TRANSACTIONS OF THE INSTITUTE OF FLUID-FLOW MACHINERY

No. 113, 2003, 157-168

ANDRZEJ. GARDZILEWICZ[a*], JERZY ŚWIRYDCZUK[a], JANUSZ BADUR[b], MICHAŁ KARCZ[b], ROBERT WERNER[c] and CZESŁAW SZYREJKO[c]

Methodology of CFD computations applied for analysing flows through steam turbine exhaust hoods

[a] *Turbine Aerodynamics Department, Institute of Fluid Flow Machinery, Polish Academy of Sciences, Fiszera 14, 80-231 Gdańsk, Poland,*

[b] *Thermo-Chemical Power Department, Institute of Fluid-Flow Machinery, Polish Academy of Sciences, Fiszera 14, 80-231 Gdańsk, Poland,*

[c] *ALSTOM Power Ltd, Elbląg, Poland*

Abstract

In the paper three different approaches and different methods of the last stage and exhaust hood calculations are presented and discussed in details. Results of our investigations have been implemented in Polish power plants, another are under development.

Keywords: Steam turbine, Exhaust hood; CFD computation

1 Introduction

Non-symmetrical flow of steam at a steam turbine exit is one of the most challenging problems in fluid dynamics [1, 2]. An exhaust hood has a complex geometry, in which the flow changes direction by 90^o, as well as a complex set of flow properties, including:

- viscosity,
- compressibility and shock waves,
- heat transfer with phase transition,
- changing thermodynamic properties of the steam at the presence of water,

*Corresponding author. E-mail address: gar@imp.gda.pl

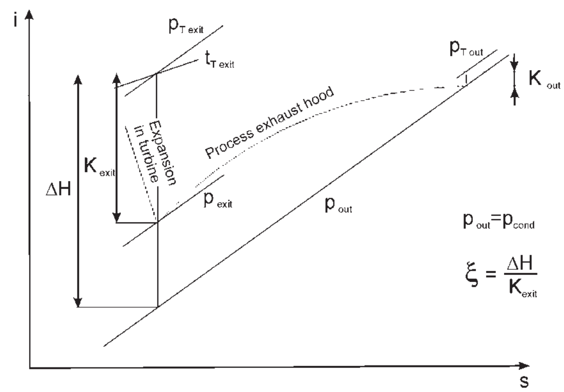

Figure 1. Definition of kinetic energy loss coefficient in the turbine exhaust hood.

- unsteady flow effects connected with vibrations of rotating blades and stiffening elements,

That was a reason why designers of this turbine part, have made vast use of model studies, most often performed on the air stands [3, 4]. Those studies have been, as a rule, simplified, providing, however, an opportunity to make a rough estimation of flow losses. Operation of the exhaust hoods is mainly based on the proper estimation of the kinetic energy loss coefficient ξ, (Fig. 1), which depends both on the geometry and flow parameters, especially velocity, changing with the loading of the turbine set.
Practical solution of set of the conservation equations in application to fluid-flow machines has been the motivation for implementing this modern procedures to design of steam turbine exhaust hoods in the nineties of the last centaury [5, 6].

2 Three methods of CFD calculations for a turbine last stage – exhaust hood designing

2.1 Measurement-based exhaust hood calculations

In the first tests, due to relatively complicated geometry of the exhaust hood, numerical calculations have been performed independently from the last stage operation, with the inlet parameters taken from measurements data, often done on a model or real turbine sets [8, 9]. This kind of calculations have also been performed at IFFM PAS Gdańsk in co-operation with the Design Office of ABB Elblag, (now ALSTOM Power Elblag) [9, 10].
Fig. 2 shows a measuring system used in the LP part of 360 MW turbine.

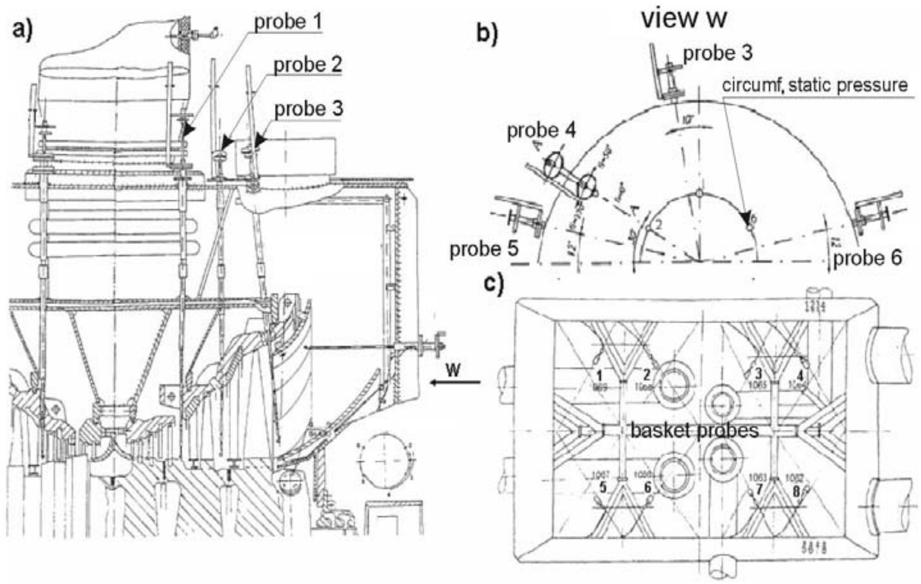

Figure 2. Measuring instrumentation in LP part of 18K-360 turbine: a) turbine axial cross-section, b) exhaust hood inlet circumferential cross-section, c) exhaust hood exit cross-section – before condenser.

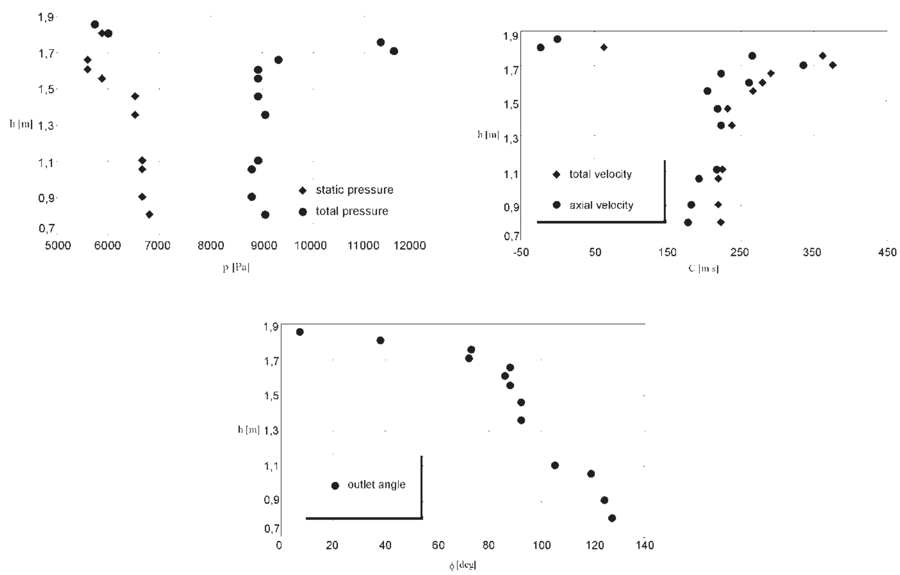

Figure 3. Radial distributions of static and total pressure, velocity, and flow angles at the 360 MW turbine last stage exit.

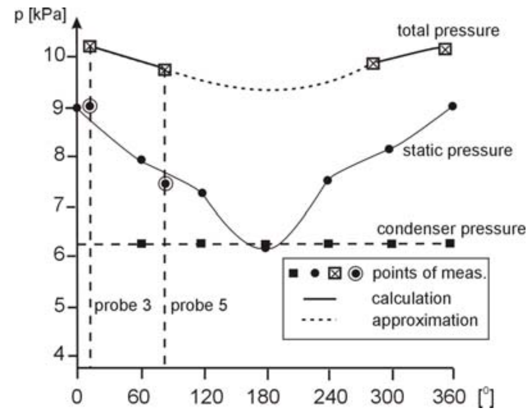

Figure 4. Circumferential distributions of static and total pressure at the last stage exit.

Recording parameters along selected lines behind the last stage made it possible to determine the distributions of pressure, temperature and the flow angles at the exhaust hood inlet. Exit parameters have been obtained from the static pressure measurements, performed in front of cooling tubes in the condenser using basket probes. Selected results of the pressure measurements are shown in Figs. 3 and 4. Exhaust hood flow calculations were performed using a standard commercial code with the RNG $k-\varepsilon$ turbulence model. Mixed structured-unstructured grids were used for defining the exhaust hood geometry, with approximate number of 1 million finite volumes [7]. Fig. 7 gives sample views of the grid applied. It is noteworthy that this rather complicated mesh referred to an empty exhaust hood, with only one supporting rib. One set of exhaust hood calculation, includ-

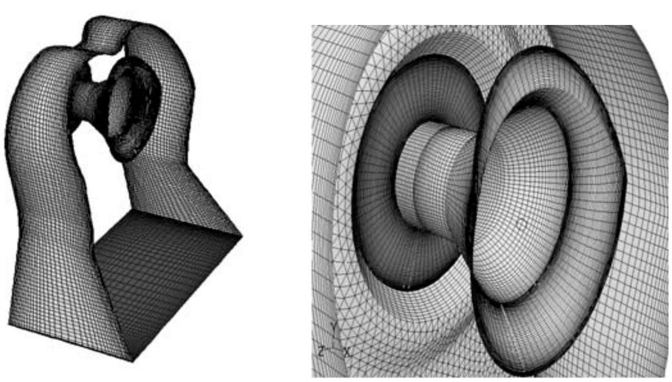

Figure 5. Structured and unstructured grid used in modelling the exhaust hood.

ing 5-10 thousand of iterations on Pentium III, needed over 100 computing hours. Characteristic patterns of the flow inside the exhaust hood are shown in Fig. 6, in the form of velocity fields. A solution of the recorded flow problems leads

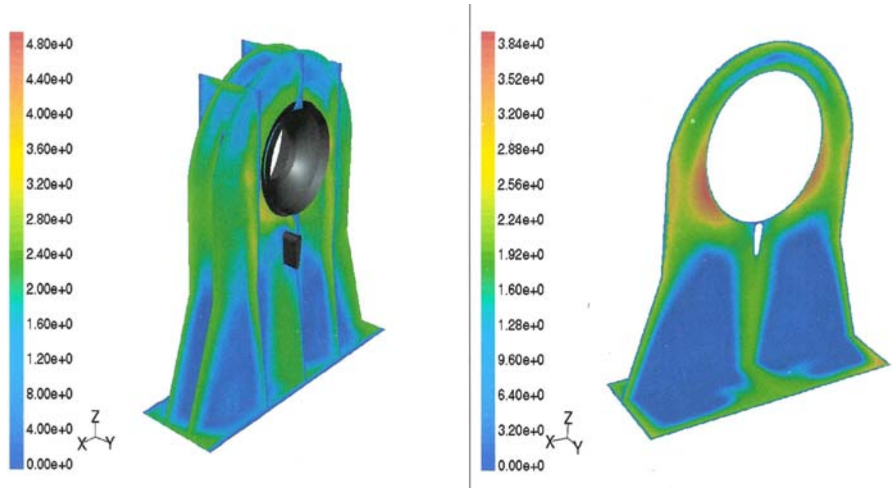

Figure 6. Velocity fields inside the 360 MW turbine exhaust hood.

to the use of rings at the turbine exit which separates the main flow from the leakage flow, thus eliminating unfavourable flow whirls, (dark colour in Fig. 7).

The implemented modification increased the calculated power output of the

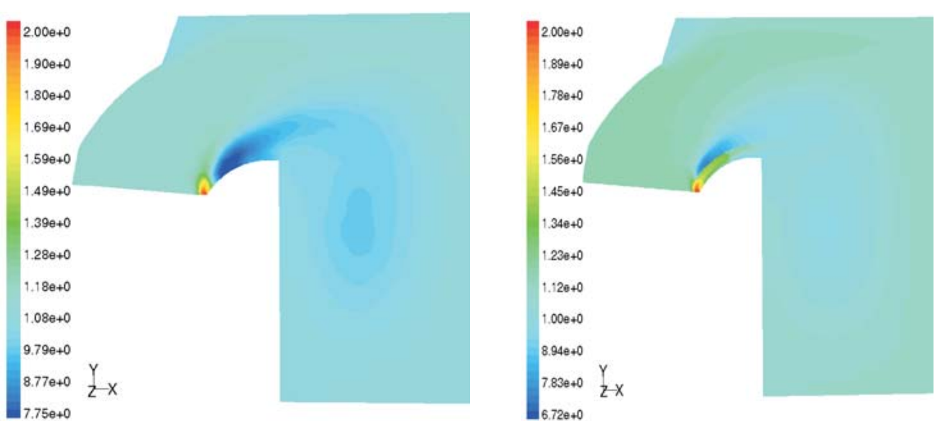

Figure 7. Total pressure field in the exhaust hood pitch plane before and after modernisation.

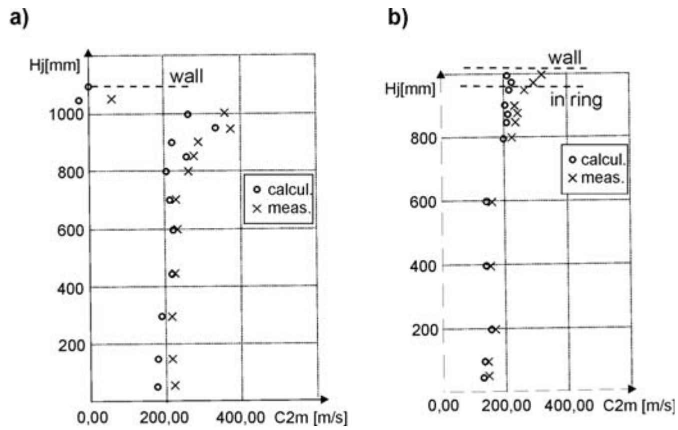

Figure 8. Measured and calculated pressure distributions at the turbine a) exit before and b) after modernisation (location probe 3, Fig. 4) [10].

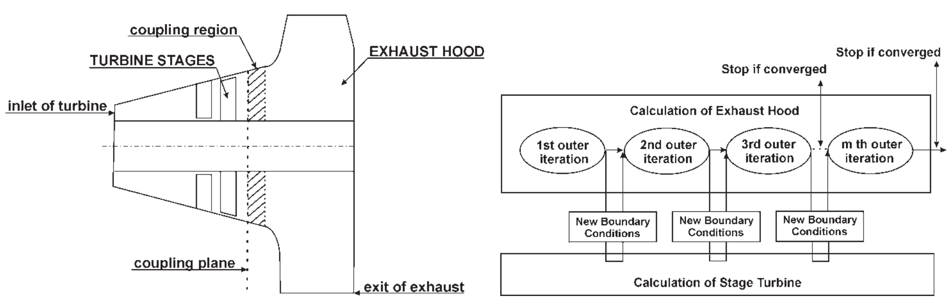

Figure 9. Coupled calculations of the turbine last stage/exhaust hood flow. Exhaust hood inlet flow parameters are assumed in the coupling plane or in the overlapping area on the base of the turbine last stage calculations [13].

turbine set by 300-500 kW. These quantities cannot be easily verified by direct measurement. The scale of elimination of the flow whirl was checked in verification measurements, performed on the real turbine before and after modernisation – see Fig. 8. Some results have also been checked on a model turbine stand at MEI, Moscow [12].

2.2 Coupled turbine stages – exhaust hood calculations.

High price of experimental investigations, together with numerical problems concerning simultaneous calculations of the flow through the last stage and exhaust hood diffuser has been the reason for implementing procedure of separate

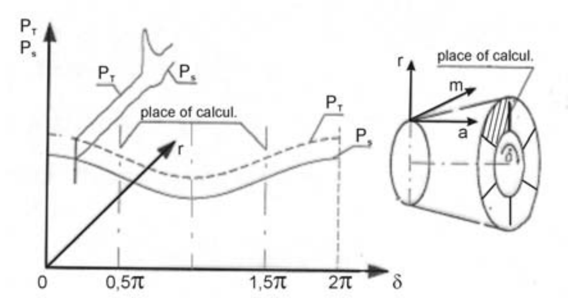

Figure 10. Radial and circumferential distributions of static and total pressure at turbine exit.

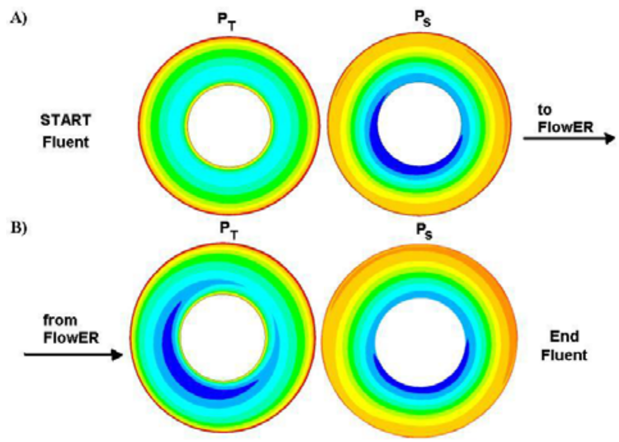

Figure 11. A) Uniform total pressure (left) and corresponding static pressure (right) distribution at diffuser inlet B)Total pressure (left) and corresponding static pressure (right) distribution at diffuser inlet (II iteration).

flow calculations in these two areas, (coupling methods). Formal rules of the calculations performed in the turbine and exhaust hood is executed in an external iteration process, which is shown schematically in Fig. 9., following the principles worked out in R&D ALSTOM [13]. Such an approach significantly reduces mesh parameters and the resulting computing time. Stage calculations are only performed, independently of the exhaust hood, for a number of variants of circumferentially symmetrical exit distributions of the static pressure, corresponding to total pressure at selected points along the circumference of the exhaust hood inlet. The results of the stage calculations make the data base for correcting circumferentially unsymmetrical conditions at the exhaust hood inlet. Radial and circumferential distributions of static and total pressure changes is schematically shown in Fig. 10. The turbine stages and exhaust hood were calculated on the base of these parameters. The methodology has been checked in this study on the design outlet of a 200 MW turbine set described in [13]. In this case the calculations were performed using two codes, the characteristics of which have collected in the Table 1 below [14]. The comparison of pressure

Table 1. Characteristics of Flower and Fluent calculations.

	Turbine stages		Exhaust hood	
Code	Flower		Fluent 6.0.12	
Grid	Structural		Hybrid	
Turbulence model	Baldwin-Lomax		RNG $k-\varepsilon$	
Gas properties	Changing κ, R, c_p, c_v		Changing κ, R, c_p, c_v	
Flow	Steady (mixing plane)		Steady	
Geometrical data	AutoCad, Catia		Catia, GAMBIT	
Parameters of:	Assumed:	Obtained:	Assumed:	Obtained:
Inlet :	p_T, t_T, α, γ	$\dot{m}$	p_T, t_T, α, γ	k, ΔH
Exit:	p_s	p_T, t_T, α, γ	p_s	$\dot{m}$
Additional numerical data	4-stage 3D calculations, circumf. symmetry, 1-2 million finite vol. 2000-6000 iterations Dual Pent. IV, 1 Gb RAM		3D unsymmetrical 1-2 million finite vol. 3000-8000 iterations Dual Pentium IV 3Gb RAM	

distributions in the coupling plane, obtained in two consecutive iterations, is presented in Fig. 11. The first iteration of the exhaust hood calculation is executed for constant pressure and temperature distribution along the exhaust hood inlet circumference. The convergence between turbine exit and exhaust hood inlet parameters is reached, in practice, after III iterations, what is shown in Fig. 12, presenting distributions of parameters averaged in radial direction.

Total pressure distributions in the last stage and inside the exhaust hood are shown in Fig. 13. The diagram reveals the last stage separation zone, which has slightly different form than in the stage calculations. Velocity vectors in the separation region located at the upper part of the diffuser are shown in Fig. 14. Work is in progress to find an optimum construction of the diffuser which would eliminate the separation shown in Fig. 14. One of examined directions concerns the effect of a kink angle, resulting from previous experience of ALSTOM in this area [15].

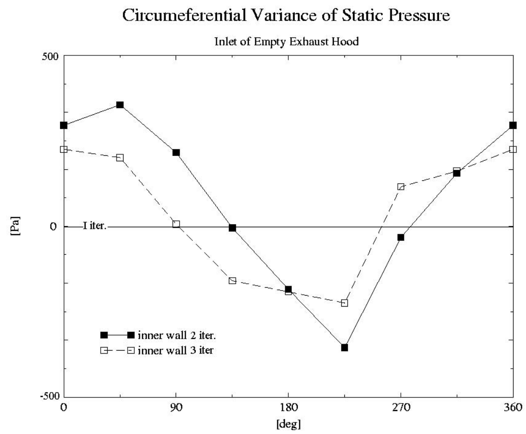

Figure 12. Comparison of circumferential static pressure distributions in iteration I, II and III (mid-span section).

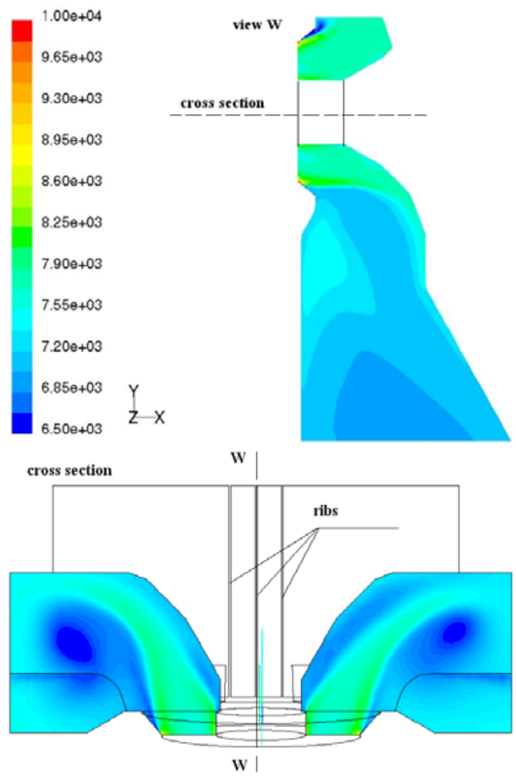

Figure 13. Velocity fields of the flow inside the 200 MW turbine exhaust hood.

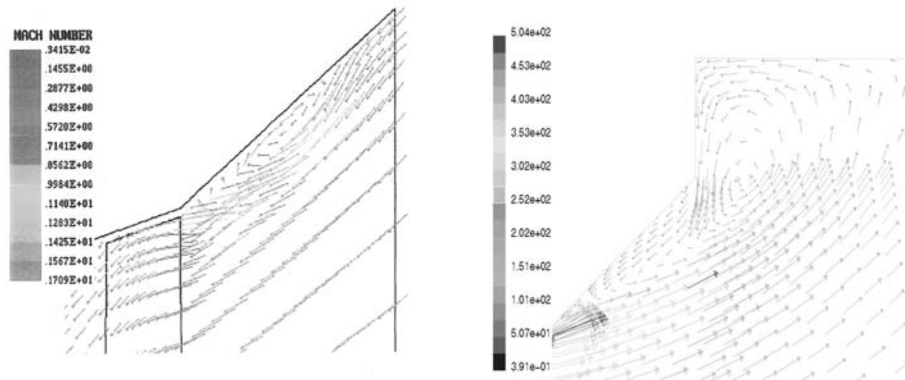

Figure 14. Velocity vectors at the 200 MW turbine behind the last stage for: a) turbine calculation, b) exhaust hood calculation.

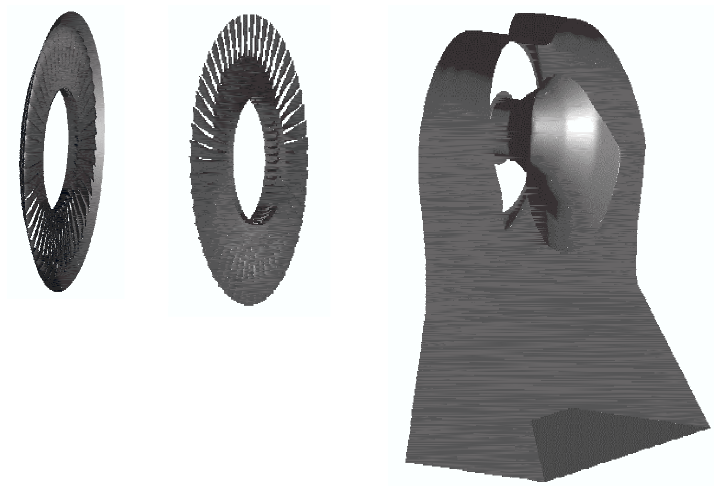

Figure 15. Modules of geometry of the last stage and exhaust hood [11].

2.3 Direct calculations of the flow through turbine and exhaust hood

Problems with preparing compatible boundary conditions at the coupling plane between the lasts stage exit and the exhaust hood diffuser inlet make the process of coupling calculations very difficult. The scale of difficulties is extended by other effects, like shock waves, condensation, and flow unsteadiness, with possible separation, recorded in the area of possible location of the coupling plane. That was why an attempt was made to perform direct calculations in the area covering both the low pressure turbine and the exhaust hood. Taking into account, however, that a standard LP turbine comprises of 8 to 10 rows, each consisting of several dozens of stator and rotor blades, and, at the same time, its exhaust hood has a set of reinforcing ribs and expansion pipes, preparing a mesh which would follow the geometry of such a complicated system with a satisfactory accuracy would require a number of millions of cells. Even for modern multi-processor computers such a task would be a serious challenge.

The first example of the computational geometry is presented below. The multi-block unstructured meshes were prepared by means of the Gambit grid generator for further flow calculation in the code Fluent. The total number of finite volumes exceeded 3 million cells i.e. in the stator vane region over 1.5 million, the rotor blade region over one million and in the exhaust hood nearly 500 thousands of computational cells. Modules of geometry of the last stage and exhaust hood are presented in Fig. 15. Flow calculation of the full geometry is in progress.

Acknowledgement The authors would like to express their gratitude to Alstom Power Ltd., Elbląg, Poland for agreement to publish the presented results of investigations.

Received 10 June 2003

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