ZÁPADOČESKÁ UNIVERZITA V PLZNI

FAKULTA STROJNÍ

KATEDRA ENERGETICKÝCH STROJŮ A ZAŘÍZENÍ

ZÁPADOČESKÁ UNIVERZITA V PLZNI

POWER SYSTEM ENGINEERING, THERMODYNAMICS & FLUID FLOW

2013

JEDNOTLIVÝ PŘÍSPĚVEK ZE SBORNÍKU

evropský sociální fond v ČR

EVROPSKÁ UNIE

MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

OP Vzdělávání pro konkurenceschopnost

INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

MEASUREMENT OF A HP/IP STEAM TURBINE DIFFUSER

HOZNEDL Michal, FELDBERG Lev Avraamovic

The results of the measurement from the basic variants of a medium-pressure/high-pressure type of a diffuser of the steam turbine Škoda are stated in the presented paper. To get an idea about the size of the loss coefficient of a basic variant of a diffuser was the objective of the measurement and to compare it with the so far identified numerical calculations. The results serve as reference ones to the other variants being researched subsequently.

Keywords: steam turbine, diffuser, measurement

Introduction

After successfully managed upgrading the output low-pressure parts of the steam turbines Škoda [1, 2] it was possible to begin upgrading the high-pressure and medium-pressure diffusers as well.

A diffuser is the part of a turbine located behind the last level of the part whose task is to compress the steam flow so that the pressure behind the last level would be as low as possible and this way the expansion line would be extended to a maximum. These changes may be reached particularly by the passive resources, which means the suitable shaping of the limiting walls, but in case of the low-pressure diffusers also by blowing an additional flow into the boundary layer [3]. The anticipated contributions in the form of the increased performance of the device depend on the output speed of the steam from the last level of the part and on the quantity of the steam and they may occur from tens to hundreds of kW.

Together with the measurement of the pressure losses and visualization of the flow of a basic variant the identification of the other suitable shaping variants of a diffuser based on CDF computations for the subsequent measurement was performed. The areas with the possible places of the flow separation and thus the potential sources of the losses were located.

1. Measurement description

A measured model is derived in the scale 1:1.75 from the medium-pressure diffuser of the steam turbine called Sredneuralskaya. Geometry of a real turbine, which means the last moving blades as well as of a diffuser is presented in Fig. 1. A scale model of a diffuser is 63 mm high and it is designed as segmented one, which means 2.5D. The opening angle of the segment is 10°. Further, a radial slit above the edge of the moving blade was simulated and there was a possibility to change the intensity of the leakage through this slit. Geometry of the slit and the clearance corresponded to geometry of a real blade. The radial clearance is at the level of 0.3 mm. A total view of geometry of the model including an input and output tract and including obvious side windows for visualization of the flow is shown in the Fig. 2. The design of the model itself enables to change the axial length of the channel as well as the length of the diffuser wall by the removable liners.

The measurement of the losses itself was evaluated by the loss coefficient defined as:

$$\zeta_c = \frac{1-\left(\dfrac{\overline{p}_2}{\overline{p}_{01}}\right)^{\frac{\kappa-1}{\kappa}}}{1-\left(\dfrac{\overline{p}_1}{\overline{p}_{01}}\right)^{\frac{\kappa-1}{\kappa}}}$$

Hereby: Index 01 – the total pressure at the inlet

Index 1 – the static pressure at the inlet

Index 2 – the static pressure at the outlet

$\overline{p}$ **-** The mean value of the pressure weighted by the cross-sectional area

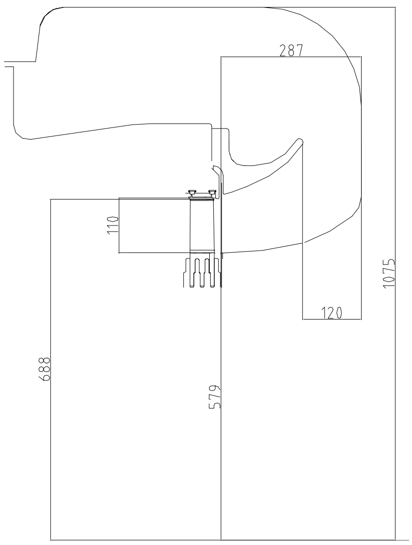

Fig. 1: Real diffuser geometry

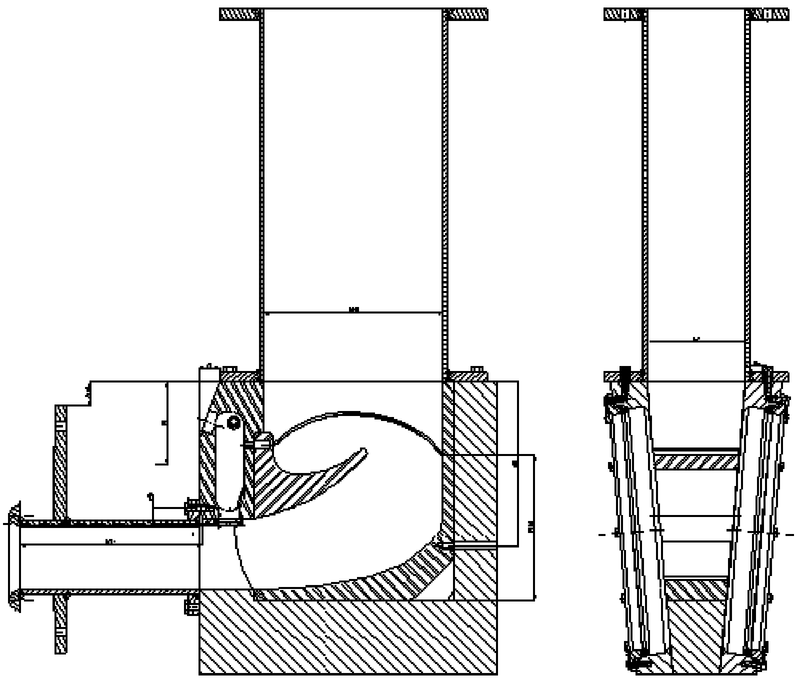

Fig. 2: A 3D view of a diffuser section model

The static pressures at the inlet and at the outlet from the domain were measured by the static wall samplings, the total pressure at the inlet into the domain by the Prandtl probe was measured, further, the mass flow volume through the main inlet and the blowing by the orifices was measured. The temperatures in the main inlet and in the blowing were measured by a thermocouple.

2. Measurement results

In the first stage it was necessary to find out the distribution of the total pressure by traversing along the height of the channel so that it would be possible to find out a characteristic position of the probe for all further measurements without traversing. The results are shown in Fig. 3. The axis y provides the ratio of the pressure measured in the stated position to the medium pressure at the inlet. The evenness of the input pressure field in the tunnel is proved. The greatest total pressure is, as assumed, at half height of the channel.

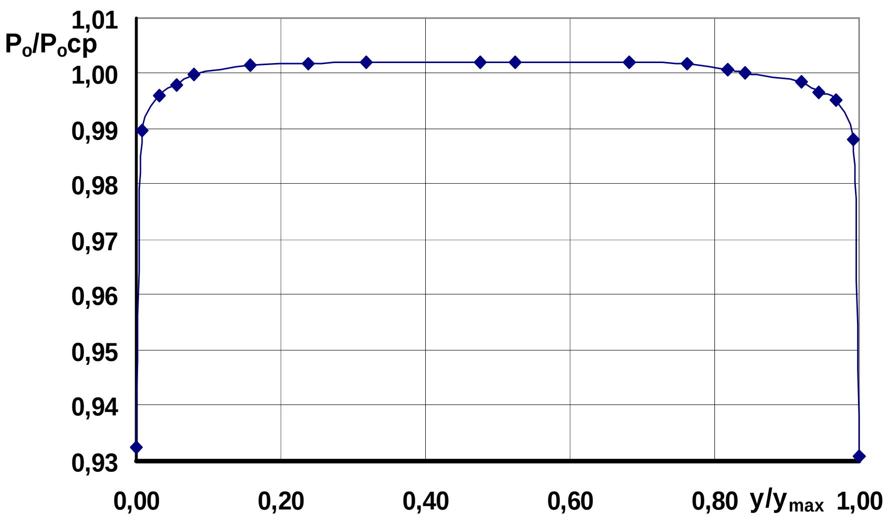

Fig. 3: The total pressure distribution along the inlet cross section

Further, it was necessary to identify the distribution of the static pressure on the walls at the inlet to the area for the left as well as for the right side of the model. This distribution is shown in the Fig. 4 and it is seen to be practically even on the both sides. From this reason it was possible to decrease the number of the pressure measurements by half.

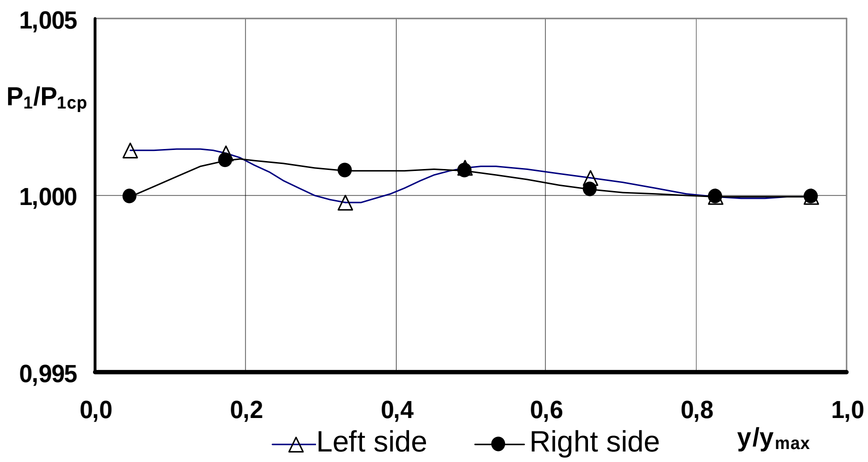

Fig. 4: The static pressure distribution along the inlet cross section

The similar measurement was performed at the outlet from the area. Here only sampling of the static pressure along the left as well as the right side in the horizontal direction was performed, see Fig. 5. The pressures on the left and right appear to be equal again and at the same time it is obvious that the pressure profile along the width of the channel is nearly constant. Its change is about 0.2% and it corresponds to the distribution of the speed in the flow.

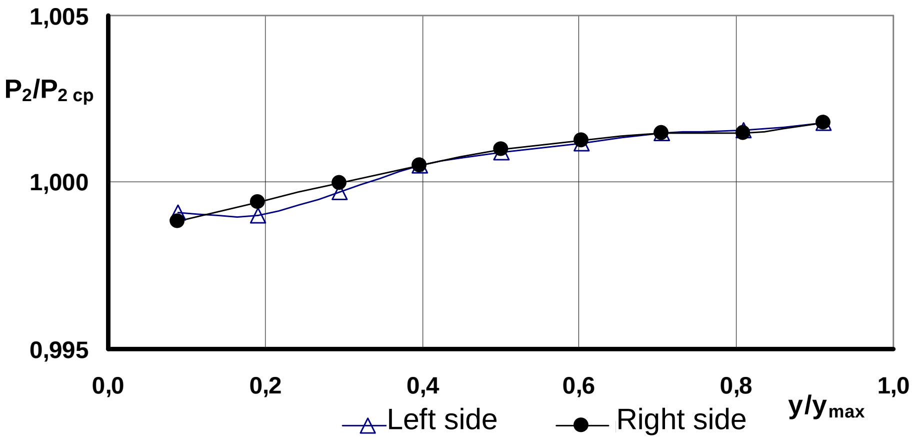

Fig. 5: The static pressure distribution along the outlet cross section

However, as the main result is defined the loss coefficient of the pressure for several different speeds at the inlet into the diffuser. Fig. 6 shows clearly that in the given range of the input speeds defined by Laval number λ the profile of the loss coefficient is constant and it reaches the values around ζ = 0.74. The nominal Laval number is λ = 0.3. It means that the diffuser works properly, however, there is still a certain chance to reduce the loss coefficient.

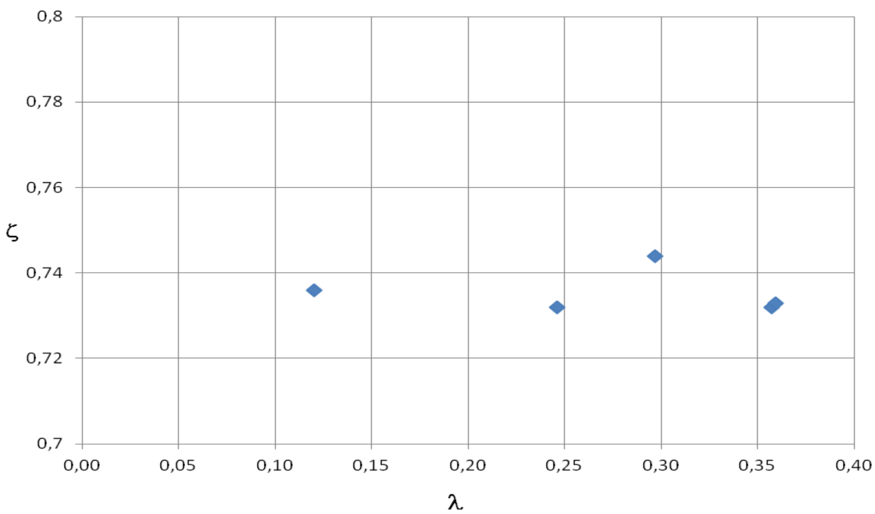

Fig. 6: The influence of the input speed on the loss coefficient

The important task was also to find out the influence of the leakage through the rotor seal on the losses. While Fig. 6 considers the proportional leakage through the rotor seal (g) to the flow volume of the main flow (G) as zero, which means g/G = 0, then in Fig. 7 this proportion increases up to the value 0,06. The real values g/G are varying in the range 0,008 ÷ 0,015. It is obvious that with the increased level of the leakage the losses increase as well. One of the reasons may be found in the different speed of both flows, whereas the speed of the medium by the leakage may be higher and the losses also increase due to mixing. The increase of the losses is virtually linear. Hereby ζ_0 = 0.74.

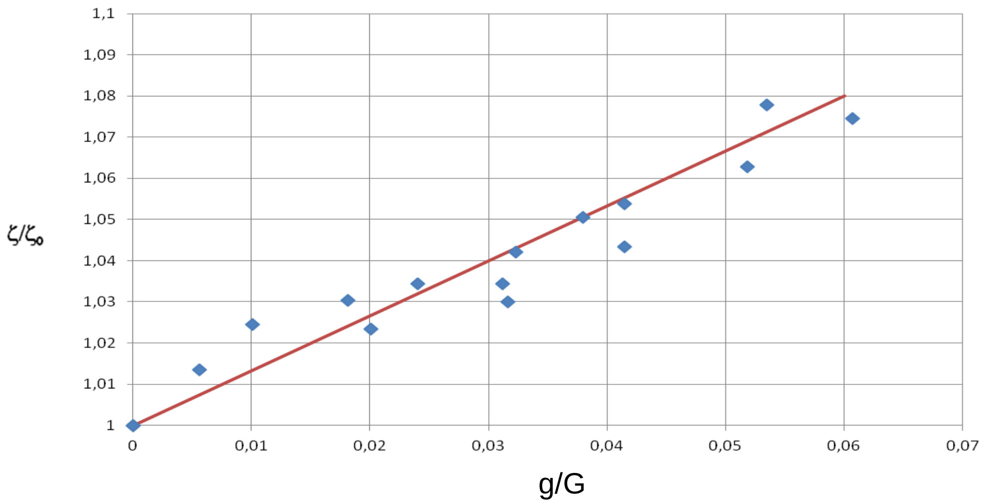

Fig. 7: The influence of the leakage flow ratio on the loss coefficient

Fig. 8 provides visualisation of the flow for the case with the leakage g/G = 0.03. The higher speed is obvious in the place of the leakage and further, a probably swirl area in the area where the flow spins on the hub wall is seen too.

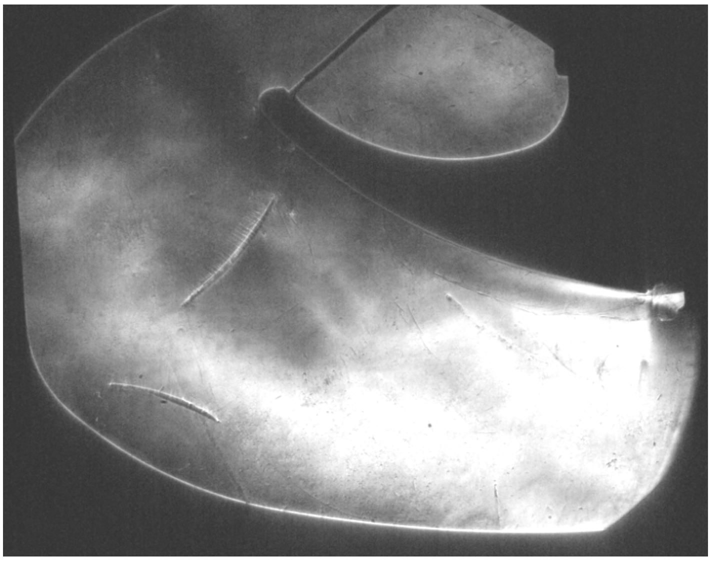

Fig. 8: Flow visualization for the case with the medium flow through the seal

To achieve the comparison series of 2D computations by the program ANSYS Fluent was performed, for the number of the combinations of axial lengths of a diffuser L2 and axial lengths of the upper limiting wall of a deflector L1, related to the length of the last blade L without the influence of the leakage through the clearance, which means g/G = 0. The results of the parametric study are shown in the Fig. 9. For the measured variant, which means for the combination L1/L = 1.58 and L2/L = 2.632 the value of the losses $\zeta = 0.76$ is calculated. The difference between the measured value of the losses and the calculated value is minimal. This is caused by the fact that in the course of flowing the flow is not separated, the boundary layers have no possibility to be developed due to the small length of the airflowed parts and due to a rather simple shape of the channel. Such conformity is very rare in the diffuser flowing in other cases.

With some caution the CFD computations for this area appear to be trustful, however, it is necessary to keep checking the selected variants experimentally.

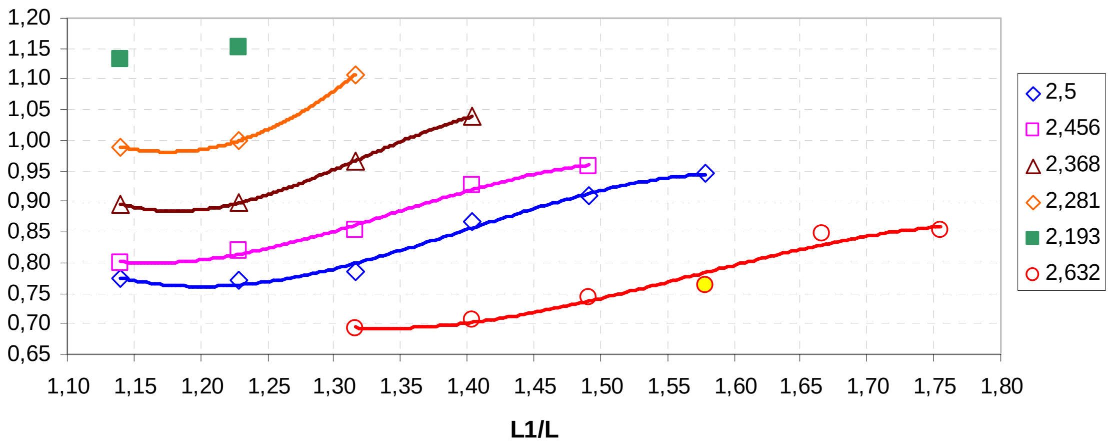

Fig. 9. The CFD parametric study of the geometrical sizes combination

Conclusion

The measurement of the first variant of a model of the medium-pressure diffuser of the steam turbine was performed. At the beginning the influence of the distribution of the static pressures as well as the total pressures at the inlet and possibly at the outlet from the measured area was tested. The minimal change of these pressures along the width of the channel was found out.

For several input speeds to the diffuser the measurement of the losses was performed. The value of the losses in the measured area of the speeds is constant $\zeta = 0.74$. Further, the dependence of the size of the leakage through the radiaal clearance on the losses was found out. If the leakage increases, the losses increase too.

The CFD computations showed a proper conformity with the measurement. They may serve as the guidelines for the proposals of the other measured options.

Literature

[1] HOZNEDL, M.; SEDLÁK, K.; POUBA, Z. Vliv zkracování axiální délky difuzoru v jednoproudém výstupním tělese parní turbíny. In: Power System Engineering, Thermodynamics & Fluid Flow – ES 2012, University of West Bohemia, Pilsen, pp. 34-38, 6/ 2012.

[2] HOZNEDL, M.; PACÁK, A.; TAJČ, L. Effect of Internal Elements of the Steam Turbine Exhaust Hood on Losses. In: Experimental Fluid Mechanics 2011, Technical University Liberec, Jičín, pp. 668-679, 11/2011.

[3] HOZNEDL, M.; LINHART, J.; TAJČ, L. Vliv vefukování do mezní vrstvy na ztrátový součinitel výstupního hrdla, In: Dynamika tekutin, Praha, pp.53-56, 10/2006.

Ing., Ph.D. HOZNEDL Michal, Doosan Škoda Power, Experimental Research, Tylova 1/57, Plzeň, +420 378 185 746, michal.hoznedl@doosan.com
Ing. CSc. FELDBERG Lev Avraamovic, NPO CKTI, Physic-technical department, Atamanskaya 3/6, Sankt Petersburg, Russia, +7 (812) 578 8741, l_feldberg@mail.ru