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NUMERICAL SIMULATION OF 3D FLOW THROUGH A CONTROL VALVE

The paper deals with numerical calculations of 3D flow through a control valve. The presented calculations were performed using commercial code FLUENT/UNS. The results of numerical simulations were compared with experimental data.

1. INTRODUCTION

In the design practice as well as in modernisation of steam turbines, CFD discovers a large potential of efficiency gains. In some cases, CFD may already replace an expensive procedure of experiments; in some others, physical phenomena associated with the flow are not sufficiently understood yet and CFD may contribute to their better understanding and increase the calculations reliability. In this paper, the calculation of flow within a control valve represents the first category of investigated problems.

Recent development of CFD is giving strong impulses and new approach to many tasks of engineering practice. It becomes now possible to solve problems which could not be solved even in the not very distant past.

Improvements in the shape of control valves offer a large potential of efficiency gains and flow stability. Interests shown by other authors (M. Stastny et al., 1997) confirm these expectations. In the paper, the results of CFD calculations of air and steam flow through a control valve based on the concept of Zariankin and Simonov (1994) are described and analyzed. This unbalanced valve of nominal diameter D_n = 106 mm was developed by ABB Zamech for modernisation purposes in one large power 200MW steam turbine. The aim of the calculations is to elaborate flow characteristics (mass flow rate vs. pressure drop in the valve) with their validation on MPI (Moscov Power Institute) experimental data.

In the paper, the authors present some of their experience on CFD application in calculations of control valves for steam turbines.

2. CALCULATION PROCEDURE

3D calculations of flow through the control valve are carried out with the aid of the commercial software package FLUENT/UNS (1997). 3D flow is modelled by Navier-Stokes equations for viscous fluid. The two-equation turbulence model k-ε with standard wall functions and the heat transfer model accounting for the effect of viscosity are assumed. The flowing gas is treated as a compressible medium and its thermodynamic properties are calculated from the thermal and caloric equation for perfect gas. The calculations draw on unstructured grids with tetrahedral finite volumes and a second-order discretisation scheme.

The assumed type of boundary conditions follows from the character of the solved problem. It is a typical problem where inlet and exit parameters are known and the mass flow rate is resultant. At the inlet, we impose the total pressure, total temperature and k-ε turbulence parameters, at the exit - static pressure is imposed. During the calculations the imposed boundary conditions are kept unchanged, and the solver yields e.g. fields of the velocity and static pressure, mass flux, and mass-averaged values of parameters in control sections of the valve.

3. RESULTS OF NUMERICAL CALCULATIONS

The calculations of flow through the control valve were carried out for relative openings equal to h_{rel} = 0.05 and 0.3 for air and h_{rel} = 0.3 for steam (Badur and Banaszkiewicz, 1998). In both cases the calculations were performed in a wide range of pressure ratio p_2/p_1. Based on geometry of the flow domain, an unstructured grid of 140 000 cells refined between the valve head and the inlet to the diffuser was assumed. A general overview of the mesh surface is presented in Fig. 1. Exemplary distributions of the static pressure and Mach number in the symmetry plane of the valve are presented in Figs. 2 and 3. Both these figures illustrate the supersonic flow of air with a shock wave that occurs in the diverging nozzle. The distribution of the velocity magnitude in the plane perpendicular to the symmetry plane and placed close to the throat is shown in Fig. 4. In this figure the outer circle represents the wall of the entrance to the diffuser, whereas the inner one is the wall of the valve head. It is worth noting that in spite of the fact that the gas is supplied to the valve chamber through a one-sided pipline, the velocity field in the vicinity of the throat is almost axisymmetric. Such a behaviour of the flow can be explained by equalizing action of the valve chamber.

The observed axisymmetric character of the flow is also confirmed by the distribution of the velocity vectors in the symmetry plane shown in Fig. 5. It is seen that the magnitude and direction of the velocity on both sides of the symmetry axis is approximately the same and the flow can be treated as axisymmetric. The velocity magnitude is largest in the central part of the diffuser, where the intensity of shock wave is highest.

The comparison of computational and experimental results is given in Fig. 6 where measured values are indicated as (■,●) and numerical points as (□,○). The experimental data are taken from Zariankin and Gardzilewicz (1994). This figure shows both qualitative and quantitative agreement of numerical calculations and experimental data. More details on these calculations can be found in Krzyżanowski et al. (1999).

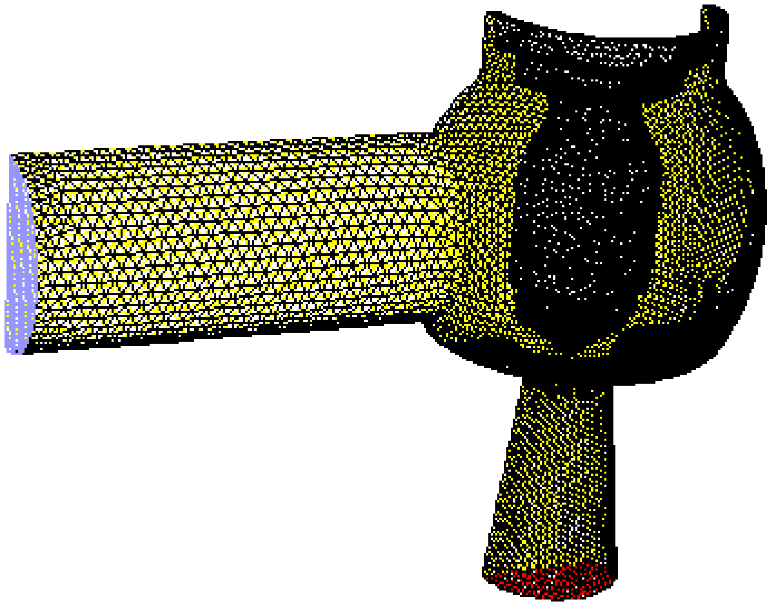

Fig. 1. Overview of the calculation grid on the valve surface.

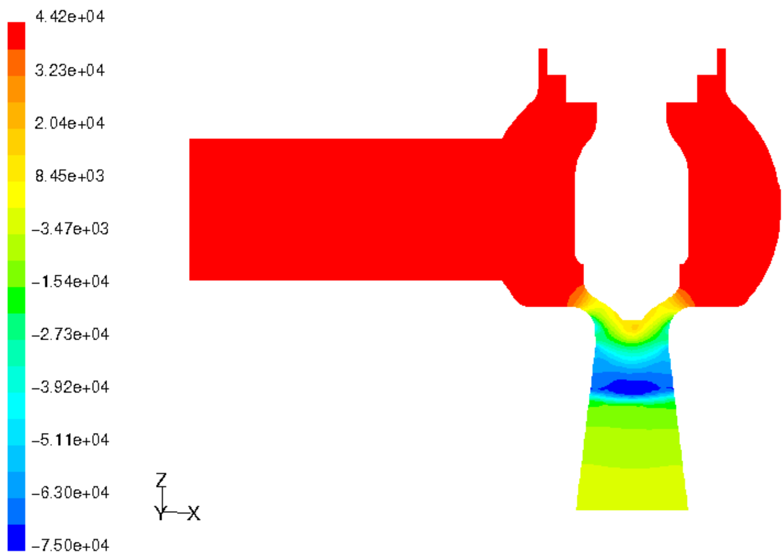

Fig. 2. The distribution of static pressure (in Pa relative to the atmospheric pressure) in the symmetry plane of the valve, $h_{rel} = 0.3$, $p_2/p_1 = 0.705$.

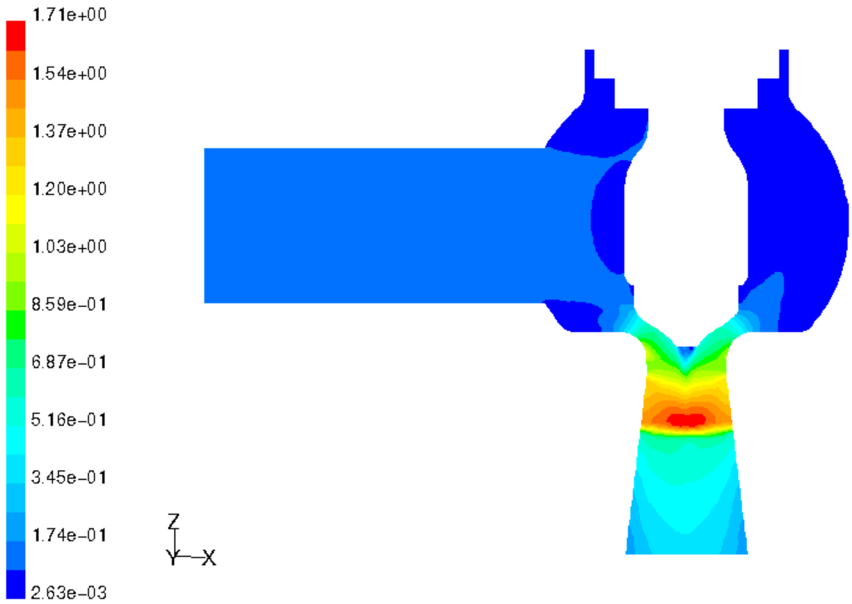

Fig. 3. The distribution of Mach number in the symmetry plane of the valve, $h_{rel} = 0.3$, $p_2/p_1 = 0.705$.

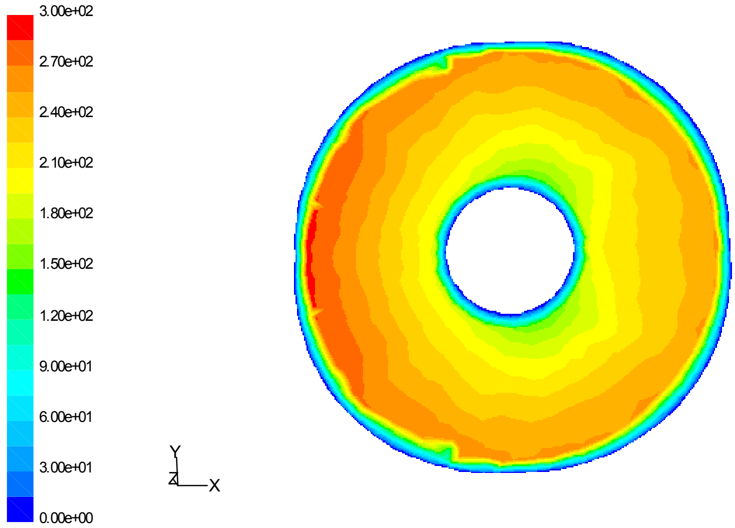

Fig. 4. The distribution of velocity magnitude in the plane perpendicular to the symmetry plane of the valve, $h_{rel} = 0.3$, $p_2/p_1 = 0.705$.

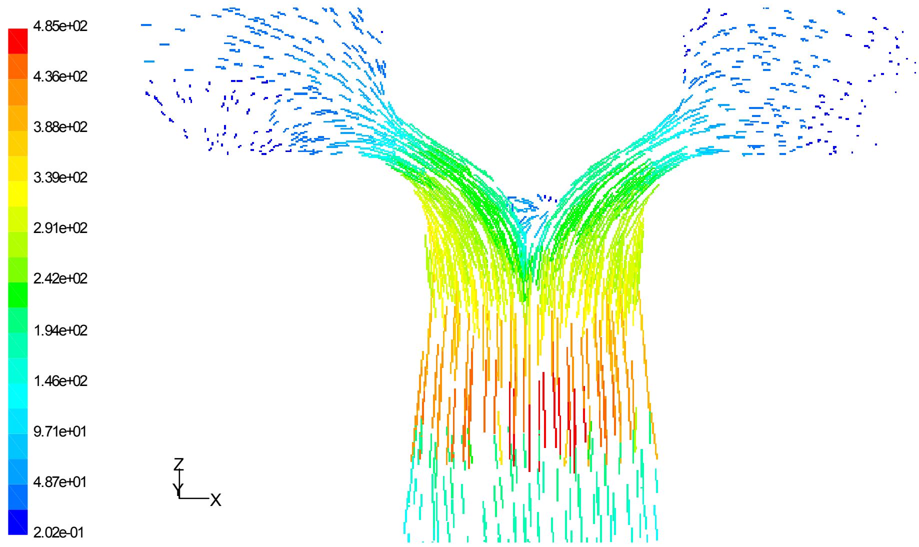

Fig. 5. The distribution of velocity vectors in the symmetry plane of the valve, $h_{rel} = 0.3$, $p_2/p_1 = 0.705$.

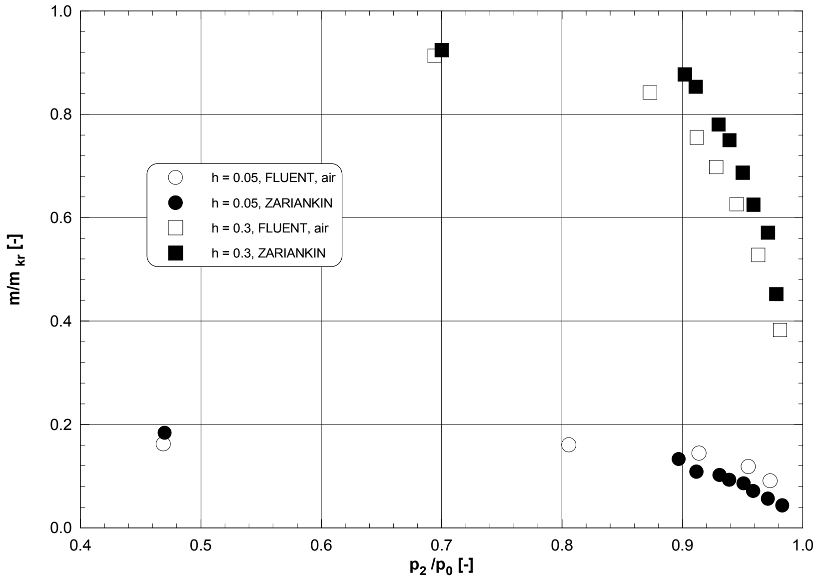

Fig. 6. The comparison of flow characteristics of the valve calculated from FLUENT/UNS and measured at MPI.

4. CONCLUSIONS

a) The code FLUENT offers large possibilities of 3D modelling of compressible viscous flows through valve channels of complex geometry.

b) The flow in the delivery pipe and in the valve chamber of Zariankin's valve is uniform, which can be seen from the distribution of fundamental flow parameters. The valve chamber assures the symmetrical flow of the medium into the throttling channel between the valve head and the inlet to the diffuser.

c) In order to correctly evaluate flow characteristics of the valve it is essential that the boundary layer flow is appropriately modelled. It is particularly important for small valve openings where the characteristic dimensions of cross-stream sections are of the order from a few to a dozen millimetres and the big share of flow takes place in the boundary layers.

d) The numerical calculations of flow of air and steam through the control valve investigated by Zariankin and Simonov (1994) give results that agree well with the measurements, which implies that the computations can predict well flow characteristics of other types of valves with different geometries, also operating on steam.

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