steam extraction area: initial design

The calculations performed for the interstage diffuser after modernisation included in total 12 different variants, calculated to select the optimal shape and location of the ring. The optimised parameters included the diameter of a pipe used for ring machining, its length and general location, as well as the location of its leading edge with respect to the stage 3 rotor blade.

The main role which the ring is to play is to direct the jet leaving stage 3 rotor blades directly to the extraction chamber inlet. This will reduce the erosion process which damages the last stage rotor blade profiles beneath the hardened part. This erosion process, extremely dangerous for the turbine, results from the fact that the leakage flow grabs water droplets collecting on stage 3 rotor tips and sprays them onto the downstream profiles.

Before introducing a new solution, an analysis of particular variants was necessary to select the most favourable ring location. On the one hand, the ring is to eliminate totally the leakage flow from the main flow, to minimise the erosion threat. On the other hand, it should secure the highest possible pressure in the extraction chamber, which in this case is equivalent to reaching the highest efficiency of the turbine set.

When the ring is too short it produces unfavourable deflection of the leakage flow which is then rapidly stopped on the outer clamping ring wall. When the ring is too long, in turn, it can direct the leakage flow with the droplets onto the bolts fastening the ring. Figure 8 shows a case where the ring is mounted too high. In this case the leakage flow is divided into two streams, one of which (1) flows to the exchanger while the second (2) joins back the main flow through the next stage blade system.

Another aspect which is to be taken into account when selecting the ring dimensions is that the ring should provide opportunities for its correct welding to the fastening ribs, which can be exposed to erosion in this area.

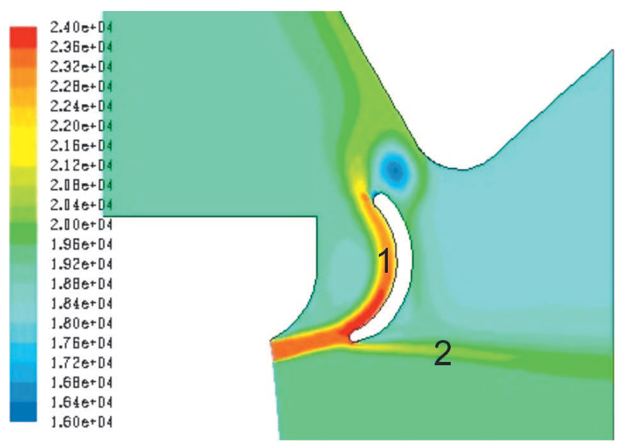

Figure 8. Total pressure distributions for ring mounted too high

When the ring is located correctly, it effectively eliminates the leakage flow from the main flow. It is also the aerodynamic wake behind the ring that is visibly reduced, and the flow at the stag 4 inlet has better distributions of kinetic parameters than those recorded in the old construction.

After modernisation, the velocities recorded in the main flow are much more uniform. The installed ring decelerates the leakage flow, which is favourable from the point of view of erosion of the next stage blade leading edges and fastening ribs. This can be easily observed when comparing the velocity fields for the two examined cases: before and after modernisation, Figure 9.

For the selected ring location, the pressure increment by 2.5kPa up to $p = 20.4$kPa was also observed in the extraction chamber, as compared to the solution without a ring.

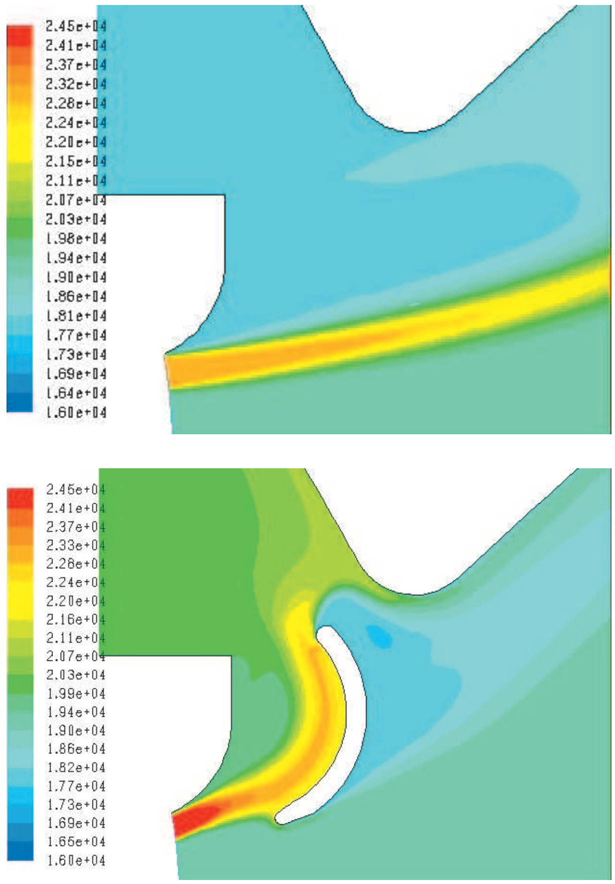

Figure 9. Comparing total pressure distributions before (top) and after modernisation (bottom)

5. Summary

The proposed modernisation of the LP turbine in the extraction chamber area can be effectively installed in the interstage diffuser and does not produce any threat of seizure during turbine start-ups and shutdowns. Additionally, the proposed solution provides opportunities for easy installation of the ring elements, which are to be fixed to the turbine body with an extremely high accuracy with respect to the stage 3 rotor blades. The optimisation of the ring location in the diffuser, done based on relevant calculations and observations of real turbines, revealed that the application of the proposed solution could bring power output gains amounting up to 400kW. These gains result from higher, most favourable load of the regenerative heat exchanger and the improved efficiency of the steam flow through the turbine blade system. The selected location of the ring in the diffuser should secure complete elimination of the high-energy leakage flow from the main flow. In the old construction this leakage flow carried water droplets from the stage 3 tip rotor blade parts and sprayed them onto the areas reaching non-hardened parts of the last stage blades, thus being a source of erosion and corrosion damages, extremely dangerous for the turbine set operation.

Noteworthy is also a low cost of manufacturing and assembly of the separating ring, as compared to other constructions with a similar purpose, which frequently require replacement of the entire turbine stage.

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