NEW APPROACH TO CALCULATIONS OF TURBINE STAGES AND REGENERATION EXTRACTION POINTS

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Abstract: The article presents 200 MW LP turbine stage calculations taking into account leakage flows over rotor blades in the regeneration extraction point area. A methodology is described which allows the user to shorten the time-consuming CFD calculations solving the Navier-Stokes equation system in the examined area. A two-stage procedure was applied in which two types of calculations were coupled together. The first type is a one-to-one passage calculation of a steam flow through the turbine stages in the vicinity of the extraction point. This type of calculations preserves the circumferential periodicity condition. The second type is a circumferentially non-symmetrical calculation of the flow through an inter-stage diffuser with an extraction chamber. The calculations were preformed using 3D CFD codes, FlowER and FLUENT, in the two above mentioned areas, respectively. The solution was found using an iterative procedure for these areas coupled by boundary conditions, until convergence of calculations was reached.

Keywords: extension point, regenerative chambers, turbine stages, leakages

1. Introduction

The main objective of the work is to analyze the steam flow through turbine stages operating in the vicinity of an extraction point. So far, numerical calculations of such systems have been made based on the circumferential symmetry assumption. The computational domain can be then reduced to one blade-to-blade passage of stator and rotor rows so as to considerably reduce the computational costs. The above simplification is a source of significant errors in estimating the operation of turbine inlets and exits, as described in experimental works [1, 2]. In addition to turbine inlets and exits, the flow non-symmetry is also caused by extraction of steam to regenerative extraction or heat station exchangers, as shown schematically in Figure 1.

This non-symmetry is further distorted in the LP part by the presence of intensive leakage flows over unshrouded rotor blades which hamper the outflow of steam to the extraction point (Figure 2).

In the present paper, this complex computational task has been accomplished on a 3D model. For numerical simplification the computational domain has been divided

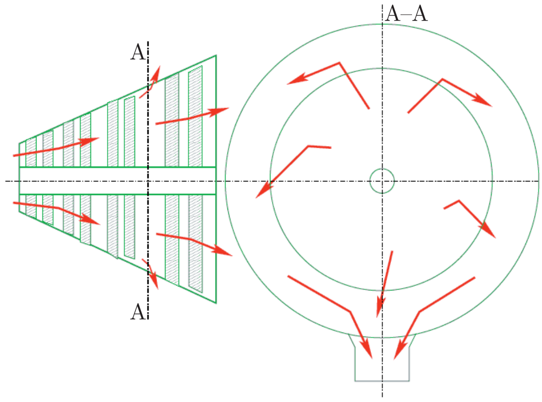

Figure 1. Scheme of flow through a turbine with an extraction point

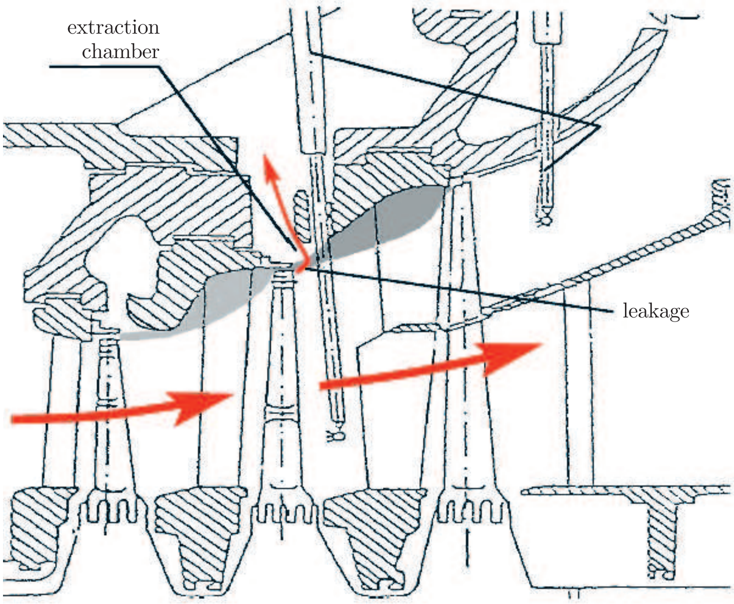

Figure 2. Flow through LP turbine stages taking into account extraction and leakage flows

into two parts. Symmetrical calculations of the flow through turbine stages have been conducted in combination with non-symmetrical calculations of a diffuser with an extraction chamber. The author's own previous experience in numerical calculations of turbine exhaust hoods has been used in [3].

2. CFD steam flow calculation through LP turbine

The methodology of combining calculations through turbine stages and through a diffuser with an extraction chamber is depicted in Figure 3, see also [4].

At the first stage, turbine stages are calculated based on the circumferential symmetry assumption. The FlowER program validated on turbine test cases has been used to complete this task [5]. Thermodynamic data for these computations have been acquired from measurements on a real object. The data take into account a variation

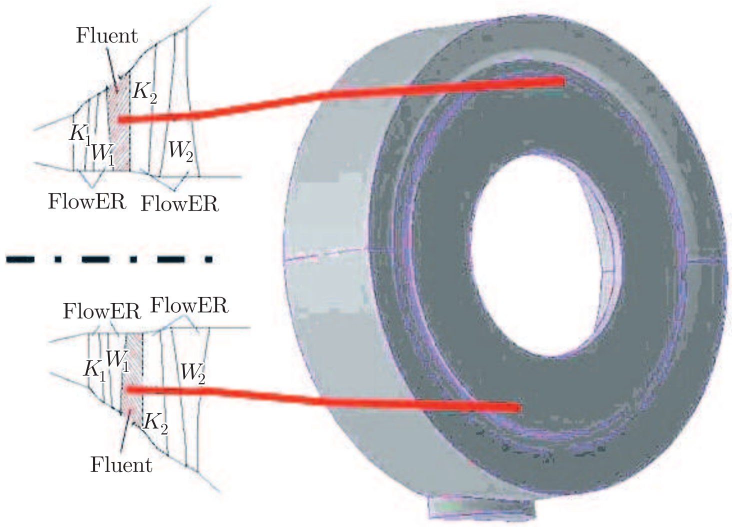

Figure 3. Principles of combining the calculations of turbine stages and a diffuser with an extraction chamber

of the flow parameters over the blade span. The results of calculation of turbine stages provide data for diffuser calculations which are conducted using the FLUENT program, see Figure 4.

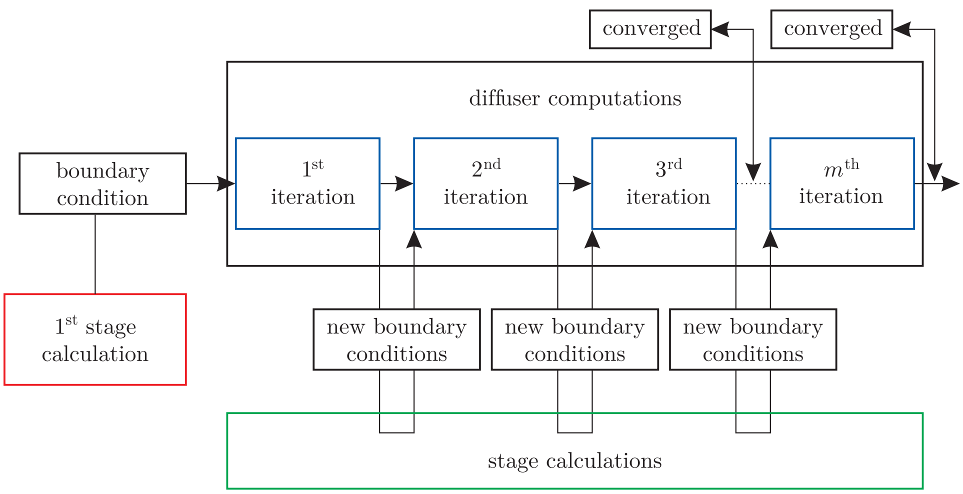

Figure 4. Data transmission method in calculations of turbine stages with an extraction point

The turbine construction geometrical data are presented in Figure 5.

The computational domain is discretized using a structural grid which contains a total of 2.5 million control volumes. The combination of an axi-symmetrical flow through turbine stages with a non-symmetrical flow through the diffuser and the extraction chamber is fulfilled by means of two mixing planes. They have been chosen to take into account the compatibility of flow conditions and solutions from the two programmes.

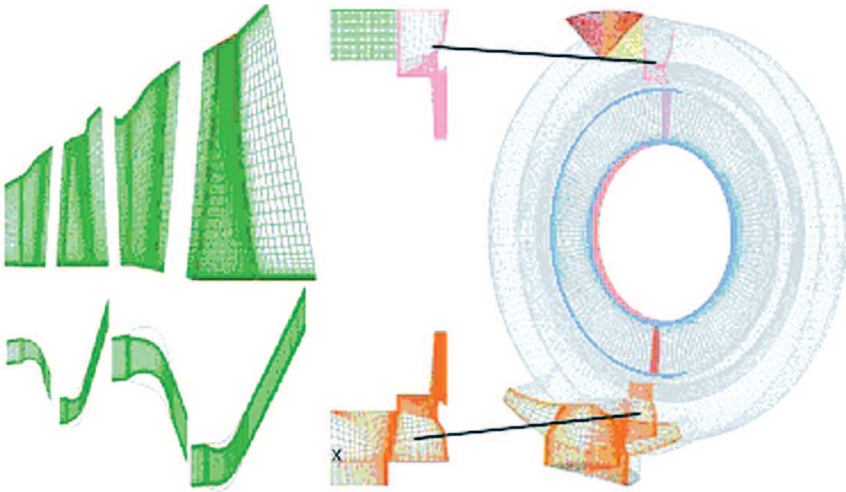

Figure 5. Computational grids for calculation of turbine stages and a diffuser with an extraction chamber

The calculations of turbine stages and diffusers in subsequent iterations generate a variation of flow parameters in the circumferential direction. Further calculations using the FlowER programme are made at four positions along the circumference to account for the solution's non-symmetry. The circumferential non-symmetry is pronounced in the mass flow rate redistribution along the circumference which is shown in Figure 6. The picture exhibits a significant effect of the leakage flow direction above the unshrouded blades on the mass flow rate distribution at the inlet to the extraction point.

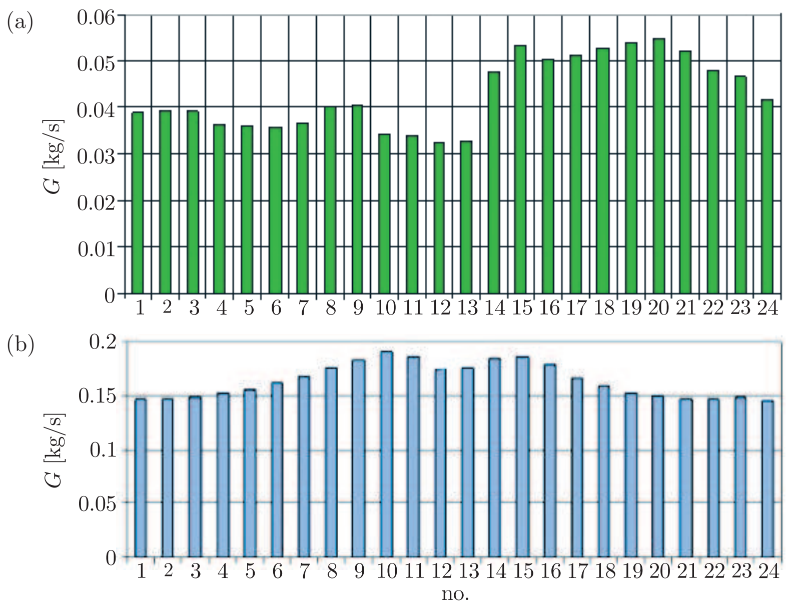

Figure 6. Mass flow rate circumferential distribution at the inlet to the extraction point (a) leakage with swirl ($G_{up} = 1$ kg/s), (b) leakage without swirl ($G_{up} = 4$ kg/s)

The convergence criterion for the algorithm of calculations is formulated in terms of a residuum of the mass flow rate along the circumference:

$$\frac{1}{n}\sum_{i=1}^{n}\frac{\Delta M_{m,i}-\Delta M_{m,i-1}}{\Delta M_{m,i}}<\text{tol.}$$

Two computational loops are needed to reach a residuum value below 5%.

Variations of flow parameters at the inlet and exit from the diffuser are given in Figure 7.

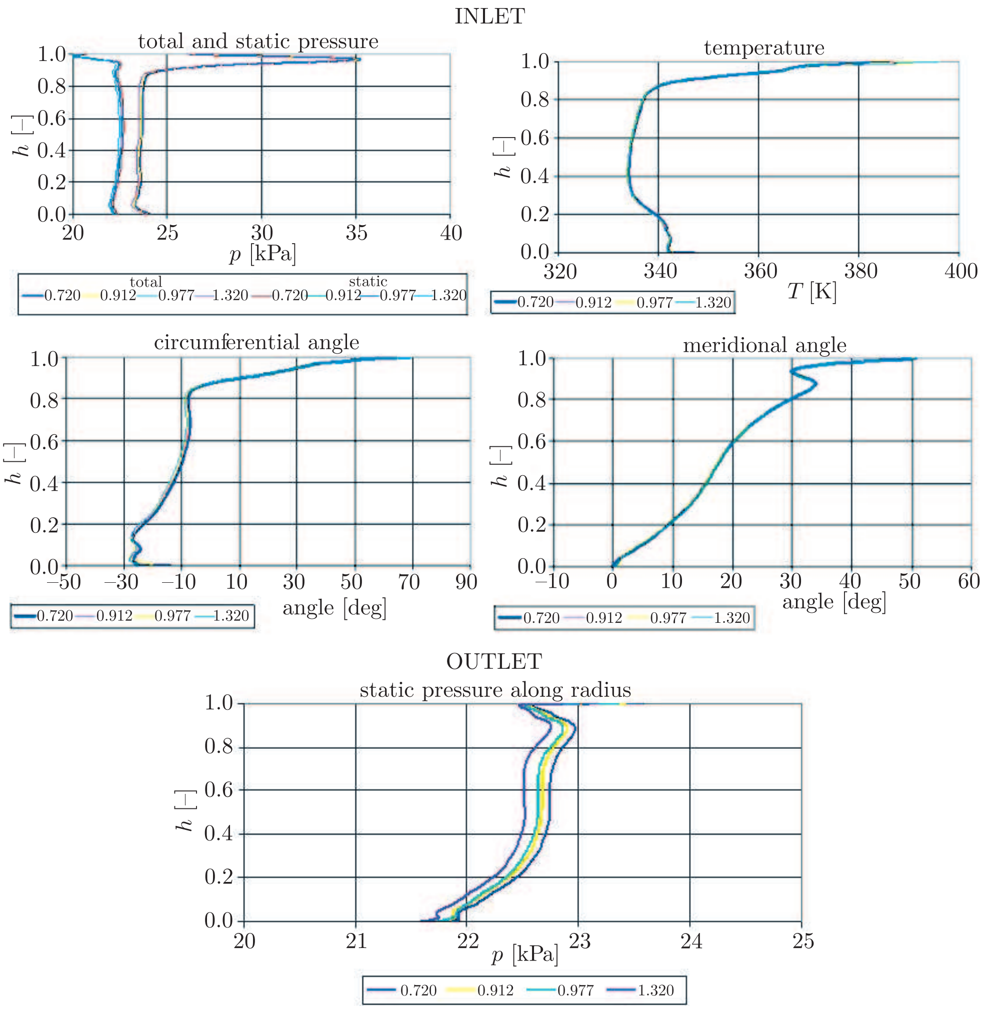

Figure 7. Variations of flow parameters at the diffuser inlet and exit along the circumference and radius [5]

The flow behaviour in the computational domain is best described by the picture of streamlines (Figure 8).

The flow velocity in characteristic diffuser sections is presented in Figure 9.

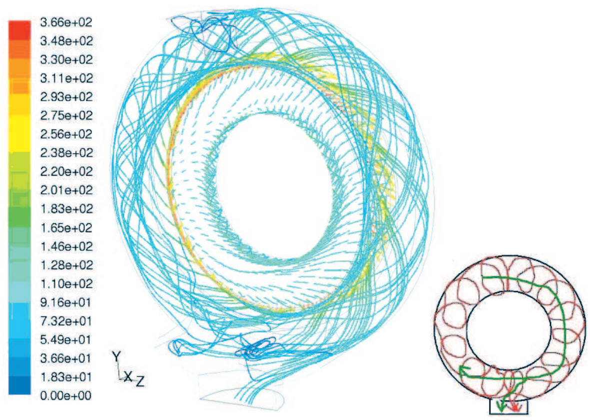

Figure 8. Streamlines in an inter-stage diffuser, extraction chamber and extraction tube

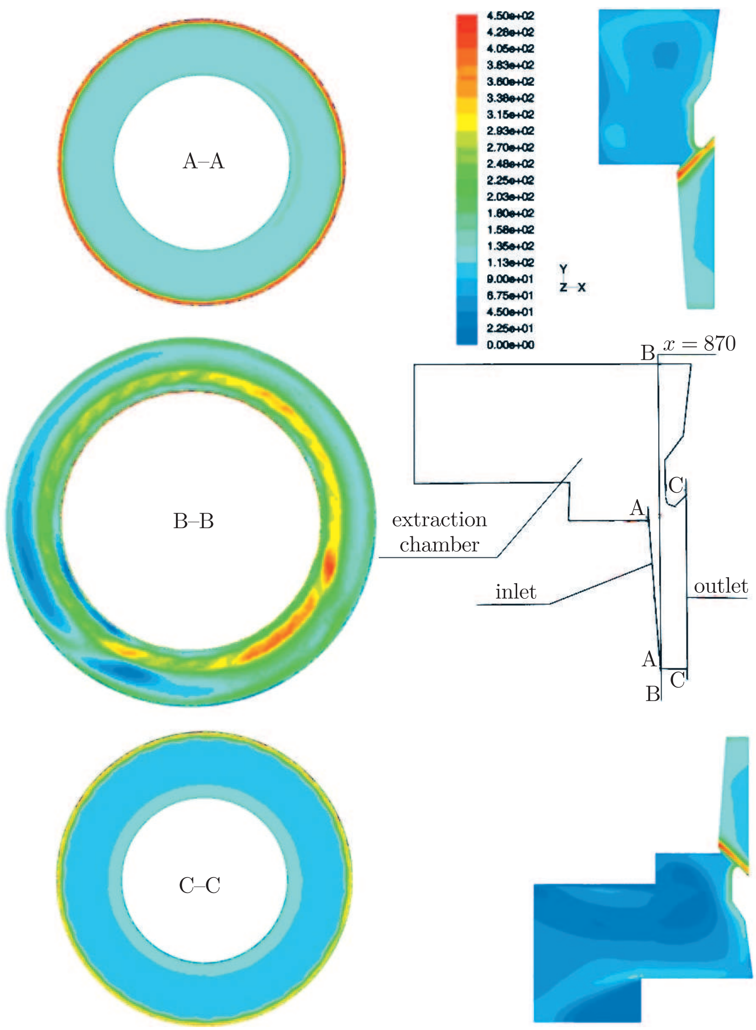

Figure 9. The flow velocity in characteristic diffuser sections [6]

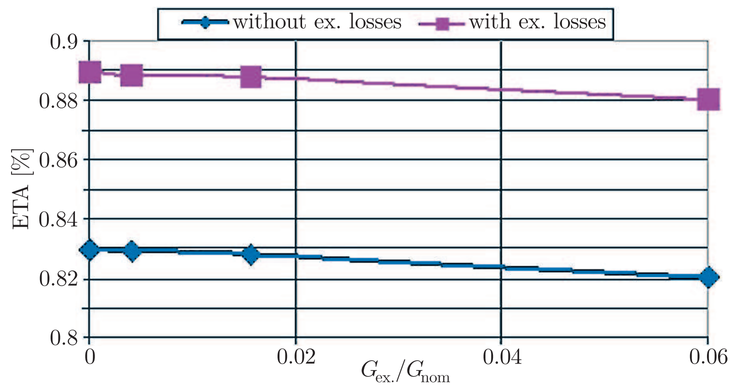

Figure 10. Change of stage efficiency as a function extraction flow mass

It has been found from balance calculations that a non-symmetrical distribution of flow parameters behind the stage has minor influence on the efficiency of the turbine stage downstream of the extraction point (Figure 10).

3. Conclusions

1. The regenerative extraction point in a turbine leads to circumferential non-symmetry of flow parameters. This non-symmetry is however not very significant and mostly felt inside the extraction chamber.
2. The non-symmetry is more visible with an increasing mass flow to the extraction point, which results in decreased flow efficiency due to a locally non-nominal inflow at the turbine blades.
3. The flow of steam to the extraction chamber is largely affected by leakage flows, especially those over unshrouded rotor blades. In this case leakage flows can block the outflow to the heat exchanger.
4. The used simplified methodology of calculations has proved successful in practice. Compared with the full geometry calculations the computational costs have been reduced by one order of magnitude.

References

[1] Gardzilewicz A 1995 *Proc. 1st Turbine European Conference, VDI Verlag Berichte*, Erlangen, Dusseldorf

[2] Garkusza A W 1983 *Aerodynamics of Steam Turbine*, Maszynostrojenie, Leningrad (in Russian)

[3] Gardzilewicz A, Świrydczuk J, Badur J, Karcz M, Werner R and Szyrejko Cz 2003 *Trans. IFFM* **113** 157

[4] Szymaniak M 2007 *The Application of a Numerical Technique to Calculation of Steam Turbine Stages with Leakage Flows and Extractions*, PhD Thesis, Institute of Fluid-Flow Machinery PAS, Gdansk (in Polish)

[5] Yershov S and Rusanov A 1995 *The Application Package FlowER for the Calculation of 3D Viscous Flows Through Multi-stage Turbomachinery*, Certificate of State Registration of Copyright, Ukrainian State Agency of Copyright, Related Rights, Kijew

[6] 2000 *FLUENT/UNS/Rampant, User's Guide*, FLUENT Inc.