23rd International Conference
ENGINEERING MECHANICS 2017
Svratka, Czech Republic, 15 – 18 May 2017

POSSIBILITY OF DAMPING PRESSURE PULSATIONS IN BALANCING CONTROL VALVES

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Abstract: *The cone shape alterations are given for balanced control valves of steam turbines and their influence is assessed on the flow field in the valve outlet diffuser. Suitable solutions are searched for, which will guarantee the stability of the boundary layer on the diffuser wall in all operating modes of the turbine. It is verified whether using steam flow from the bypass valve can prevent separation of the main steam flow from the diffuser wall. Various variants of the steam outlet from the valve cone are considered.*

Keywords: Steam turbine, Valve, Vibration.

1. Introduction

The maximum lifting force of an unbalanced valve is proportional to the inlet pressure and the valve seat diameter squared. If the lifting force exceeds the possibilities of the servo drive, it is necessary to use a higher number of unbalanced valves or to regulate the turbine using balanced valves. With a more complicated construction of balanced valves their operating reliability is lower than that of traditional control valves. Here a part of the spindle is formed by a bypass valve, from which the big cone is suspended. It is lifted from the seat after the initial balancing caused by the steam flow through the bypass valve. In balanced valves it is necessary to guarantee positive snub force on the freely suspended cone for all turbine modes with a sufficient margin for abrupt step increase of pressure under the cone. The valves work in a wide range of lift and pressure ratios. A complex flow field occurs under the valve cone. A flow vortex or possible separation from the diffuser wall or cone wall appears. Pressure vibrations are generated in a broad range of frequencies. Vibration of the natural frequencies of the valve part or the pipe system with the corresponding spectrum frequency can cause mechanical damage. Especially in valves with higher flow area problems with high frequency pulsations and corresponding vibrations fully appeared. The aim of the paper is to show the character of flow field under the cone for selected operating modes and the connection between the shape of the cone and the diffuser and the steam flow from the bypass valve. Ways of damping or limiting fluctuational components causes by pressure pulsations are searched for.

2. Summary of findings of the balanced valve variants

In many cases attempts appear to use a shaped valve cone. It is supposed that in specific operating modes of the turbine and a fully open valve fewer pressure losses occur than in the valve with a perforated cone. For partial opening of the valve Laval's nozzle occurs between the cone profile and the seat and diffuser wall. A step pressure change in the shock wave occurs for higher value Mach number than for the flat bottom cone.

In Fig. 1 a computational study is presented for the flow in the valve with the shaped cone. Mach number is up to 2.46. The rotationally symmetrical computation variant is used (Matas, 2001). 3D calculation confirms the existence of unordered velocity field with unbalanced pressure distribution on the cone

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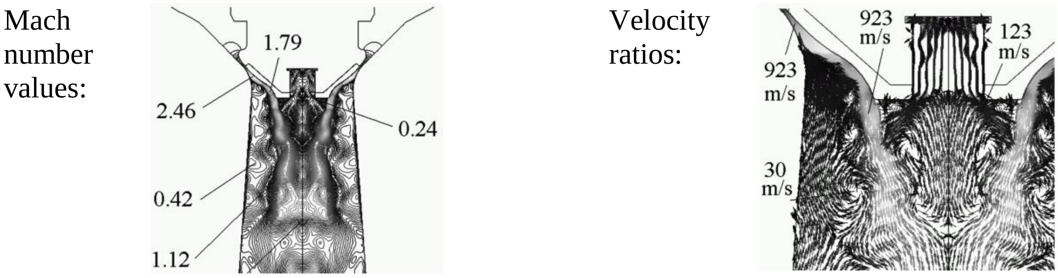

Fig. 1: Mach numbers and velocities distribution in the valve diffuser with a shaped cone.

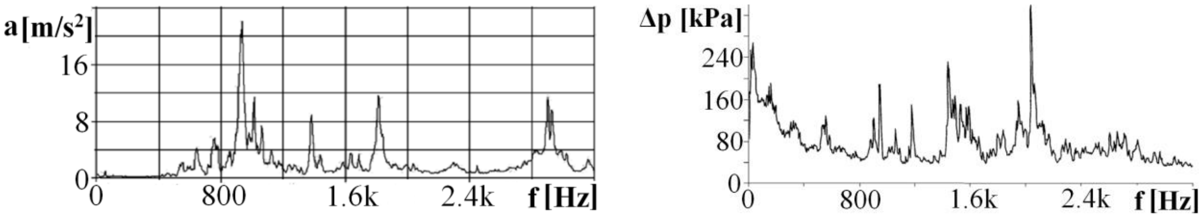

Fig. 2: Spindle acceleration and pressure pulsations behind the shaped cone in dependence on frequency.

surface. Pressure pulsations occur on the cone and a spectrum of pulsations of different frequencies appear in the flow. In Fig. 2 an example is given of acceleration in the valve spindle and the course of pressure pulsations on the diffuser outlet. Frequency spectra are similar, but not identical. Pressure pulsations reach up to 8 % of the inlet pressure value. The cause of low frequency vibrations is related with flow separation and vortex structures occurrence. High frequency vibrations appear for small lift of the valve cone and large pressure drops. Provided there are in the piping system supersonic speeds with excess kinetic energy, it results in its obstruction in the system of shock waves. Interaction of various waves with vortex areas in the diffuser is related with the so-called trans-sonic unsteadiness, which is the source of high frequency pressure pulsations of steam.

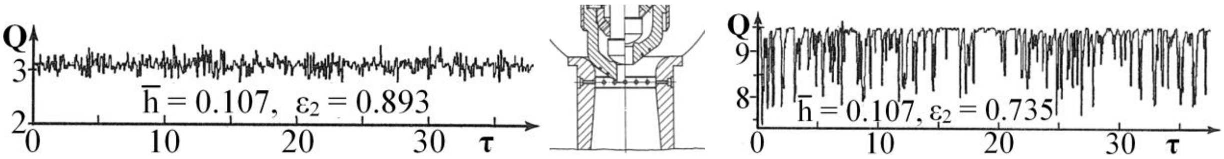

Fig. 3: Oscillograms of forces operating on the spindle with a shaped cone and a central opening.

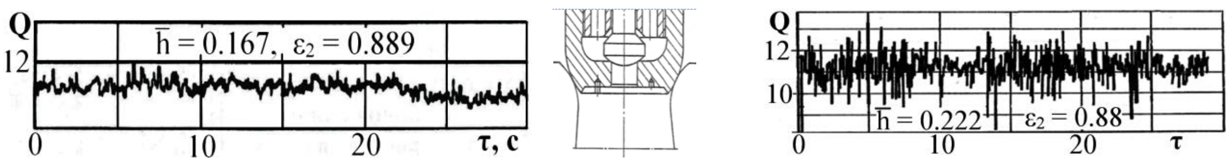

Fig. 4: Oscillogram of forces operating on the valve spindle with the flat bottom transition cone.

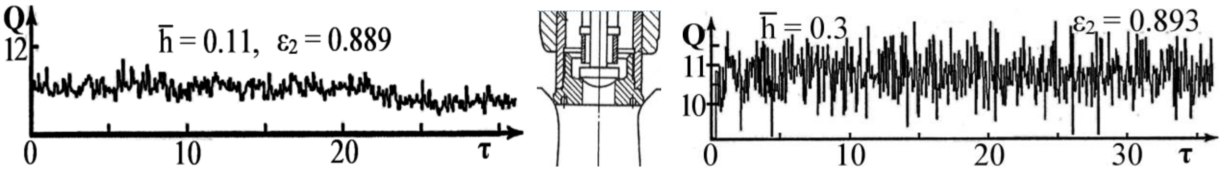

Fig. 5: Oscillograms of forces operating on the flat bottom cone and a central opening.

The influence of pressure pulsation on the cone can be mapped using time records of force operating on the valve spindle. It shows that the load force can vary in the range up to 10 ÷ 15 % of mean force on the cone. From the records of load force on the spindle given in Figs. 3, 4 and 5 it is evident that force fluctuations are not directly related to the cone shape. For the shaped cone, the cone with a flat bottom transition and for the flat bottom cone similar amplitudes of load force are calculated. Pressure pulsations are related with vortex and possible flow separation from the diffuser wall. The central inlet opening can contribute to the diffuser wall separation.

3. Possibilities of damping pressure pulsations

Damping pressure pulsations and thus vibrations of the balanced valve is enabled by using a muffler (damper) installed in the valve. Its placement and characteristic flow is evident from Fig. 6. Experimentally lowering pressure pulses and vibrations on the valve was confirmed (Šťastný at all, 2003). Using the damper velocity ratios under the cone changed. In the original valve – see Fig. 1, flow separation from the diffuser wall under the cone occurred. After damper installation stream flow separation from the diffuser wall does not occur. It is confirmed by distribution of Mach numbers in the diffuser neck.

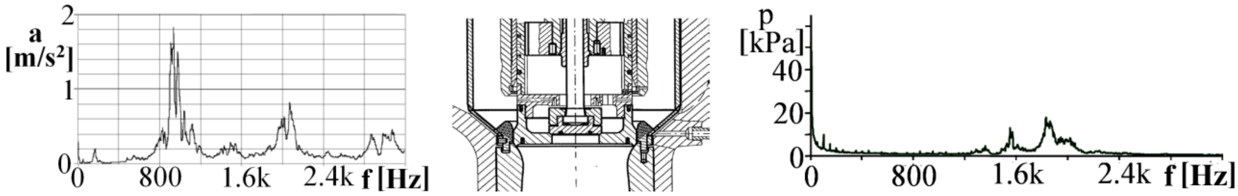

Fig. 6: Vibrations on the spindle and pressure pulsation under the cone with damper.

Stream flow separation from the diffuser wall can considerably contribute to the existence of intensive pressure pulsations. When the flow follows a curved surface effects known as Coanda effect are applied. Flow separation occurs at a certain pressure and curve of the wall ratio. The Coanda pressure ratio is shown in Fig. 7. Here also the valve construction is given with corresponding pressure and wall curves.

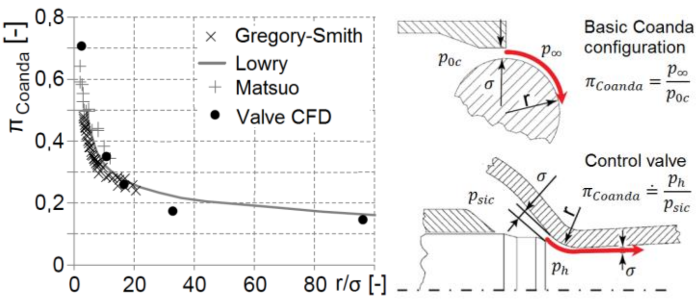

Fig. 7: Coanda pressure ratio.

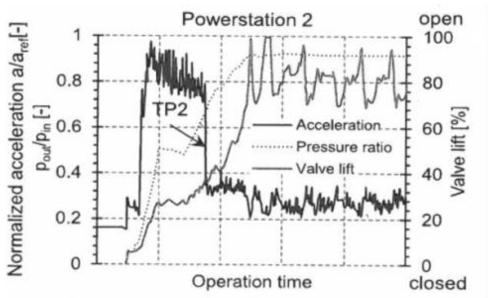

Fig. 8: Acceleration on the valve under Coanda effect.

Corresponding pressure ratio is given by the operating parameters of the turbine. To the pressure ratio a corresponding mass steam flow is assigned and thus the lift of the cone. The only parameter that can influence the separation and non-separation states is the radius of curved surface *r*. It is desirable to be as large as possible, but it is impossible to increase it limitlessly. The fact that in flow separation pressure pulsations and also vibrations increase is confirmed by experiment carried out by the Siemens company (Domicich at all, 2015). In Fig. 8 cone lifts are recorded as well as pressure ratios and acceleration on the valve during the start of turbine operation. The step change in acceleration for certain lift of the cone and pressure ratio is evident.

Widening the diffuser can influence the pressure loss and the location of possible flow separation. Experiments on valves with the diffuser opening angle of 7° and 10° confirmed lower intensity of vibrations for valves with smaller widening. For seven-stage diffuser also the value of pressure loss is more favourable. The main reason for valve construction with a seven-stage diffuser is operating reliability and vibration and noise damping. However, it cannot fully prevent the flow separation from the diffuser wall.

It is possible to test whether, for balanced valves, the steam from the bypass valve can be used to stabilize the flow field in the diffuser. Instead of central opening, a perforated bottom could be use. It is desirable to limit the vortex influence under the cone and guarantee flow in the positive direction in the whole cross section of the diffuser throat. From the flow computational study it is evident that this requirement is not met. In the valve flow separation from the diffuser wall appears and backward flow occurs. Another adjustment can be done by directing the steam flow from the bypass valve to the diffuser wall using holes drilled sidelong in the cone bottom. In the 2D model of the cone several operating modes were tested. In the variant with balancing, attaching the flow to the diffuser wall was confirmed. Positive results are also achieved for the valve with a shaped cone and steam outlet from the bypass valve directed to the diffuser wall. Its flow and the resulting load force for two lifts of the cone are shown in Fig. 9. In the experiment for the steady lift of the load force pressure ratio on the valve was gradually decreasing. The step change in the load force occurs during transition to the transonic flow. The fluctuational component of tensile force did not increase significantly. There is a strong vibration damping compared to valves with central outlet opening (Fig. 3).

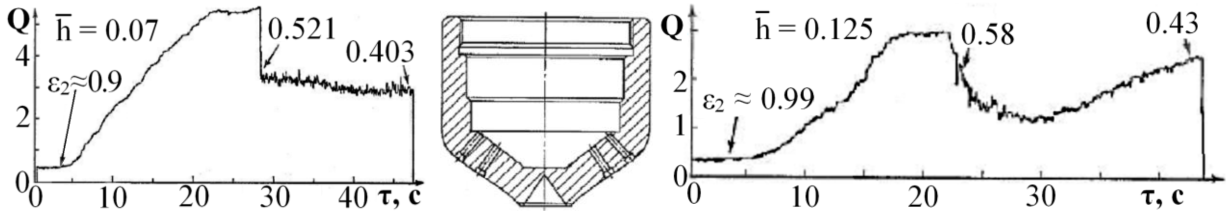

Fig. 9: Oscillogram of shaped cone vibrations with wall perforation for variable pressure ratio ε_2.

Also the flow calculations in valves with a flat bottom cone and with slots for steam from the bypass valve show lower sensibility to flow separation from the diffuser wall. The version with two rows of slots is given in Fig. 10. Calculations for the one-row slot version are found in Fig. 11. It is evident that location of outlet openings, direction of steam flow, mass flow and steam dynamics from the bypass valve are vital. It is related with pressure distribution inside the valve and thus with the resulting force necessary for separating the big cone from the seat. Besides the flow in the diffuser it is necessary to consider the steam flow through the inner parts of the valve.

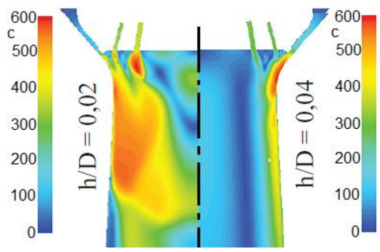

Fig. 10:Velocity distribution in the diffuser, two rows of slots.

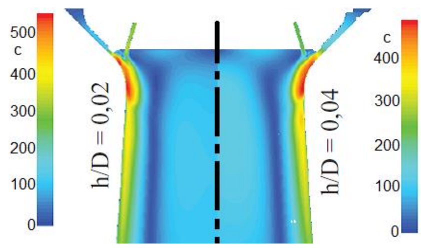

Fig. 11:Velocity distribution in the diffuser, one row of slots.

4. Conclusions

As a result of the vortex under the cone, turbulent and unsteady velocity field occurs in the valves. Pressure pulsations appear in the broad range of frequencies. ● The central outlet opening in balanced valves contributes to the existence of flow separation from the diffuser wall as well as to the increase of fluctuational force operating on the valve spindle. ● Flow separation from the diffuser wall is also a result of Coanda effect for a specific pressure ratio on the valve. ● Pressure pulsations can be damped using special dampers or by using steam flow from the bypass valve. It is also necessary to consider pressure ratios in the inner parts of the valve. ● A positive influence of steam from the bypass valve is demonstrated in valves with a shaped cone as well as in valves with flat–bottom cones.

Acknowledgement

This work has been supported by the project SGS-2016-045 (Increasing the efficiency, reliability and service life of power system machines and devices 4).

References

Matas, R. (2001) Numerical Solution of Axisymmetric Models of the Steam Turbine Control Valves at off Design Conditions. Proceedings of the Colloquium Fluid Dynamic 2001, pp. 51-54, Prague.

Šťastný, M., Bednář, L., Tajč, L., Kolář, P., Martinů, P. and Matas, R. (2003) Pulsating Flows in the Inlet of a Nuclear Steam Turbine, 5th European Conference on Turbomachinery, Prague.

Domicich, C.B., Bendra F., Brillert D., Dahmen, H.J. and Musch, C. (2015) Improving the Design of Steam Turbine Inlet Valves by Numerical Method for Enhanced Part Load Operation, 11th European Conference on Turbomachinery.