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THE IMPACT OF SHAPE ADJUSTMENTS OF A VALVE CHAMBER ON LOSSES IN THE CONTROL VALVE OF THE STEAM TURBINE

L. Bednář[1], L. Tajč[2], M. Miczán[3], M. Hoznedl[4], P. Kočárník[5], S. Jirků[6]

Abstract: *Computational study of pressure and energy losses in the control valve of the steam turbine is carried out. The impact of misalignment of a valve cone toward the valve chamber while changing the width of a parting rib in the chamber is assessed. The impact of the dimensions of the valve chamber on losses is examined. An optimal solution to misalignment of a valve cone, dimensions of the valve chamber and the width of a parting rib is established.*

Keywords: Steam turbine, control valve.

1. Introduction

There are certain practices, recommendations and rules for designing dimensions and shapes of the valve chamber of control valves. DOOSAN ŠKODA POWER applies rich historical experience in constructing control valves. The findings from experiments on models of valves are implemented too. Experience from the valve operations in power stations is considered as well. It is always necessary to harmonize the requirement of minimum losses in the particular operation of the turbine with the reliable and safe operation during the start-up and the reduced performance of the turbine. Current computational possibilities enable examination of some recommendations as well as certain practices in terms of their impact on energy losses. They enable assessment whether there are also certain reserves of shape adjustments of the chamber which would lead to minimization of losses. Based on analysing published data the Czech Technical University in Prague conducted a computational study focused on assessing different connections to the different shape adjustments of the chamber valve and formation of pressure losses in the valve chamber and the output diffuser [Kočárník, 2011]. Computations are confined to operating at full valve opening.

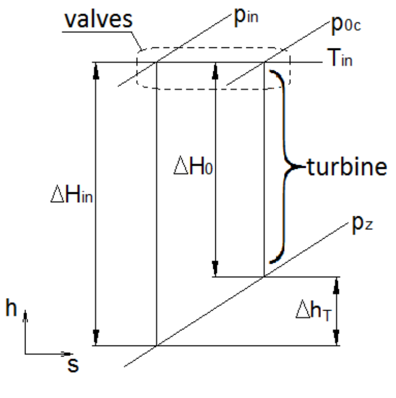

Fig. 1: Process of throttling steam when TV and CV valves are fully opened and expansion on the turbine

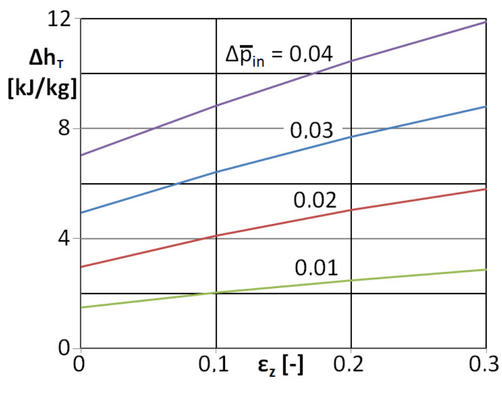

Fig. 2: Reduction of enthalpy drop in valves depending on the pressure loss
$\Delta p / p_{in} = 0{,}03 \ (p_{in} = 13\ MPa,\ t_{in} = 545\ °C)$

[1] Ing. Lukáš Bednář: Doosan Škoda Power s. r. o., Tylova 1/57, 301 28 Plzeň; CZ, lukas.bednar@doosan.com
[2] Ing. Ladislav Tajč, CSc.: University of West Bohemia, Univerzitní ul. 8, 306 14 Plzeň; CZ, ladislav.tajc@doosan.com
[3] Ing. Martin Miczán: Doosan Škoda Power s. r. o., Tylova 1/57, 301 28 Plzeň; CZ, martin.miczan@doosan.com
[4] Ing. Michal Hoznedl, Ph.D.: Doosan Škoda Power s. r. o., Tylova 1/57, 301 28 Plzeň; CZ, ladislav.tajc@doosan.com
[5] Ing. Petr Kočárník, PhD.: ČVUT Praha, Technická 2, A3-516a, 166 27 Praha 6 - Dejvice; CZ, kocarnik@fel.cvut.cz
[6] Doc. Ing. Slavomír Jirků, CSc.: ČVUT Praha, Technická 2, A3-516a, 166 27 Praha 6 - Dejvice; CZ, jirku@fel.cvut.cz

2. Impact of the energy loss in the valve on reducing the turbine output

The requirement to reduce losses in the valve is related to its impact on the loss of the turbine output. The process of throttling the steam in the tripping valve (TV) and the control valve (CV) is presented in fig. 1.

The energy loss of the turbine depending on the pressure loss in the valve can be expressed as:

$$\Delta h_T = \frac{k\, RT_{in}}{k-1}\left[\left(\frac{p_z}{p_{oc}}\right)^{\frac{k-1}{k}} - \left(\frac{p_z}{p_{in}}\right)^{\frac{k-1}{k}}\right] \quad (1)$$

p_z is the pressure behind the high pressure (HP) part of the turbine, k is isentropic exponent.

If we apply designation $\varepsilon_z = p_z/p_{in}$ and $\Delta\overline{p}_{in} = (p_{in} - p_{oc})/p_{in}$, thus we get for the energy loss:

$$\Delta h_T = \frac{k\, RT_{in}}{k-1}\,(\varepsilon_z)^{\frac{k-1}{k}}\left(\frac{1}{(1-\Delta\overline{p}_{in})^{\frac{k-1}{k}}} - 1\right) \quad (2)$$

The unexploited turbine output is specified using the formula $N = \dot{m}\Delta h_T \eta$, where $\dot{m}$ is the mass flow through HP part of the turbine and η is its efficiency.

The energy loss in the valve for the different pressure conditions ε_z on HP part of the turbine and for the proportional pressure loss in the valve $\Delta\overline{p}_{in}$ is shown in fig. 2. Formation of the unexploited turbine output is related to it in fig. 3. The proportional pressure loss in the valve is very important. According to results of measurement on the type version of a balance control valve [Mackovič & Němec, 2012] and on stop valve [Tajč & al., 2005] this loss is cca 3 % of the inlet total pressure. In the control valve itself the loss generates at the level of 2 %. The resulting pressure loss can be effected by the choice of valve dimensions. The performed computational study could clarify whether there is another possibility how to reduce this loss.

3. Computations of losses in the valve at a rated operation of the turbine

Scheme of the layout of the valve chamber is shown in fig. 4. A valve parting rib having the width A shall stabilize the flow in the valve chamber and support the formation of two symmetrical flows entering the diffuser under the cone. Its importance was experimentally confirmed in various works [Kamyrin & Revzin, 1954; Robozev, 1963]. Formation of two vortices under the cone is connected to the flow bend by 90°. The screen, which prevents strange particles from penetrating from the boiler to the turbine, contributes to reducing formation of vortices.

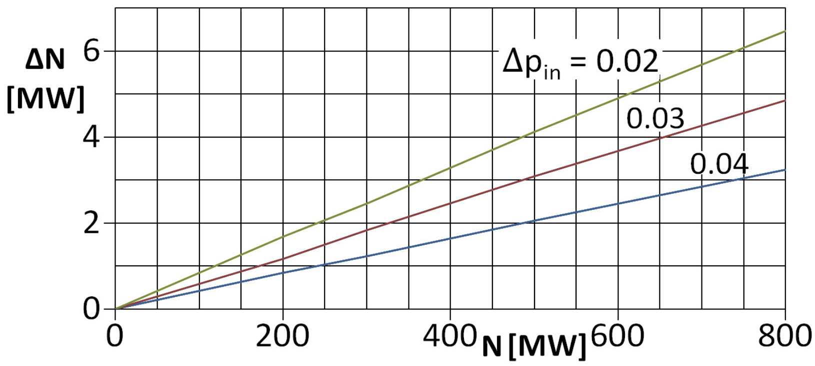

Fig. 3: Impact of the pressure loss in the valve on the loss of turbine performance

Velocity conditions in the valve chamber are affected by misalignment of the valve towards the valve chamber. When there is an inappropriate ratio between the valve chamber diameter and the diffuser throat diameter, complicated circulating flows are related to the increase in pressure loss which may arise [Kamyrin, 1969]. Therefore, the basic version of computation studies focused on assessing the impact of a rib and misalignment of the valve on the size of the loss coefficient. An optimal size of the valve chamber was researched too.

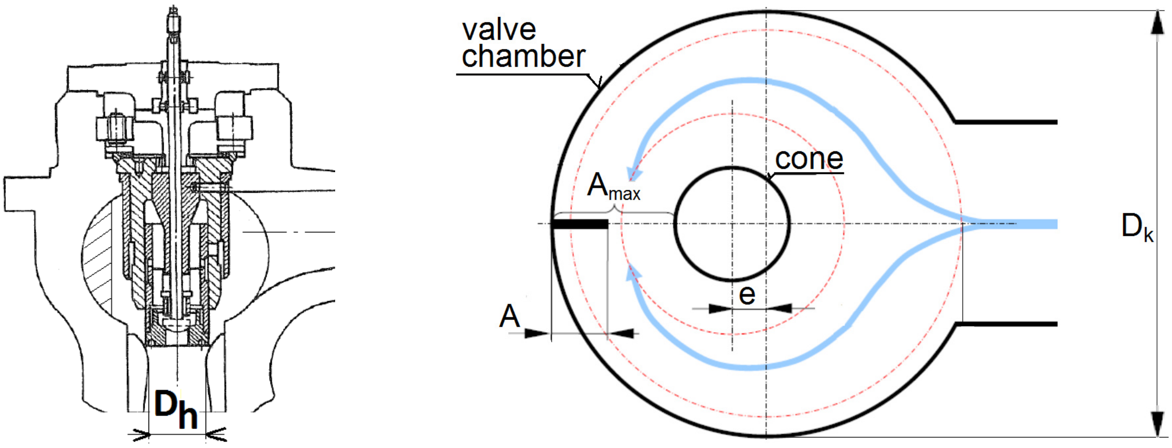

Fig. 4: Scheme of the valve chamber

The loss coefficient may be evaluated as the proportion of the pressure loss to the dynamic pressure in the inlet pipes:

$$\zeta_A = \frac{p_1 - p_2}{\frac{1}{2}\rho c_{1ax}^2} - \frac{c_{2ax}^2 - c_{1ax}^2}{c_{1ax}^2} \tag{3}$$

It may also be elaborated as the difference between input and output energy related to the kinetic energy in the input section:

$$\zeta_B = \frac{E_z}{E_{k1}} = \frac{E_{k1} + E_{p1} - (E_{k2} + E_{p2})}{E_{k1}} \tag{4}$$

The kinetic as well as potential energy E_k and E_p is included. The advantage of numerical computations is also the possibility to map the dimensionless components of velocity as well as components of energy in the entire channel. Computation study is based on the assumption of input velocity $c_{in} = 50\ m/s$ with the volume flow $1.272\ m^3/s$.

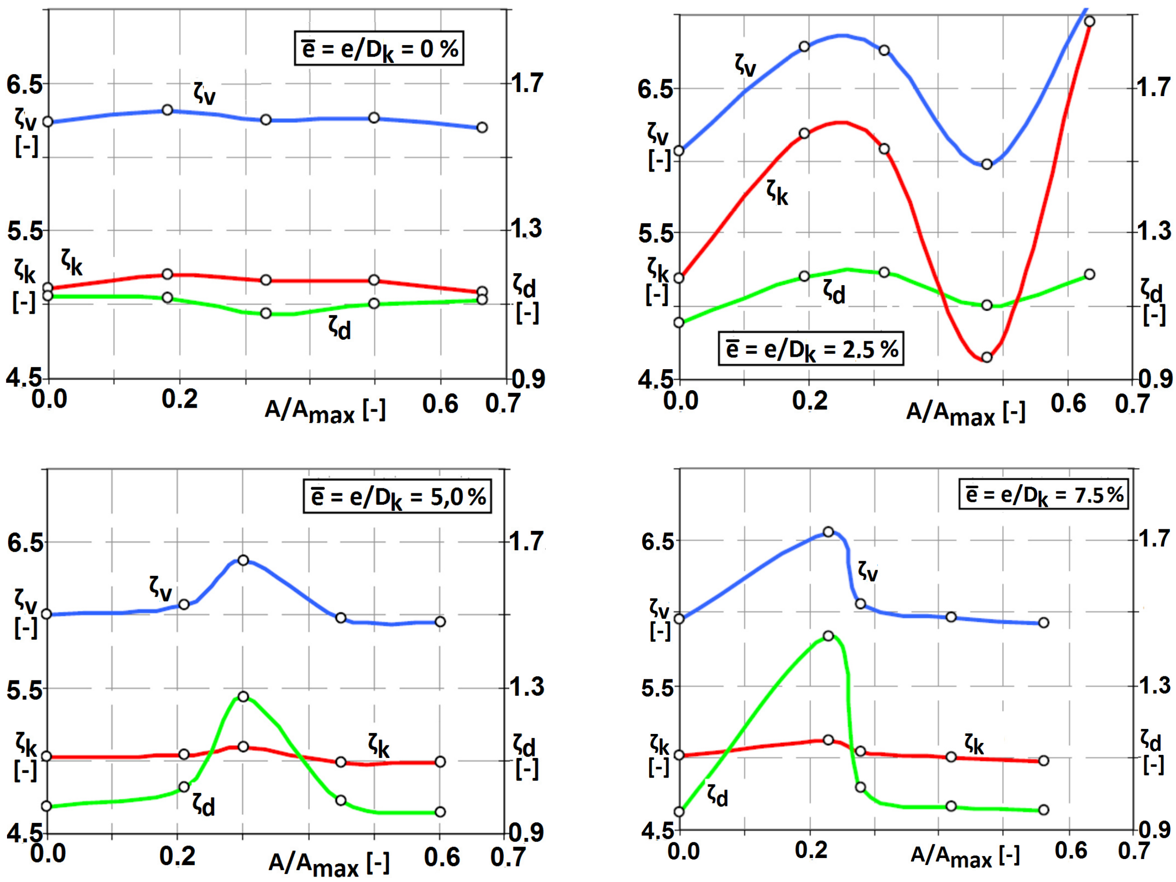

Fig. 5: The energy loss in the valve

Fig. 5 shows the course of the energy loss coefficient of the valve ζ_v, the valve chamber ζ_k and the diffuser ζ_d. In the diffuser, its path from the throat at the entry to the follow-up pipes is considered. It is shown that in a certain configuration of valve misalignment and the size of the rib, the loss coefficient of the valve increases. In small misalignment ($\bar{e}$ = 2.5 %) the loss in the valve chamber increases. In misalignment $\bar{e}$ = 5 and 7.5 % the loss in the diffuser increases. It is essential that the minimum value of the loss coefficient of the valve virtually does not differ from the layout with zero misalignment and without a rib. In a fully open valve the loss in the valve chamber is always bigger than the loss in the diffuser section.

Fig. 6 shows the values of loss coefficients as the function of eccentricity e for the variant with a zero width of the rib. There is also presented the minimum value ζ_{vmin} for optimal dimensions of a rib. ζ_{vmax} appears to be for the least appropriate dimensions of a rib. It is evident that omission of a rib has no significant effect on the final value of the loss coefficient. The losses are reduced by the increase of the eccentricity. The eccentricity of 7.5 % is optimal. The flow in the diffuser mainly contributes to the drop of the loss coefficient. Misalignment of the valve toward the valve chamber has no significant impact on the irregularity in velocity distribution in the valve. Their course for a throat and exit from the diffuser is shown in fig. 7. Irregularities of velocity equalise between the throats to the end of the diffusor.

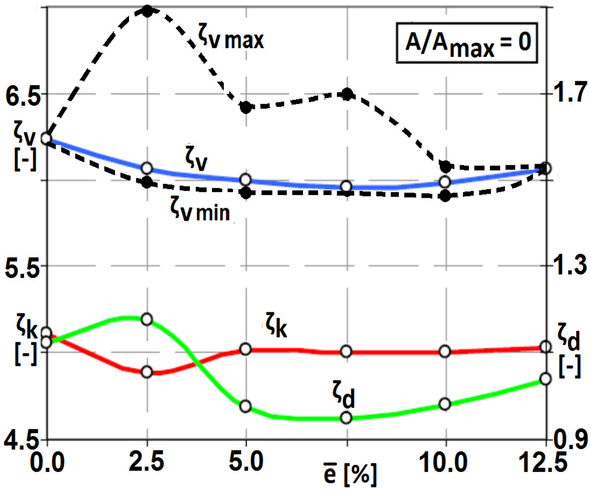

Fig. 6: Courses of loss coefficients

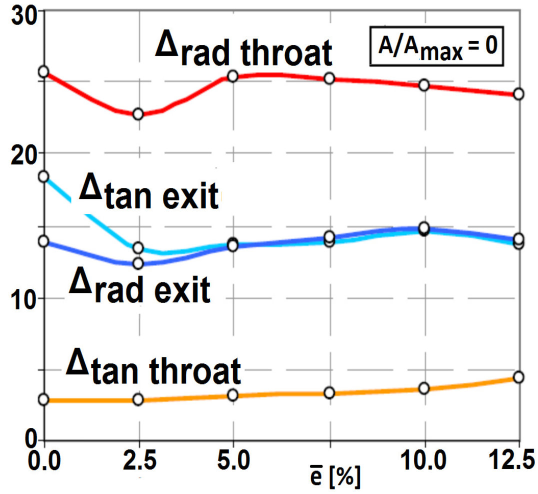

Fig. 7: Irregularities of flow distributions

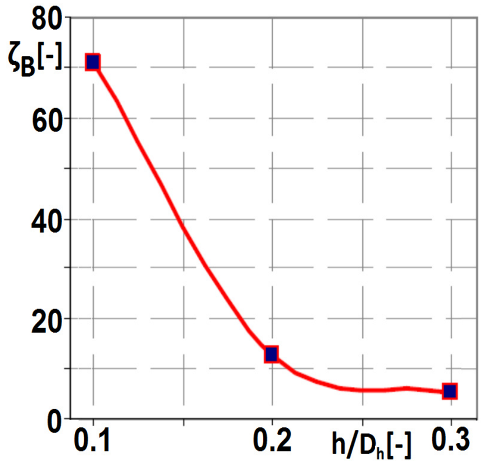

Fig. 8: Loss coefficient of the valve

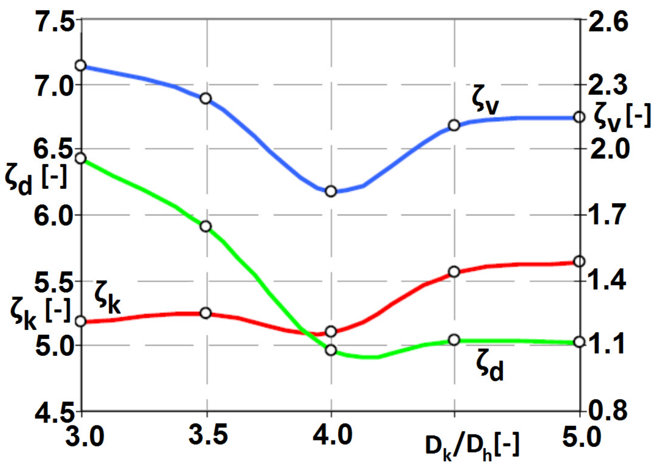

Fig. 9: Impact of the chamber diameter on the losses

A computation study was also undertaken. It focused on determining the loss coefficients in the valve with the misalignment of 10 % with applying a rib and without a rib [Kočárník, 2010]. The dimensions of the valve chamber and a rib correspond to the valve which is ready for experimental verification. The results of computations for misalignment of 0 and 10 % are processed in table 1.

Table 1: Results of computations for misalignment of 0 and 10 % with a rib and without it

variant	rib	ζ_A [-]	ζ_B [-]	η [%]	$\bar{c}_{tan}$ [%]	$\bar{c}_{rad}$ [%]	$\bar{E}_{ktan}$ [%]	$\bar{E}_{krad}$ [%]	Δc_{ax} [%] Tangential course	Radial course
1	no	6.77	6.18	30.70	1.10	4.30	0.30	0.40	25.10	38.50
$\bar{e}$ = 0 %	yes	6.86	6.21	31.00	0.50	4.60	0.40	0.50	27.30	39.20
2	no	6.54	5.91	32.30	15.80	4.30	0.30	0.50	28.00	42.30
$\bar{e}$ = 10 %	yes	6.56	5.08	33.30	0.00	4.30	0.20	0.60	30.10	41.80

The lowest values of loss coefficients are shown by variant 2. $\bar{c}^*_{tan}$ and $\bar{c}^*_{rad}$ are dimensionless mean tangential and radial components of velocity standardized to the mean value of an axial component of velocity $\bar{c}^*_{ax}$. Mean values of the dimensionless kinetic energy in tangential course and radical course $\bar{E}^*_{ktan}$ a $\bar{E}^*_{krad}$ are standardized by the mean value of the kinetic energy in axial course $\bar{E}^*_{kax}$.

For the other variant with a rib, for three values of a relative lift of the cone is created the characteristics of the valve $\zeta = \zeta(h/D_h)$. Computed parameters are shown in table 2, course of the loss coefficient is shown in fig. 8.

Table 1 also shows the mean square error of the distribution of an axial component of velocity $\Delta\bar{c}^*_{ax}$ for a specified course. Average values of velocity components and the kinetic energy are relating to the output cross-section of the diffuser. Although the kinetic energy in the output is based on the axial course of the flow, the value of the loss coefficient ζ_B with the precise calculation is by cca 1.5 % lower than the value ζ_A. The differences between the variant 1 and 2 are according to the values ζ_B insignificant. When assessing the adjustments of the chamber according to parameter ζ_A the difference comes up to 1 %. It is also confirmed by the difference of efficiency, which is up to 3 %. Efficiency is defined as the ration between output and input energy.

Table 2: Computed parameters of the other variant with a rib

h/D_h [-]	ζ_A [-]	ζ_B [-]	η [%]	$\bar{c}^*_{tan}$ [%]	$\bar{c}^*_{rad}$ [%]	$\bar{E}^*_{ktan}$ [%]	$\bar{E}^*_{krad}$ [%]	Δc^*_{ax} [%] Tangential course	Radial course
0.1	74.1	70.8	6.3	0.5	4.7	0.4	0.3	30.5	77.6
0.2	13.2	12.8	16.5	0.5	2.8	0.0	0.2	11.8	28.3
0.3	6.56	5.08	33.3	0.0	4.3	0.2	0.6	30.1	41.8

With the lift declining and reducing the flow area in the valve, the value of the loss coefficient increases. For this computation, the assessment of the loss itself in the valve chamber and the diffuser was not performed. It is highly probable that the increase of the losses is related to the velocity conditions in the diffuser. The accuracy of the choice of the diameter D_k of the valve chamber was checked. In practice, the ratio D_k/D_h an interval from 3.3 up to 4.3 is recommended. Therefore, for verification five models with the ratio $D/D_k = 3; 3.5; 4; 4.5;$ 5 were built. Courses of the loss coefficient are shown in fig. 9. From the computations it is clear that the minimum value of the loss coefficient roughly corresponds to the value of the ratio $D_k/D_h = 4$, for lower values the losses in the output diffuser increase significantly, in higher values the loss in the valve chamber increases.

4. Conclusions

The energy loss in the valve reduces the turbine performance. It is desired that in the design operating conditions of the turbine the pressure or energy loss in the valve would be minimized. Installation of a rib in the valve chamber may reduce, but may also significantly increase the value of the loss coefficient of the valve. After omitting a rib its value is comparable with its minimum value ζ_{vmin}. Misalignment of the valve toward the valve chamber helps to reduce losses. The eccentricity of 7.5 % is the most appropriate. The diameter of the valve chamber has impact on the losses. $D_k/D_h = 4$ is optimal. Under non-designing operating conditions the reduction of the pressure in the valve is desirable. The increased value of the loss coefficient is probably related to the increase of the losses in the diffuser, where the effect of the abrupt change of the cross-section is applied.

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