18th International Conference
ENGINEERING MECHANICS 2012
Svratka, Czech Republic, May 14 – 17, 2012

pp. 97–101
Paper **#131**

FLOW VISUALIZATION IN CONTROL VALVE WITH PROFILING CONE

L. Bednář[*], L. Tajč[**], M. Miczan[***], L. A. Feldberg[****]

Abstract: *The results from aerodynamic research on the model control valve with profiling cone of steam turbine ĠKODA are presented. Experimental work was realized in the research laboratory CKTI Sankt Petersburg. Pressure pulsations under cone in a big range of operational parameters were measured. Measurements were realized by means of optical interferometry.*

Keywords: ***valve, profiling cone, visualization.***

1. Introduction

The result of the requirements to build turbines operated under constantly increasing admission pressures and higher unit ratings is the necessity to steer the momentary power of the turbine via control valves with relief. As of now, ŠKODA POWER a. s. does not yet offer these valve types in its product portfolio. After the rather limited success of the application of licence to a relief valve for the 1000 MW turbine, the topics of operational reliability and shape of the control valve cone have received systematic attention. Individual variants of the potential valve designs are subject to thorough testing at various laboratory stands. Among the highly useful benefit is the possibility to visualise the flow inside the valves that is realised by CKTI in St. Petersburg under the supervision of ŠKODA POWER (Feldberg 2005). Calculations of flow inside the valves are useful as well (Matas 2004).

Numerous experiments have indicated that designs using a single central relief port are not suitable. New publications (Zarjankin & Simonov 2005) recommend that the cone use a perforated wall. In the valve for the 1000 MW turbine, the perforated ring – damper assisted in the suppression of extreme pressure pulsation during startup at high pressure loss with elevated local values of Mach numbers. A disadvantage of the damper is that it is present also at rated operating conditions. This disadvantage could be removed by controlled steam discharge through the perforated wall of the cone.

The CKTI laboratory has carried out tests to verify the shaped valve cone with relief holes. The needs of the visualisation process required that a desk model of the valve cone be prepared, including the holes. Visualisations were realised using the shadowing method in a Töpler machine and using a Mach – Zehnder interferometer. Pressure pulses are evaluated according to the change in the local optical signal. The relative change of specific gravity is proportional to the relative change of light intensity:

$$\frac{\Delta\rho}{\rho} = \frac{\lambda}{\pi L K \rho} \cdot \frac{\Delta J}{J_0}, \qquad (1)$$

ΔJ, J_0 change of intensity in the interference image and its basic value,

[*] Ing. Lukáš BEDNÁŘ: ŠKODA POWER a. s., R&D/EV, Tylova 1/57; 328 00 Plzeň; CZ, e-mail: lukas.bednar@doosan.com

[**] Ing. Ladislav TAJČ, CSc.: ŠKODA POWER a. s., R&D/EVP, Tylova 1/57, 328 00 Plzeň, e-mail: ladislav.tajc@doosan.com

[***] Ing. Martin MICZÁN: ŠKODA POWER a. s., R&D/EVP, Tylova 1/57; 328 00 Plzeň; CZ, e-mail: martin.miczan@doosan.com

[****] Ing. Lev Avramovič FELDBERG, NPO CKTI; Atamanskaya str. 3/6, 191167 St. Petersburg; Russia; e-mail: l_feldberg@mail.ru

Δρ, ρ change of specific gravity and specific gravity of steam,

λ, K wavelength of light and constant $k = 22.7 \cdot 10^{-5}\ m^3/kg$,

L width of work section.

The following equation governs pressure pulsation:

$$\frac{\Delta p}{p} = \frac{T}{R} \cdot \frac{\Delta \rho}{\rho}, \qquad (2)$$

T temperature,

R gas constant.

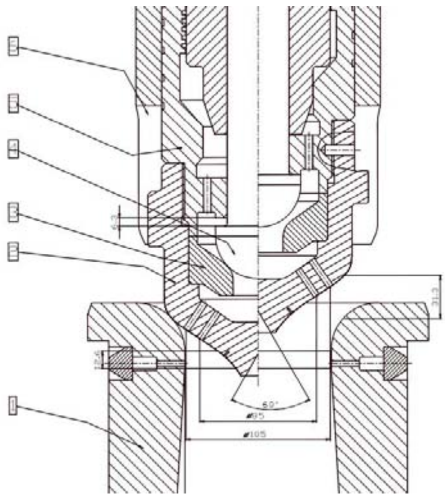


Figure 1: Actual rendering of a cone in a relief valve

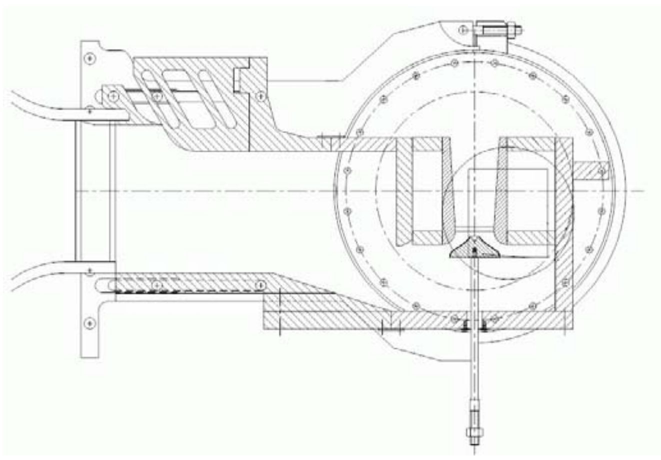


Figure 2: Model of a valve featuring a shaped cone and relief port

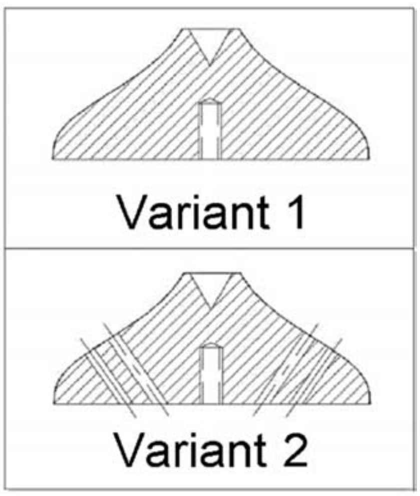


Figure 3 Tested variants of the cone

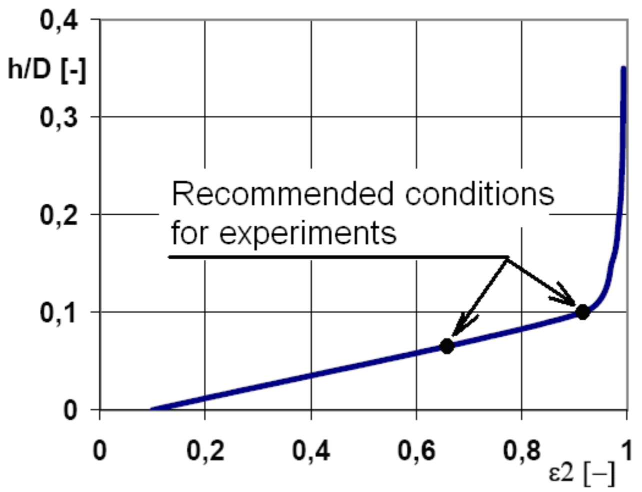


Figure 4: Operational characteristics of the valve, MEI

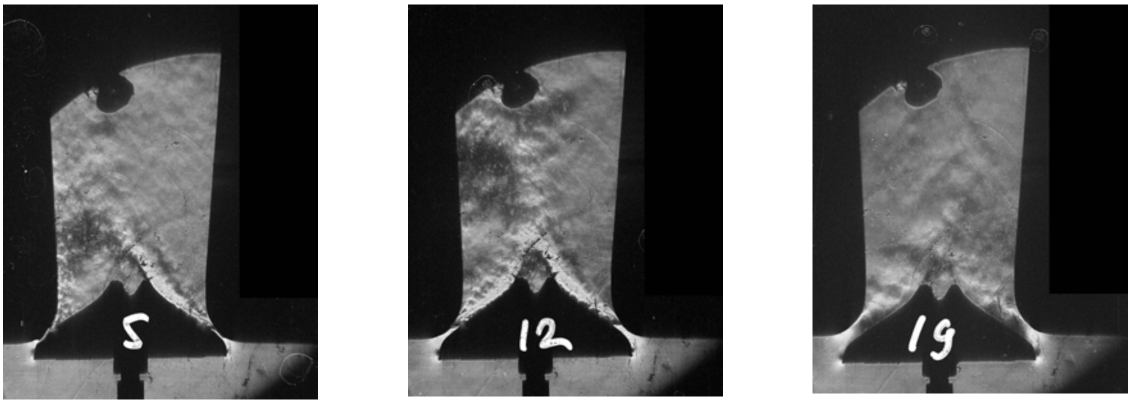
2. Design of Experiment and Valve Model

The design of the valve assumed for verification by experiment is shown in Figure 1. The cone profile has been prepared using information from the MEI (Moscow Power Engineering Institute). The model for visualisation of flow requires the transition and 3D realisation of the part of interest into a 2D system. For that reason, the number of holes in the model was reduced to preserve the proportional flow area relevant to the neck area. The model of the cone has been simplified against the original part – see Figure 2. Pressure above the cone is assumed equal to that at the valve intake port. The tested variants are shown in Figure 3. While the first variant shows the cone without perforation, the second models two rows of relief holes. The wind tunnel at CKTI allows the modelling of pressure situations in the valve ranging from $p_2/p_0 = 0.27 \div 0.97$, which corresponds to relative cone lift $h/D_0 = 0.05$ and $p_2/p_0 = 0.66$ as well as $h/D_0 = 0.1$ with $p_2/p_0 = 0.92$.

3. Flow Visualisation

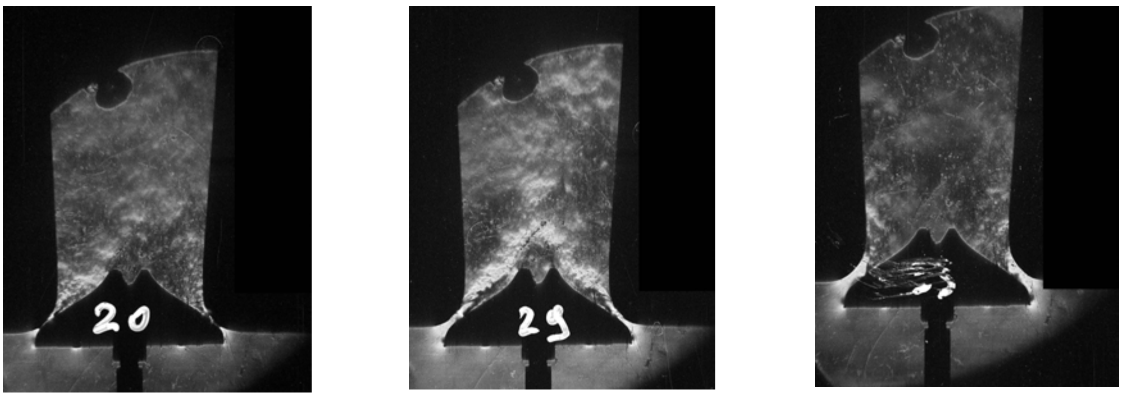
Visualisation of flow using the shadow method has been realised for a wide variety of operating modes. Figure 5 provides an overview of three pressure ratios and lift for variant 1 (cone without perforation). Low lift and low pressure ratio delivers irregular distribution of flow fields. At one side of the cone, separated flow occurs while at the other side of the cone, flow attraction to the cone prevails.

As the lift and pressure ratio increases, the flow fields become balanced and the flow adheres to the cone constantly. The entire area under the cone becomes filled at a lift $h/D_0 = 0.11$ and pressure ratio $p_2/p_0 = 0.87$.



Var.1.: $h/D_0=0.02$, $p_2/p_0=0.35$ Var.1.: $h/D_0=0.06$, $P_2/P_0=0.41$ Var.1.: $h/D_0=0.11$, $P_2/P_0=0.87$

Figure 5: Visualisation of flow under the cone without perforation



Var.2.: $h/D_0=0.01$, $P_2/P_0=0.35$ Var.2.: $h/D_0=0.06$, $P_2/P_0=0.41$ Var.2.: $h/D_0=0.09$, $P_2/P_0=0.75$

Figure 6: Visualisation of flow under the cone with perforation

The effects of the relief holes can also be inferred from a series of images of flow fields in Figure 6. Relief holes promote stabilisation of flow fields in separating the flow from the cone. The flow lines from the holes possess an ejection effect that leads to partial intake of steam from the environment. A certain asymmetry in specific gravity distribution shows at $h/D = 0.06$ and $p_2/p_0 = 0.41$. However, symmetrical distribution of pressure remains preserved on the cone surface.

4. Measuring of Pressure Pulses

Interferometric measuring enables the assessment of velocity fields, Mach numbers, and changes in pressure pulsation in the location of interest. Locations of pressure pulsation measurement are shown in Figure 7. Assumed are measuring locations in the valve axis under the cone as well as locations across the diffuser neck. Distribution of Mach numbers for cones with and without relief, respectively, is shown in Figure 8. They are compared at identical valve lift $h/D_0 = 0.02$ and pressure ratio $p_2/p_0 = 0.92$. The maximum velocities occur on the surface of the diffuser seat. In cones without relief, a considerable loss of velocity occurs in the central section of the diffuser. Relief holes assist in balancing the velocity in the central section of the diffuser channel. The higher velocities in the seat area assist in limiting the potential separation of flow from the diffuser wall, which promotes the efficiency of the diffuser.

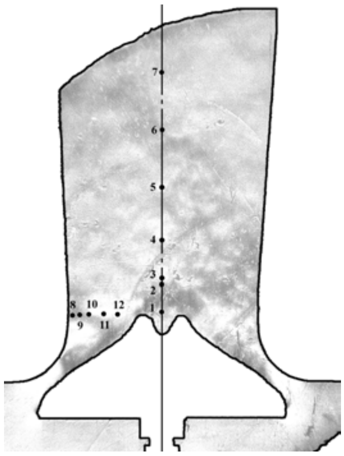


Figure 7: Locations for measuring pressure pulsation

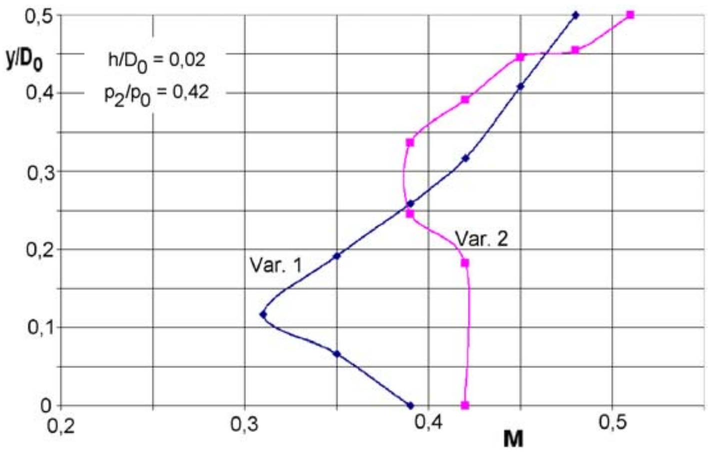


Figure 8: Distribution of Mach numbers in the neck of the diffuser for two variants of cone design

A comparative study of the frequency spectra at light intensity acquired via the shadow and interference methods show higher sensitivity when the interference method is used. The higher sensitivity shows especially in the low frequency range. The interference method looks at changes in specific gravity while the shadow method records changes in the gravity gradient. A comparison of the light intensity spectra in response to frequency taken in location 3 under the cone is shown in Figure 9. Individual peaks of discrete frequencies correspond to the inherent frequencies of the system. Light intensity records taken in the axis under the cone (locations 0 ÷ 7) are shown in Figure 10. Thus a wide band of vibration with the values made visible at inherent frequencies is confirmed. Pulsation in the valve inlet chamber (location 0) are a digit place lower than in the area under the cone. The distribution of the integral value of pulsation intensity in relation to the value in location 1 is shown in Figure 11. As the distance progresses, pulsation intensity becomes up to 3.5 times stronger. Maximum values occur where the flow of media from both sides of the cone coalesce. In the analysed model, the distance was 30 mm from the bottom of the cone.

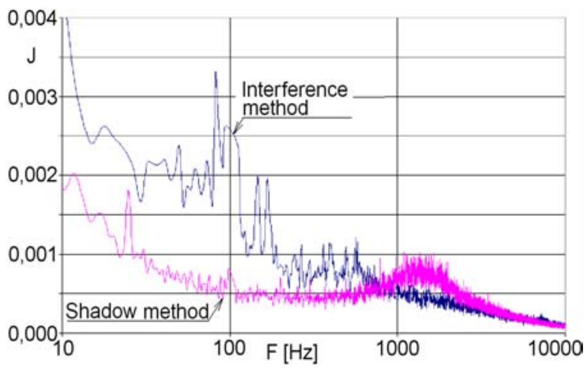


Figure 9: Measuring of pulsation using various optical methods

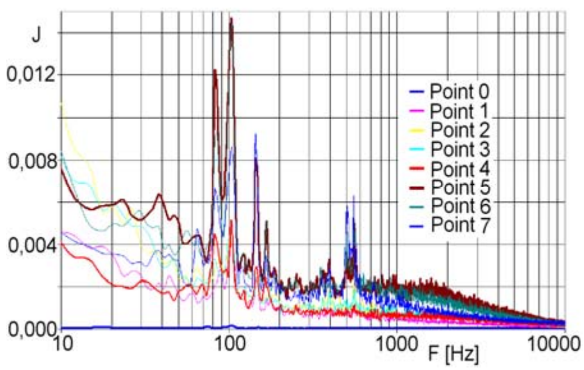


Figure 10: Pulsation spectra in the axis under a cone without relief

Attention was also given to the effect of cone perforation to the intensity of pulsation in the flow. Figure 12 brings a comparison of the pulsation spectra in the neck of the diffuser used in cones with and without perforation, respectively. Perforation clearly assists in damping the pressure pulsation. In the frequency range 90 ÷ 100 Hz, the damping ratio is 10 ÷ 15; in the frequency range 100 ÷ 1000 Hz, the damping ratio is 5 ÷ 10, and in the frequency range 1000 ÷ 10000 Hz the damping ratio is 3 ÷ 5. The assessment of pressure pulsation intensity shows that it is present in various sections of the flow field in the range from 2 to 10%.

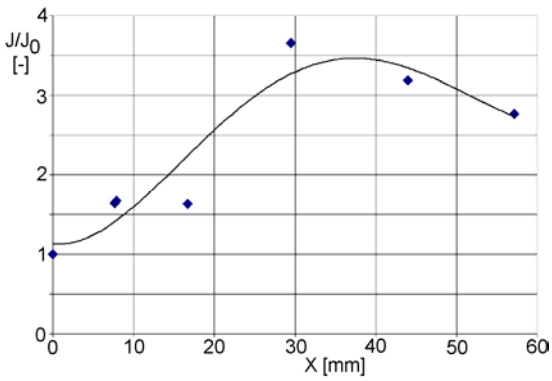


Figure 11: Distribution of pulsation intensity along the channel axis

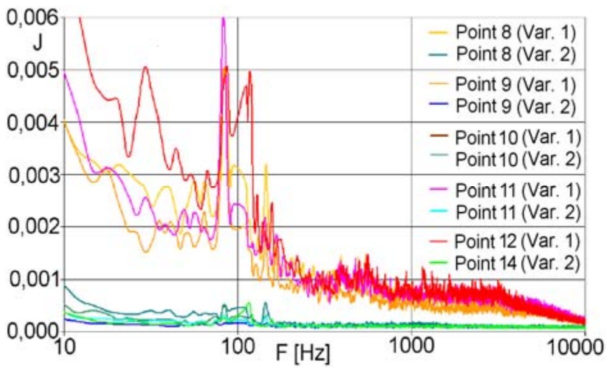


Figure 12: Pulsation spectra in the diffuser neck at cones with and without relief, respectively

5. Conclusions

Flow under the cone of the control valve having the shape as suggested by the MEI may, under certain pressure conditions and at low lift, be unstable with differential flow arrangement on the opposite sides of the cone.

Cone perforation assists in stabilising the flow in the diffuser and under the cone. It also provides symmetrical flow field in the surroundings of the cone. The velocities become balanced in the neck of the diffuser. Flow separation from the cone is evident.

Pressure pulsation ranging from 2 to 10% is present in a non-relief cone.

Maximum pulsation occurs in the area under the cone where the flow from both sides of the cone amalgamates.

Cone perforation assists in damping the pressure pulsation. Damping ratio amounts to 10 to 15 in the low frequency range.

References

Фелдберг Л. А. (2005) Исследование аэродинамических характеристик разгруженного регулирующего клапана на оптическом стенде, *счет ЦКТИ*.

Matas R. (2004) Numerical simulation of flow in shape modifications of control valves in steam turbines for supercritical steam parameters, *Research report NTC Pilsen*.

Зарянкин А. Е. & Симонов Б. М. (2005) Регулирующие и стопорно-регулирующие клапаны паровых турбин, *Издательство МЭИ*.