Pressure losses reduction in a steam turbine compact valve

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Abstract. Valves are integral parts of modern steam turbines. They provide flexible operations and fast load changes which have become more often due to the increasing share of renewable energy. Along with this, the low pressure loss is required for guaranteed operation conditions. This paper is concerned with investigation of pressure losses in the compact valve, which is used as a valve for the intermediate-pressure turbine part, and its geometry modification to lower overall pressure losses. The investigation is based on results of numerical simulations which were carried out in the Doosan Skoda Power Company using a package of ANSYS software tools. Source of increased pressure losses in the compact valve is identified and a way of its reduction is proposed based on the comparison of the current results with data from a typical control valve model. Data analysis is provided in the paper.

1 Introduction

The energy industry cannot reasonably survive without modern steam turbines with high flexibility and efficiency [1]. Therefore, steam turbines have to be enhanced in all their parts including valves. As can be found in different sources [2-6], valves for steam turbines have become objects for a wide research and development. Doosan Skoda Power along with other external cooperative organizations, in this case with the Institute of Thermomechanics of the Czech Academy of Sciences, has also a strong tradition of valves research [7-10].

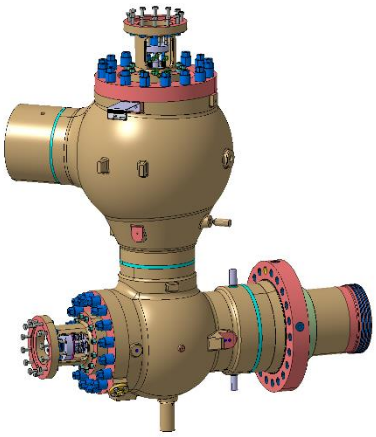

Fig. 1. Compact valve assembly [11].

The current research activities include namely the investigation of flow field in complex modern valve assemblies with focus on pressure losses as well as pressure fluctuations. Once the performance of an existing valve assembly is assessed, the attempt to reduce the pressure loss can be done.

Wide range of measurements on the current valve assembly with the compact control valve (Fig. 1) has been already carried out and published in [11, 12]. In these publications, details of comparisons between numerical simulations and experimental data have been discussed as well. It was concluded that the differences are reasonable and numerical simulations are suitable for further studies. As a consequence, the attempt to change the valve geometry to reduce pressure loss was done and it is presented in this paper.

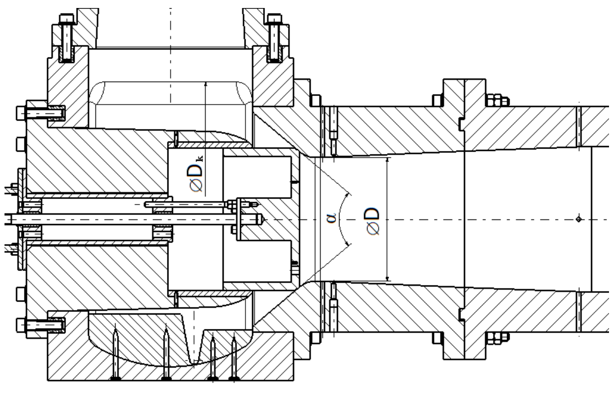

Fig. 2. Cross-section through the compact valve [12].

Since the volumetric flow rate of steam is significantly greater in the intermediate-pressure turbine part in compare with the high-pressure turbine part, the valves have to be also larger. Due to this, the valves are more expensive. In order to keep production costs low, the compact valve assemblies have been designed. The compact means that the ratio between D_k/D, see Fig. 2, is smaller than in typical control valves. For the same

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diameter D, it is shown in Fig. 3. Since D_k is smaller, a free space for steam in the control valve chamber is also smaller. It was identified as a possible reason why pressure losses are greater than in typical control valves [12].

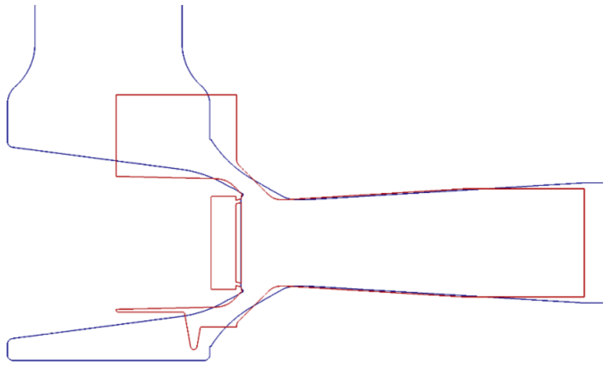

Fig. 3. Relative comparison of cross-section through the valve chamber, a typical control valve (blue) and a compact control valve (red) [12].

Dimensions D_k, α and D (see Fig. 2) cannot be enlarged if the valve has to be compact. However, the valve cone suspension can be changed, thus the space in the valve chamber can be enlarged. It is shown in numerical models (Figs. 5 and 6) and results with pressure flow fields (Figs. 8 and 9) where the space for the flow field is greater in the new chamber. There is assumption that this may reduce pressure losses. Thanks to the numerical simulations, it can be validated.

2 Numerical model

The numerical models were created according to the experimental one. The original compact valve is shown in Fig. 4. It consists of inlet and outlet pipelines which are shown in the blue colour, one stop valve which is shown in the red colour and one control valve which is shown in the green colour. The model with the changed control valve is shown in Fig. 5. It can be seen that the valve cone suspension is smaller therefore the free space in the valve chamber is greater.

A hexahedral as well as tetrahedral meshes, see Fig. 6, were used to create the numerical model. The typical mesh quality criteria and also the recommendation of the turbulence model to keep y+<5 was satisfied [12].

The flowing medium was defined as dry air with thermodynamic parameters according to the experiment. A high resolution scheme was used to compute the steady state RANS solution with a compressible turbulent model k-ω SST. Inlet and outlet boundary conditions were specified according to measured data [11, 12]. For this study, ten different boundary conditions for two different control valve models were calculated. In all cases, the control valve is fully open.

Simulation convergence criteria were quantified by 10^{-4} residual target value. Furthermore, the global mass flow rate imbalances and imbalances of required pressure losses were also monitored to be less than 0.1%.

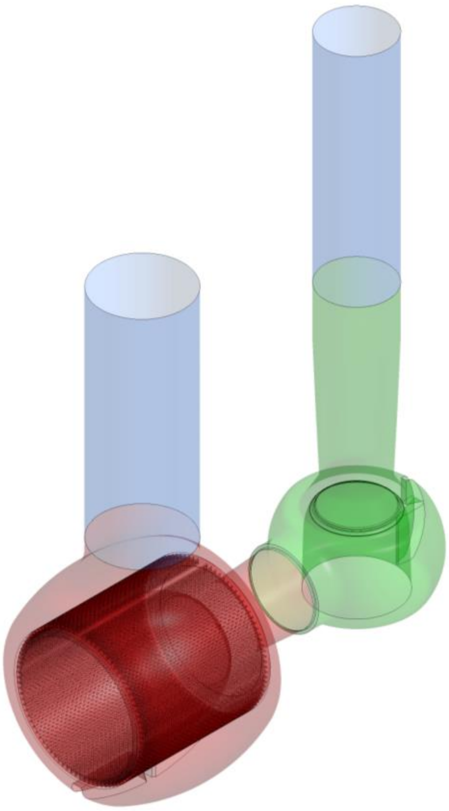

Fig. 4. Compact valve model assembly with the original control valve chamber.

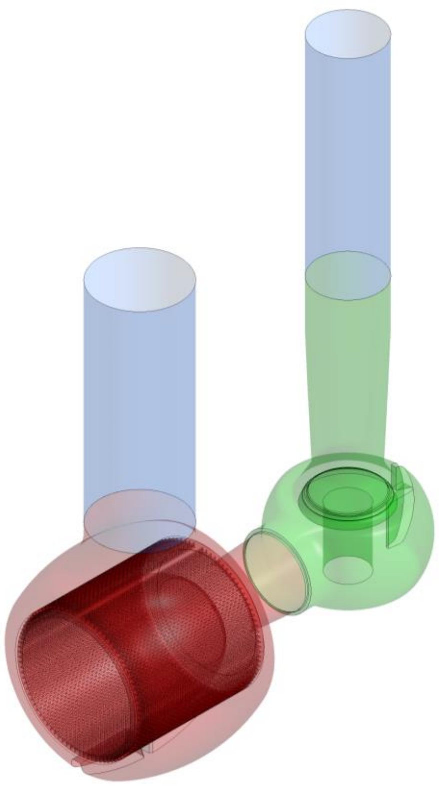

Fig. 5. Compact valve model assembly with the control valve chamber with greater space.

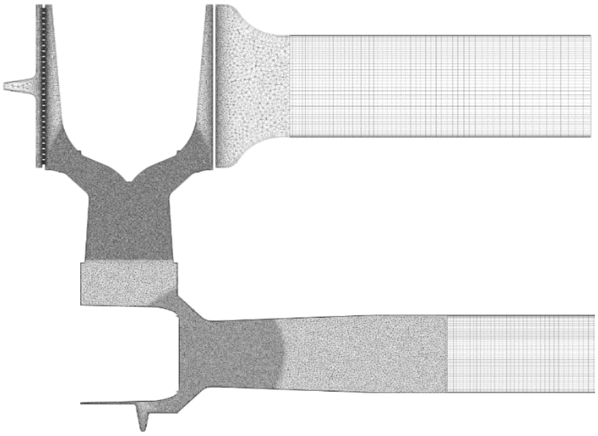

Fig. 6. Mesh in the cross-section through the model [12].

3 Results and discussion

The evaluation of the calculated results can be depicted in the form of valve characteristics. It is widely used to generalize results for pressure loss models for control valves. A valve characteristic is a graph of the dependency between pressure ratio $\varepsilon = p_2/p_1$ and mass flow ratio $q = Q/Q_{cr}$ for different valve cone lifts. In this study, only the case with maximal valve cone lift is presented. More valve cone lifts are presented in [12].

p_2 is the pressure downstream of the control valve (at the interface between the control valve domain outlet and the outlet pipeline inlet, see Fig. 4), p_1 is the pressure upstream of the control valve (at the interface between the stop valve domain outlet and the control valve domain inlet, see Fig. 4), Q is the mass flow rate through the valve and Q_{cr} is the critical mass flow rate which is defined as:

$$Q_{cr} = A_{dif} \cdot \sqrt{\frac{p_{1t}}{v_{1t}}} \cdot \sqrt{\gamma \cdot \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}} \tag{1}$$

A_{dif} is the cross-sectional area of the control valve diffuser throat with diameter D (see Fig. 2), p_{1t} is the inlet total pressure, v_{1t} is the inlet total specific volume and γ is the heat capacity ratio.

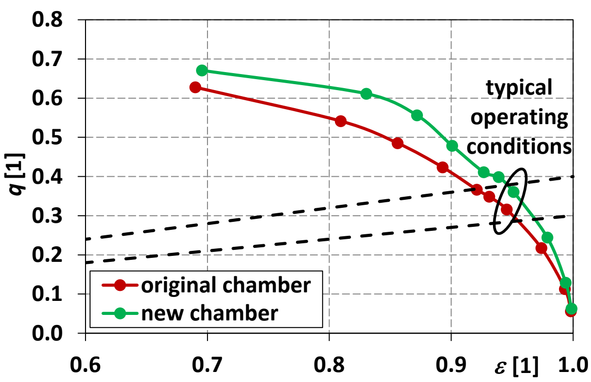

Fig. 7. Comparison of valve characteristics for fully open valve.

The comparison of calculated valve characteristics is shown in Fig. 7. It can be seen that for the same pressure ratio, the mass flow ratio is greater in the valve with the new chamber. It means that the pressure loss is smaller. In practice, for the required mass flow rate, the pressure ratio is greater which presents a lower pressure loss.

For the typical operating conditions (see Fig. 7), the pressure flow field in the cross-section of the original valve chamber and the new chamber is shown in Fig. 8 and Fig. 9, respectively. It can be seen that there is greater asymmetry and significant vortex under the cone in the valve with the original chamber (see Fig. 8). On the contrary, the flow field is more symmetric and without significant vortex in the chamber with the greater space. Due to the greater space, the flow can be more stabilized and equalized before going under the cone to the diffuser. As a result, the pressure losses are lower. It was detected in all cases with different mass flow ratios (see Fig. 7).

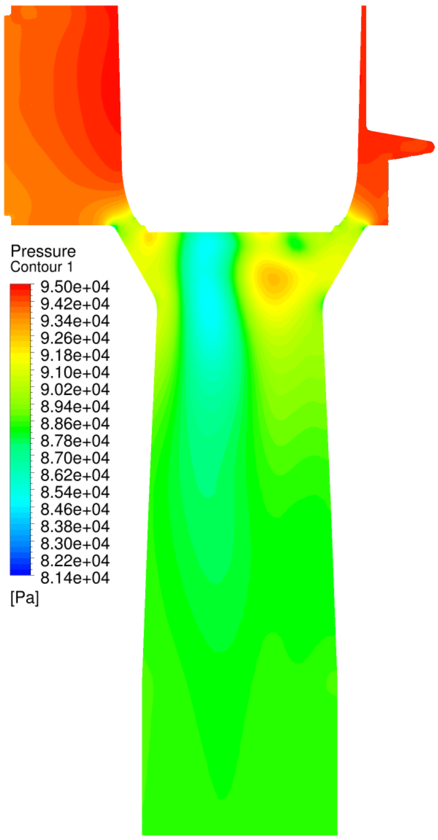

Fig. 8. Pressure flow field in the compact valve with the original chamber.

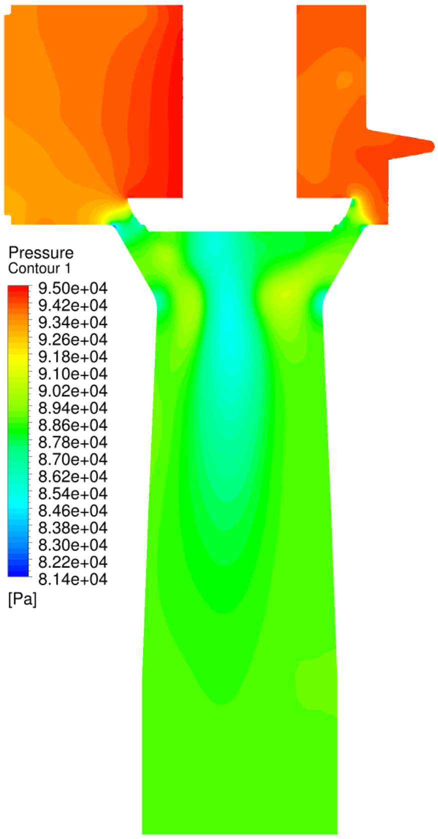

Fig. 9. Pressure flow field in the compact valve with the new chamber.

4 Conclusions

There is a potential in reducing of pressure losses in the modern compact valve. Thanks to the numerical simulations it was found out that the pressure loss is reduced when the space around the valve cone in the valve chamber is enlarged. It can be achieved by only changing the valve suspension, therefore keeping the valve to be compact.

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