19th International Conference
ENGINEERING MECHANICS 2013
Svratka, Czech Republic, May 13 – 16, 2013

PROTECTIVE SCREEN AND ITS INFLUENCE ON THE RELIABILITY OF THE CONTROL VALVE OPERATION

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Abstract: *The standard version of the control and stop valve of steam turbines is mentioned. The pressure loss caused by the screen at the valve entrance is assessed. The results of different experiments and the 3D numeric simulation are presented. The influence of the screen on the loss, the suitability of the direction openings and the input spin of the flow in the valves is described. The pressure loss in the combined valve and the influence of the screen on even distribution under the valve cone is mentioned.*

Keywords: ***Turbine, valve, screen, experiments, flow.***

1. Introduction

The screens in the control valves shall prevent penetration of the extraneous particals to the blade part of the steam turbines. They have become an integral part of all valves as a protective element. However, the screens also have the influence on the pressure distribution and the pressure loss. Over the years the different arrangements of the screens have been tested. Most of all the issues of the operational reliability and minimizing losses in the rated performance of the turbine have been followed. The operational reliability is connected to the shape of the cone. The screen seems to be rather understood as a protective element. The size of the screen holes has stabilized at the dimensions 8 - 12 mm. With regard to minimizing the losses the screen is installed in the place, where a maximal area may be utilized and where the minimal speed may be applied. The entrance chamber of the valve appears to be such a place. The practice has shown that the screen does not stop the particles of a small size flying through. In many cases when the turbine is put into operation and when the flow part is blown through, the blades are damaged by grits or by any other dirts from the boiler. When the surface of the blades gets rougher, from the beginning of the turbine operation, the deterioration of its thermodynamic efficiency is caused. Therefore the efficiency of the screen is discussed. There are considerations to diminish the holes in the screens, to change or to remove the screen after the turbine is put into operation or after the individual dirt catchers are installed. The issue is, whether the screen before the valve is an effective element and to what extent it contributes to reliability of the steam turbines. It is necessary to consider the contribution of the rotation of the input flow as well as usability of the ribs in the entrance chamber of the valve. The objective of the work is to summarize the available information from the research of the flow through the valves being equipped with the screens and being without the screens.

2. The pressure loss in the valves

The characteristic arrangement of the quick-shut off and non-lightweight control valves is shown in the Fig. 1.

The detail of the design of the control valve is shown in the Fig. 2. In this case it is non-lightweight valve with the cone having the flat bottom. There are cca 1000 holes having the diameter 12 mm in the screen. The angled notches in the bottom part of the screen make the part of the flow rotate in a certain extent. The flow rotation shall stabilize the flow in the input diffuser.

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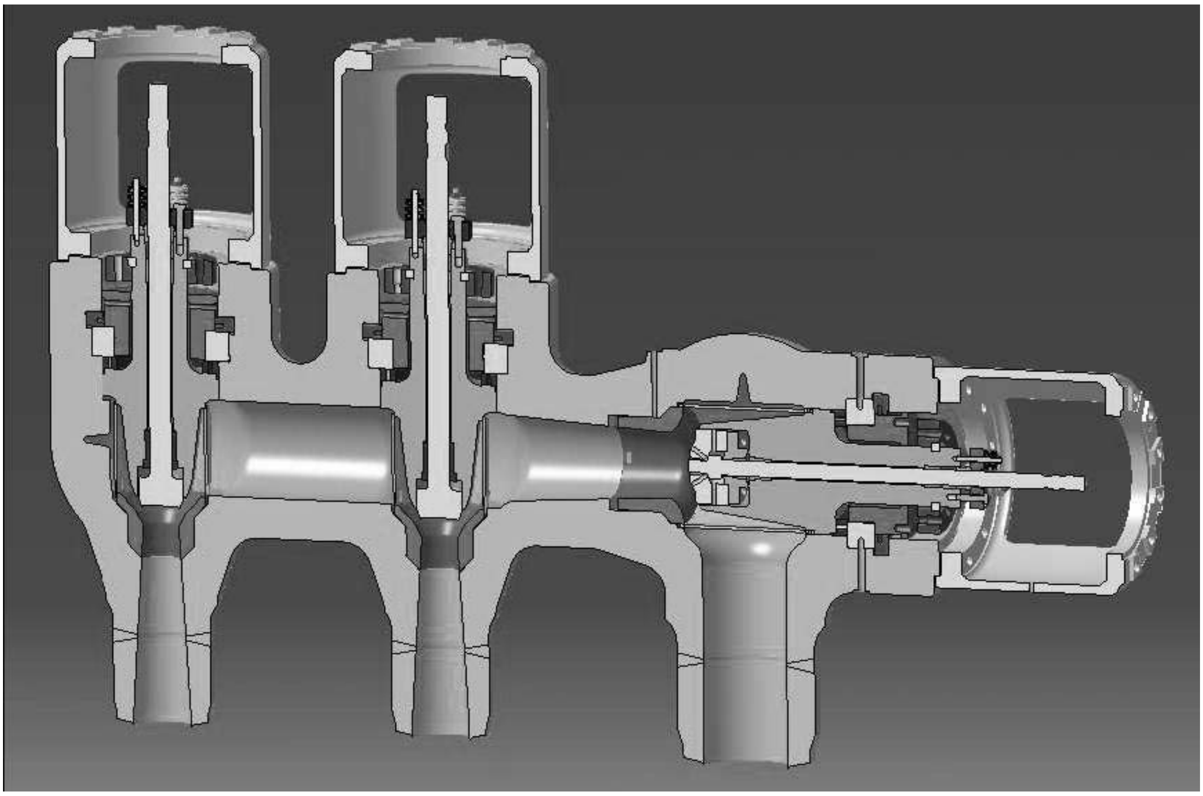

Fig. 1: The arrangement of the non-lightweight valves

Although a diffuser has the higher pressure loss than a confusser or straight pipes, its application is required due to the reduction of the output speed and reduction of the pressure loss in the pipes between the valves and the nozzle segments in the turbine. The length of the pipes may be up to 12 m.

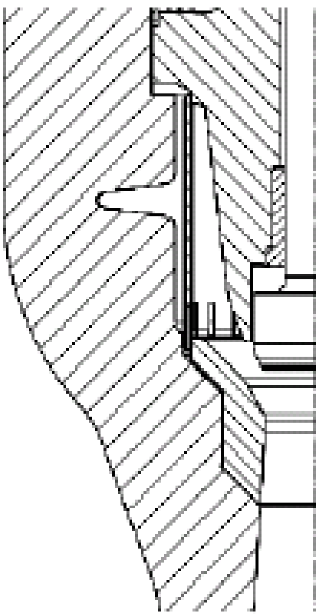

Fig. 2: The detail section of the control valve

The effort to diminish the passive volumes before the turbine itself has led to the creation of the combined valves. The illustration of this combined solution is shown in the Fig. 3. In this case the usage of the screen in one or both valves is also considered. A diffuser is not used for this type of the valve. The basic dimensions are so that the speed inside the valve would be minimized. This ensures the low total loss as well as the acceptable noise generated in the valve.

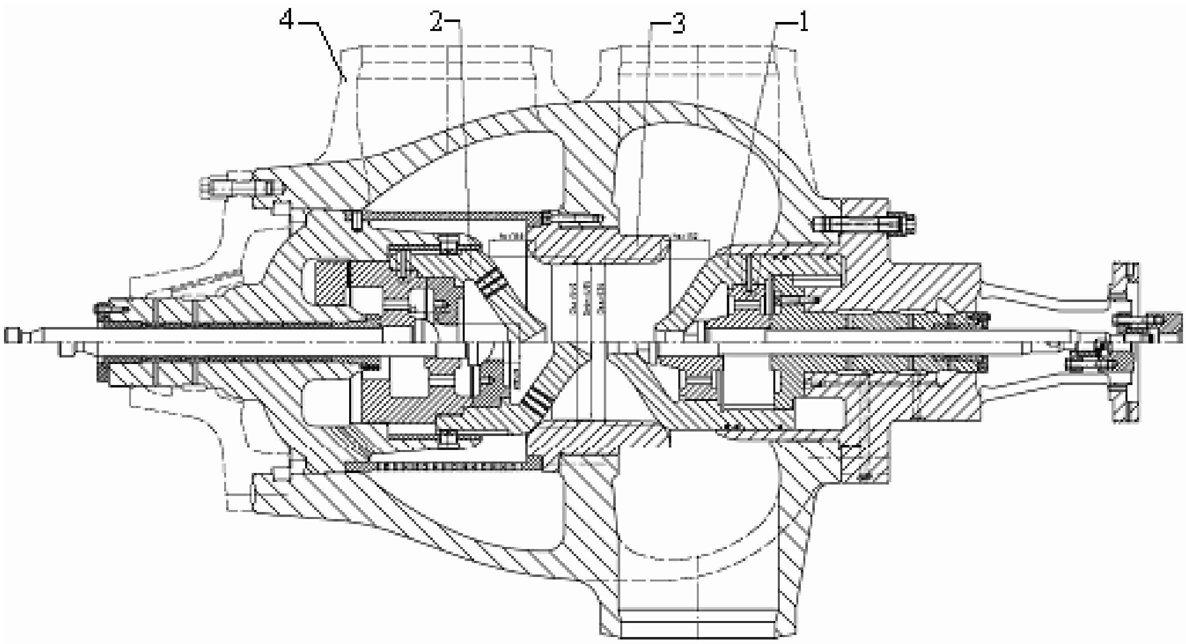

Fig. 3: Example of embodiment of the combined valve

It may be generally said that the flow conditions in the valve depend on the operation of the turbine. By the change of the cone lift of the valve, the flow area is changed and by this the mass flow through the valve is changed too. The pressure before the turbine is regulated. The flow in the valve is changed from supersonic through transonic to subsonic one.

The pressure loss in the valve is caused by the difference of the total pressures before and behind the valve. The pressure loss in the screen becomes a part of this loss. According to (Kolář & Vinopal, 1963) this may be defined by using the loss coefficient ζ. Following shall be applied

$$\Delta p = \zeta \cdot \rho \frac{w_0^2}{2}$$

w_0 is the speed before the screen. The following relation indicates the loss coefficient

$$\zeta = \frac{\zeta_v + c(1 - f_n) + (1 - f_n)^2 + \lambda \frac{\ell}{d}}{f_n^2} \tag{1}$$

whereas $f_n = \frac{F_1}{F_2}$ - area ratio of the holes to the area

$\frac{\ell}{d}$ - proportional depth of the screen hole

λ - frictional loss coefficient

c – additional experimental coefficient

ζ_v – coefficient of the curvature on the flow.

For the screens made of the thicker plate the following fact is applied: ζ = 0.5 and c changes depending on $\frac{\ell}{d}$ according to the dependence in the Fig. 4.

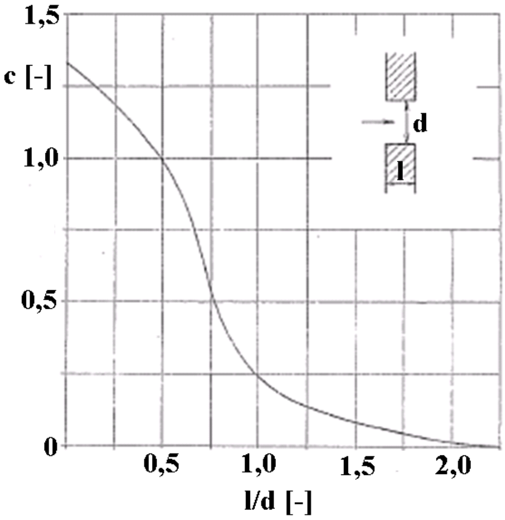

Fig. 4: Coefficient c depending on the ratio of the plate thickeness to the diameter of the circular cross-section

Most of the screens are designed with the holes d = 12 mm for the plate with ℓ = 10 mm. For this arrangement c = 0.37 and λ = 0.015 may be considered.

Due to the modern technology of the production, the screens having the diameter d = 3 mm are getting to be be used as well.

As the Fig. 5 shows, for both screens approximately the same dependence of the loss coefficient on the proportional flow area occurs.

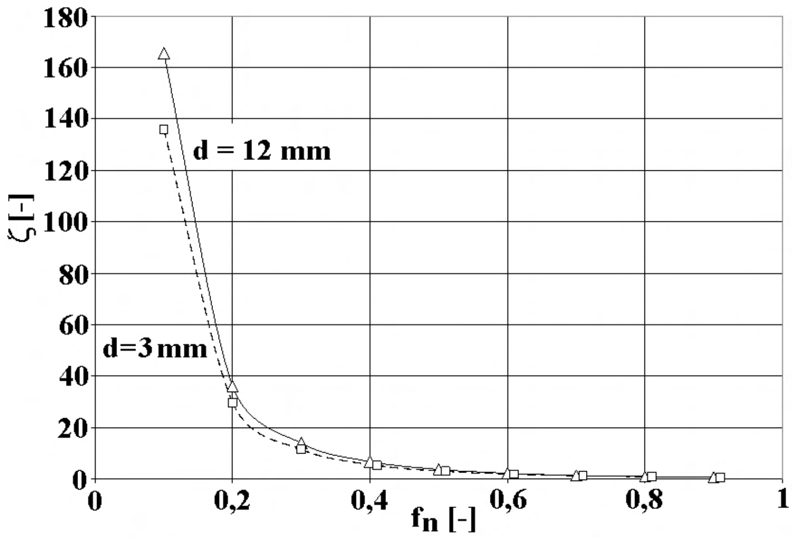

Fig. 5: The loss coefficient of the inflow through the perforated sheet

Assuming the proportional blockage of the screen (the flow capacity of the screen) $f_n \doteq 0.39$ the loss coefficient is $\zeta \doteq 7.3$. For the turbine with the input parameters of the steam T_0 = 595 °C and p_0 = 27.16 Mpa, the theoretical pressure loss is $\Delta p \doteq 0.6$ bar, which represents 0.22 % of the input pressure. With the reduced performance of the turbine and lower input of the dynamic pressure the theoretical input pressure loss shall be lower as well. However, the real pressure loss shall be higher than the theoretical one since the constant pressure distribution along the real screen does not exist and the purely vertical steam inlet to the screen does not exist either. The tangential component of the speed and uneven speed ratios along the height of the screen are applied. The valve must be reliable in all modes of the turbine. When the turbine starts, the supersonic and transonic flow occurs in the valves. This is the flow in the curve when a sudden cross-section change occurs. The real pressure loss on the screen and in the whole valve in the different modes may be provided only experimentally. When the gas moves, in the curved channels the specific phenomenons described for example in (Dejč, 1961) arise. The flow with being curved by 90° is shown in the Fig. 6.

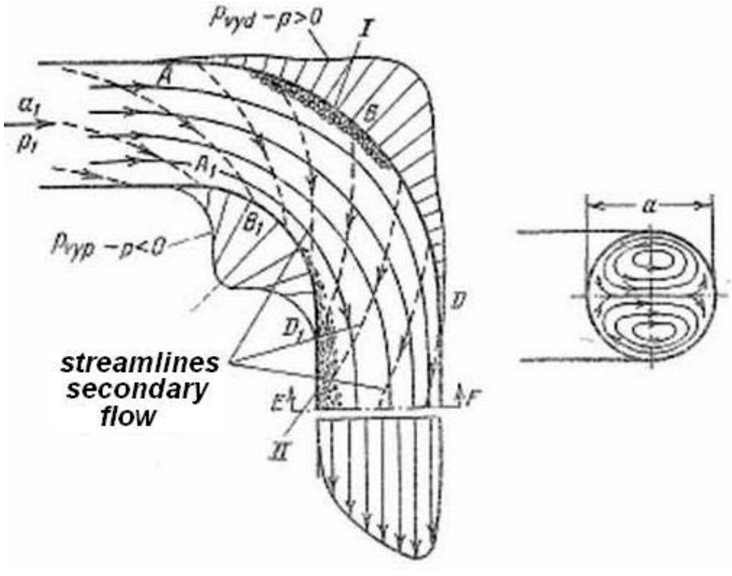

Fig. 6: The flow movement in the curved channel

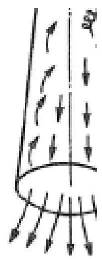

Fig. 7: The characteristic flow phenomenons in the valves

Whereas the gas particles move along the curved trajectories, the pressures on the outer (concave) and inner (convex) wall of the channel are mutually different. The particles inside the flow move to the outer wall under the influence of the centrifugal force. In the curved channels the secondary flow arises resulting in a pair of vortices in the output section. Similar phenomenons also occur in the valve, where the cone of the valve is inserted into the curve. As the Fig. 7 shows, in the valves the flow separation from the cone of the valve occurs additionally, in the certain modes the flow separation from the wall of the diffuser occurs too. The step changes of the pressure within the transonic and supersonic flow together with the flow separation from the wall of the diffuser may lead to the destruction of the pipes behind the valve. The screen itself together with the rib in the entrance chamber should help to stabilize the flow conditions in the valves in all operating states.

The screen helps, despite the certain pressure loss, to balance the velocity fields. Due to the screen, the effect of 3D flow, which arises when bypassing the cone of the valve, may be suppressed. The dynamic pressures behind the screen around the perimeter of the cone may be balanced by an adequate choise of the density of the screen and its loss coefficient. This way the predisposition of the valve to create the pressure pulsation is reduced. The experiments with the screens published for example in (Povch) may contribute to the adequate choice of the density of the screen. In the Fig. 8 the distribution of the dynamic pressure before and behind the screen for the different values of the loss coefficient is stated. The velocity fields are balanced at the value $\zeta = 3$. In the valves the value of the loss coefficient should be similar or slightly higher. It certainly depends on the pressure distribution on the 3D flow in the valve and on the speed of the steam before the screen as well. This may also be influenced by an area of the screen. Searching the optimal performance of the screen by the choice of its loss coefficient has still been an open issue. However, in each case it is obvious that the screen contributes to the stability of the flow in the valves and to the improvement of their operational reliability. The valve works with the different cone lifts and the pressure gradients. The efficiency of the screen does not have to be the same in the different operating modes of the turbine and of the valve. When the turbine starts, the mass flow through the valve is relatively low. The pressure loss in the screen may be marginal in comparison with the rated turbine operation, when the maximum quantity of the steam flows through the valve. However, in terms of reliability of the valve operation the states, when the turbine starts, are the most important when in the valve the step changes of the pressure from the shock waves occur. The screen itself does not prevent the creation of the pressure pulsation.

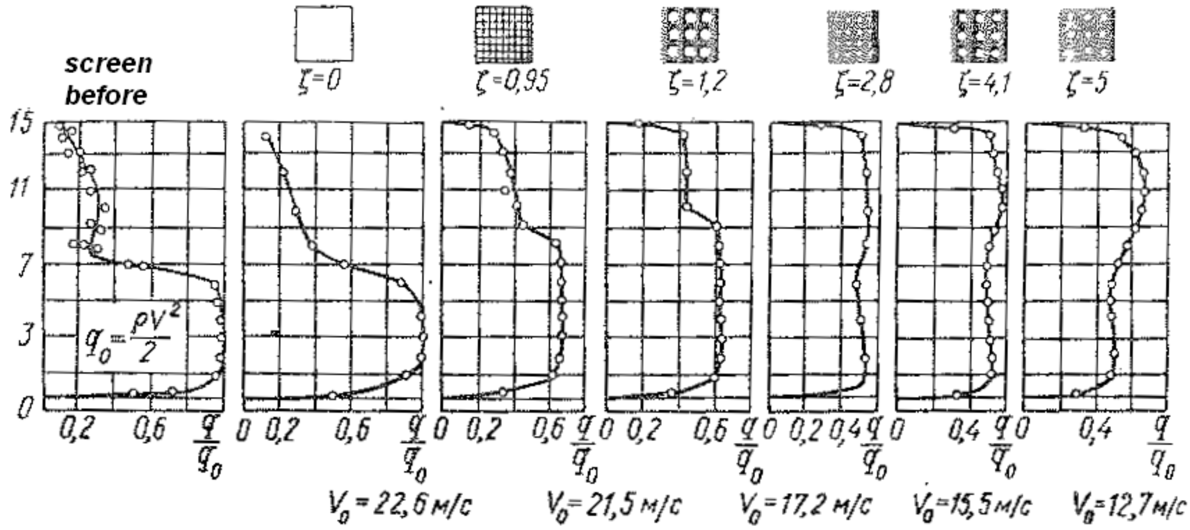

Fig. 8: The dynamic pressure before and behind the screen for the different values of the loss coefficient

The aerodynamic characteristics of the valves

Several modifications of the shape of the cone and the entrance part of the valve contributed to the reduction of the losses and to the improvement of reliability of the valve. Instead of a spherical or profiled shape of the cone, a cone with the flat bottom and injected was implemented. This way the place of the flow separation on the cone under the transonic flow was stabilized. The entrance angle of the conical seat got reduced for α = 60 deg. The reduction of the entrance angle resulted in the increase in the proportion of the static pressures behind and before the valve $\varepsilon = p_2 / p_0$. In the standard operation when the dimensionless mass flow is assumed q = 0.3 and the valve lift h/D = 0.3, the pressure ration increased from ε = 0.985 to ε = 0.988.

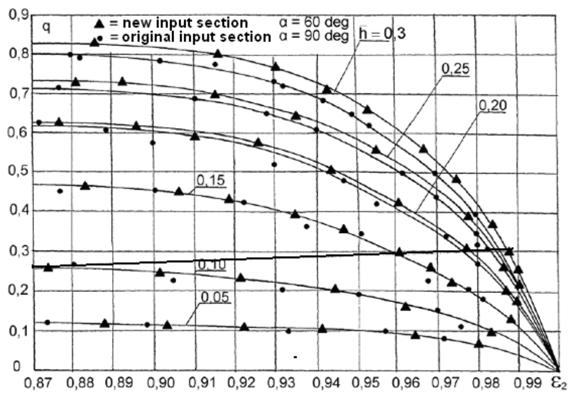

Fig. 9: The flow characteristic of the valve with the injected cone

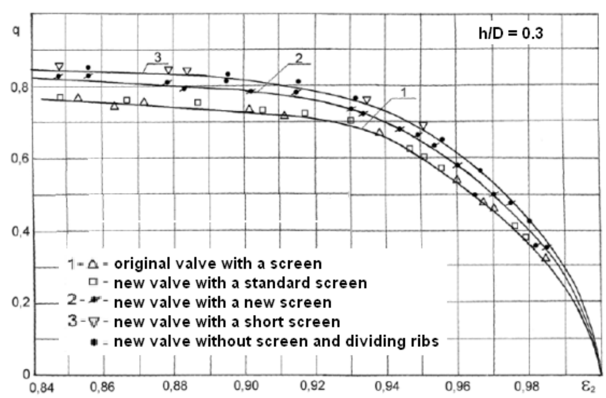

Fig. 10: The influence of the screen on the flow characteristic of the valve

The flow characteristic is shown in the Fig. 9. The contribution of the reduction of the entrance angle is well visible. The influence of the screen on the pressure loss is shown in the diagram in the Fig. 10. The valve, having the cone with the flat bottom, with the original screen did not result in the reduction of the pressure loss. After using a new screen the pressure loss of the valve was reduced. To upgrade the screen means to implement the notches on the bottom part, where they make the part of the flow rotate in the certain extent. The rotation of the flow helps to its better adhesion to the wall of the diffuser and these results in the reduction of the total pressure loss. For the flow q = 0.3 and

$\bar{h} = 0.3$ the pressure ration increased from ε = 0.985 to ε = 0.988. After removing the screen as well as the rib ε_2 = 0.99 was reached. It is proved that the screen always causes a certain pressure loss. However, the screen with the angled notches is more suitable than the screen without the notches.

A 3D numeric study enabling to assess the mutual influence of the rib and the directional holes on the screen (Jirka, 2007) has been carried out. In the Fig. 11 there is the flow field in the middle section of the supply pipe and the screen in the area of the circular holes. The rib on the opposite side to the steam supply helps to create the symmetrical arrangement of the flow. A radial entrance to the screen is well visible. Another situation occurs in the part with the directional holes. The relevant flow field is shown in the Fig. 12.

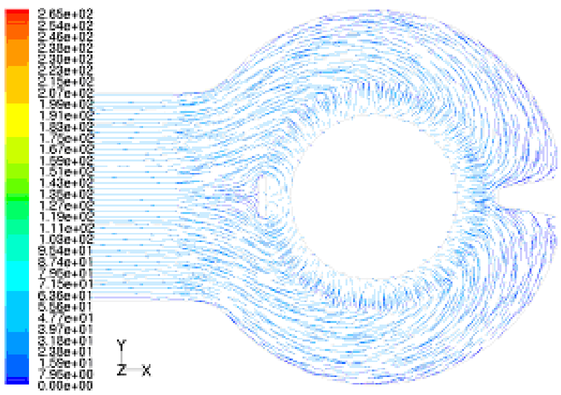

Fig. 11: The flow field in the section of the screen in the area of the circular holes (ε = 0,98)

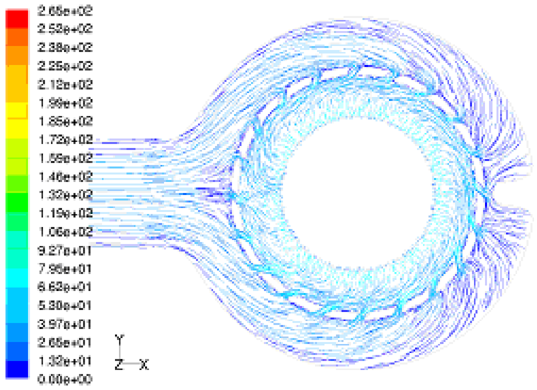

Fig. 12: The flow field in the part of the directional holes (ε = 0,98)

Adjusting the holes in the screen may lead to the certain asymmetry of the flow field. The rib, in this case, helps to fill up the holes on one side better. The conditions are contrary on the opposite side. Cca 80 % of the total mass flow flows through the circular holes in the screen. 20 % of the mass flow flows through the directional holes. The Fig. 13 shows how the flow through the individual notches is different.

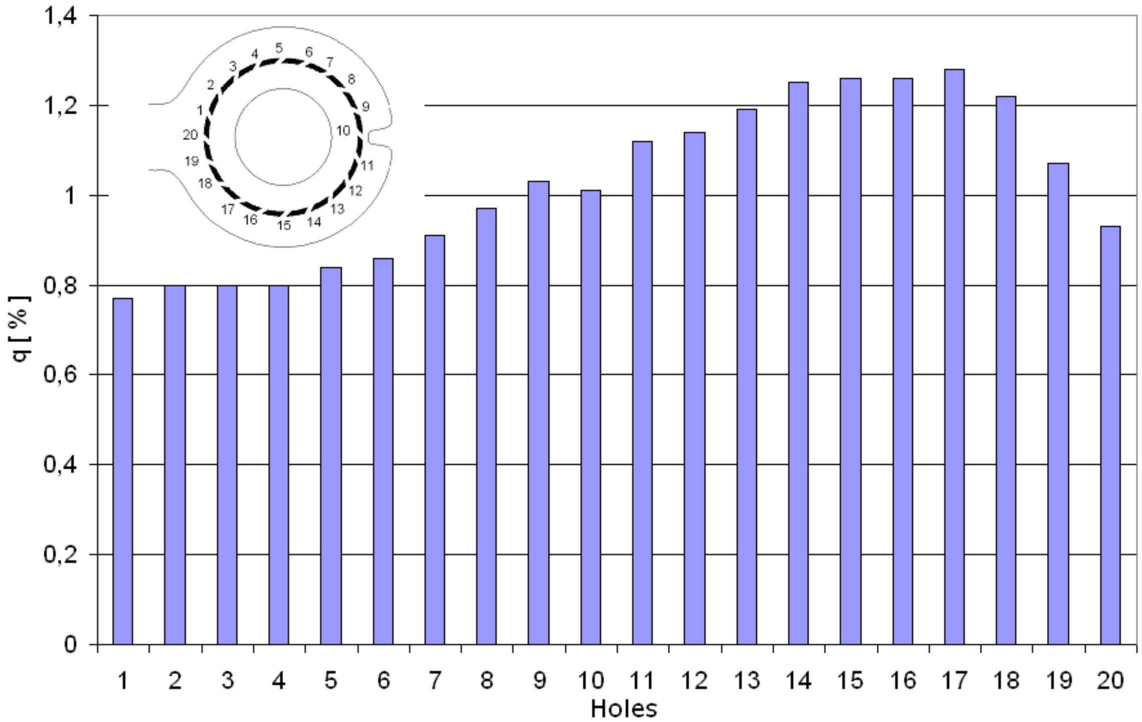

Fig. 13: The distribution of the mass flow in the directional holes of the screen

The differences may be up to ±20 %. The notches in the screen are the source of the certain imbalance in the distribution of the velocity field behind the screen. However, this negative phenomenon is suppressed by the positive influence of the centrifugal force and by the adhesion of the steam flow to the wall of the diffuser under the cone of the valve.The flow separation from the wall would have bigger influence on the losses and on the reliable function of the valve.

The experiments and the calculations performed in MEI (Zarjankin, 2006) demonstrate how important the creation of the balanced pressure distribution and the velocity around the perimeter of the valve is. The different designs of the screens were tested on the model of the combined valve according to the Fig. 3. The explanation of the flow ratios on the valve was also supported by the 3D calculations. In the Fig. 14 there is the velocity field in the fully open valve. Also in this case the zones with the separated flow and imbalanced velocity distribution occur in the valve. When using the screen the velocity field changed significantly. As the Fig. 15 shows, the pressure and velocity field were even.

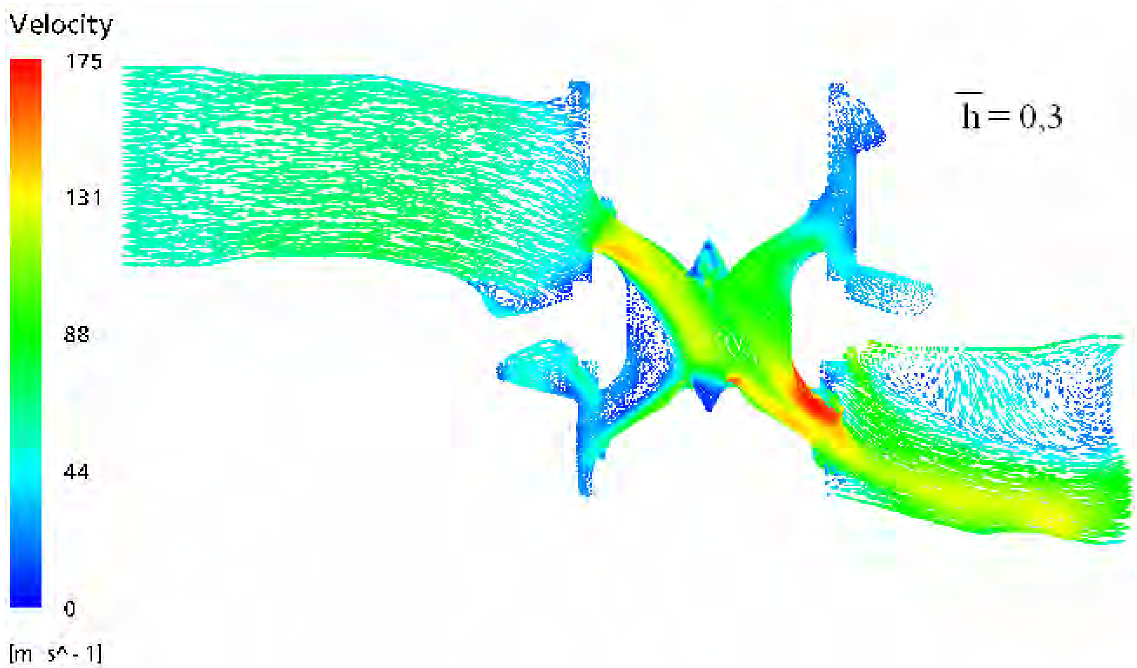

Fig. 14: The velocity field in the combined valve without the screen

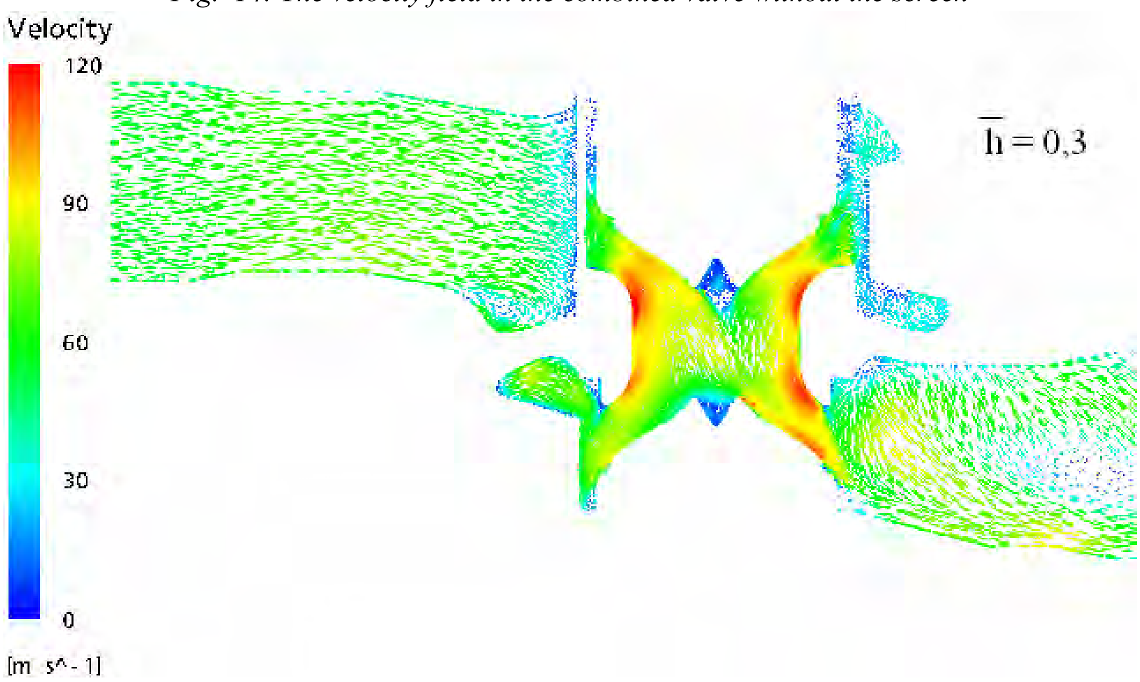

Fig. 15: The velocity field of the combined valve with the screen

Within the experiment with the combined valve the screen with the parts having the different size of the holes around the perimeter was used. The core idea is based on the imagination that in the section being opposite the intake pipe, the greater dynamic pressure shall be applied than on the opposite side. Smaller holes or the blind part of the screen oriented against the intake could contribute to the balanced flow field. The results of the experiments are for $\overline{h} = 0.3$ shown in the Fig. 16 and Fig. 17.

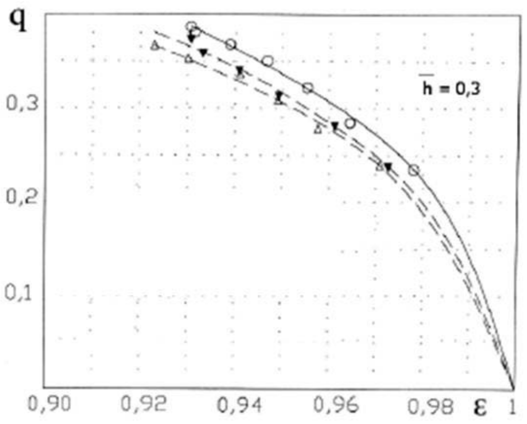

Fig. 16: The influence of the screen on the mass flow

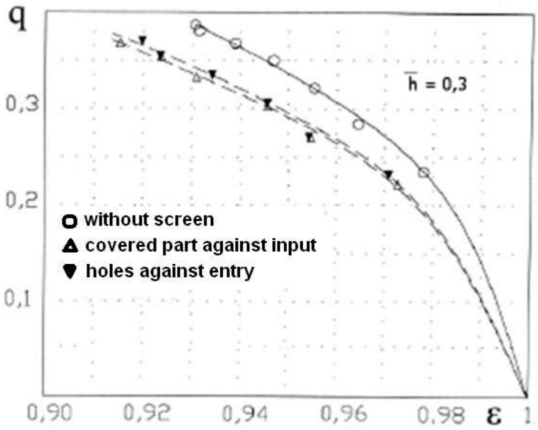

Fig. 17: The influence of two screens on the mass flow

The combined valve without the screen has the pressure loss representing 4 % of the input pressure when the valve is fully open. However, there is the uneven velocity field in the valve. After using the screen the pressure loss increases up to 4.5 %. Covering the holes oriented against the entrance leads only to the increase in the pressure loss. Therefore this modification is not very suitable. When using the screen in the control and quick shut-off valve the pressure loss increases up to 5.4 % in the input pressure. From the practical point of view one screen seems to be sufficient. Even after using one screen the pressure and velocity fields are balanced.

The shape of the cone influences not only the total pressure loss in the valve, but also the axial force acting on the spindle. In the profiled cone the intensive impact phenomenons and pressure jumps particularly at higher values of Mach´s figures occur. The high frequency vibration of the valve and of the supply pipes to the turbine may occur. The usage of the flat bottom of the cone and installation of the additional screen (a muffler) to the basic screen contributed to the reliable function of the valve in the transonic flow. The original and new design of the valve is shown in the Fig. 18 and Fig. 19.

Fig. 18: The control valve with the profiled cone

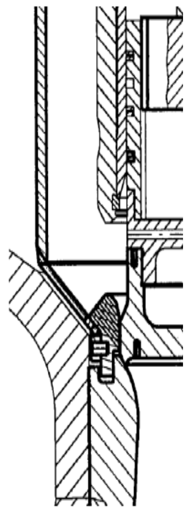

Fig. 19: The control valve with the flat bottom and a muffler

The Fig. 20 ÷ Fig. 22 show how the flow characteristic of the valve changed.

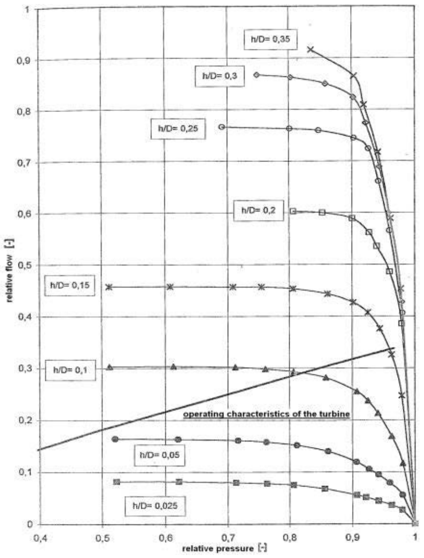

Fig. 20: The flow characteristic of the original valve

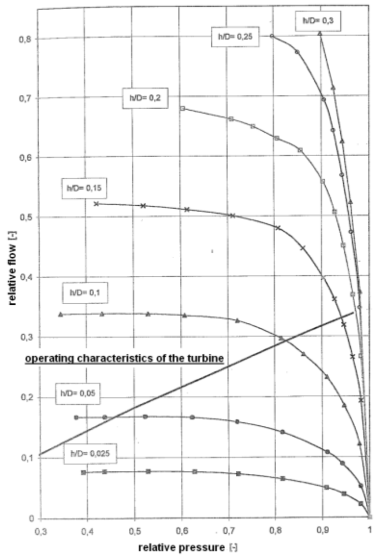

Fig. 21: The flow characteristic of the valve without a muffler

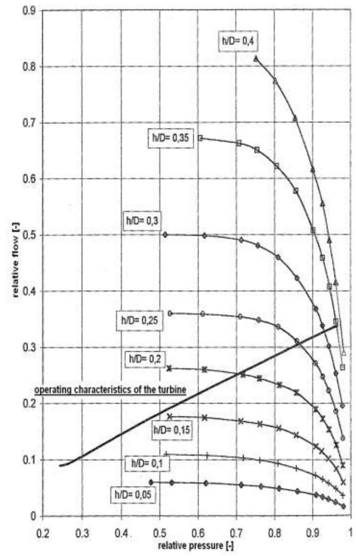

Fig. 22: The flow characteristic of the modified valve with a muffler

To reach the same mass flow it is necessary to set a higher lift of the cone. The changes also concern the needed pressure ratio. However, it is substantial that a muffler enables to measure the vibration of the pipes. The reliable operation of the turbine is in the certain case more important than the pressure loss in the valve. The reduction of the acceleration measured in the valve before and after installation of a muffler is demonstranted in the Fig. 23 and Fig. 24.

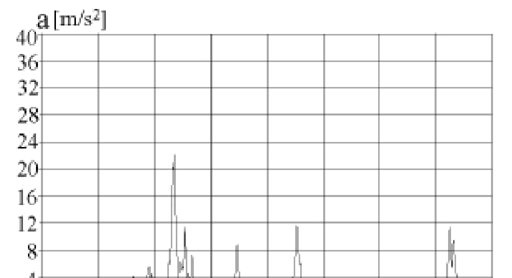

Fig. 23: Acceleration in the valve without a muffler

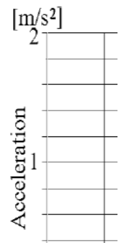

Fig. 24: Acceleration in the valve with a muffler

After the changes had been implemented, the character of the velocity field before the cone changed. This is also proved by the conclusions of the numeric studies (Kočárník, 2012). In the Fig. 25 there is the distribution of Mach´s figures under the original profiled cone. The separation of the flow from the wall of the diffuser is well visible. The muffler contributed, as the Fig. 26 shows, to stabilization of the flow nearby the wall of the diffuser. The muffler plays the similar role here as the notches on the screen making the part of the steam flow rotate. The issue concerns particularly the lightweight control valves, where the steam discharge from the bypass valve in the middle part of the big cone may help, due to the ejection effect of the flow, to separate the main flow of the steam from the wall of the diffuser.

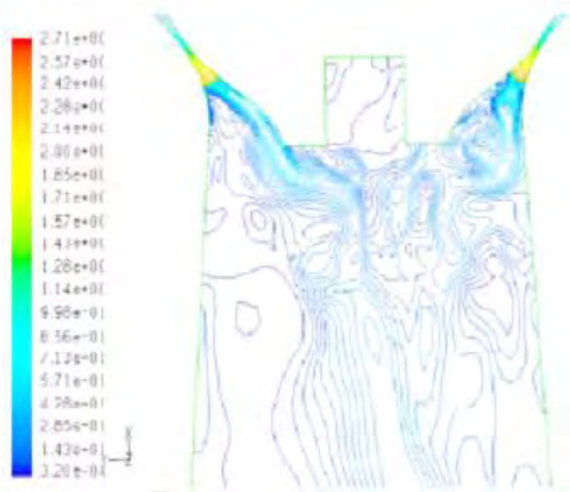

Fig. 25: The flow field in the original valve

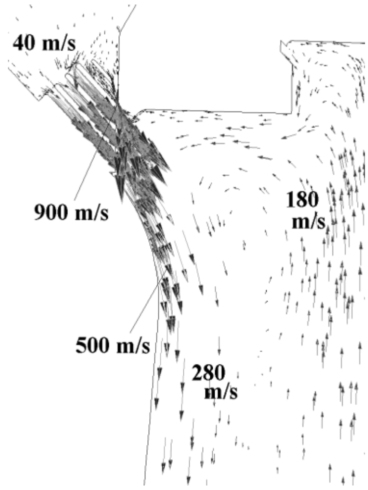

Fig. 26: The velocity vectors in the valve with a muffler

The experimental verification of the properties of a new design of the lightweight control valve has been carried out. The flow characteristics for the valve with the screen and without the screen have been obtained. They are shown in the Fig. 27 and Fig. 28.

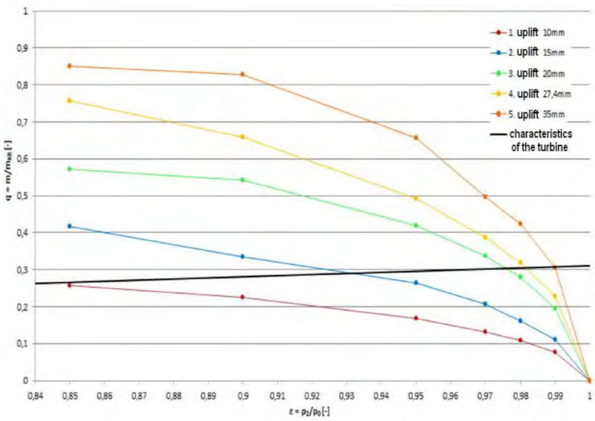

Fig. 27: The flow characteristic of the valve without the screen

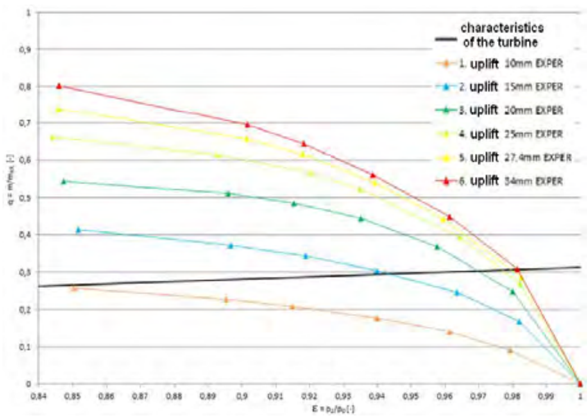

Fig. 28: The flow characterstic of the valve with the screen

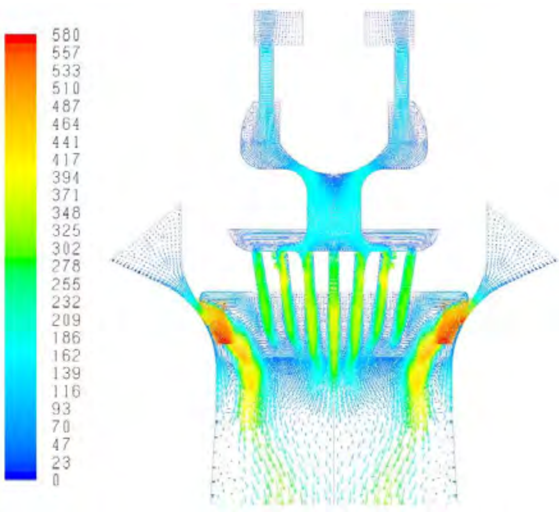

Fig. 29: The central steam discharge from the bypass valve

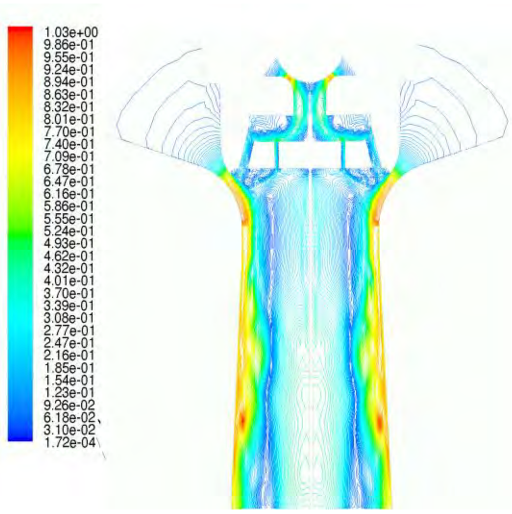

Fig. 30: The peripheral steam discharge from the bypass valve

The creen in this case does not have the directional notches. Thus, it is not the source of the partial rotation of the flow under the cone. For a stated flow of the valve the flow area through the valve is the same as the area in the diffuser throat, whereas the cone lift is 27.4 mm. When the cone lift is higher, the influence of the increase in the area under the cone on the regulation of the mass flow may not be effective. For the variant of the valve with the screen this assumption is proved. However, this does not apply to the valve without the screen. Due to the uneven distribution of the pressures and the velocity in the valve the valve may regulate the steam flow even when the lift of the cone has the greater range. In the relatively low mass flows the pressure loss on the screen is insignificant and the influence of the flow in the valve is unimportant. To prevent the separation of the flow from the wall of the diffuser, it would be required to use the screen with the notches or to stabilize the flow along the wall differently. Instead of the central steam discharge from the bypass cone the discharge on the perimeter of the big cone may be used. The numeric studies (Matas, 2006; Kočárník, 2012) showed a positive effect of this arrangement. In the Fig. 29 there is the flow under the cone in the central steam discharge. The Fig. 30 shows the flow with the steam discharge along the perimeter of the cone. The different character of the flow is apparent.

3. Conclusions

The muffler in the lightweight valve helps to stabilize the flow under the cone and it prevents the separation of the flow from the wall of the diffuser.

The steam discharge from the bypass valve in its central part helps, due to the ejection effect, to separate the main flow from the wall of the diffuser. It is the source of the impulses, the pressure pulsations and the vibrations of the pipes.The location of the discharge in the peripheral part of the big cone helps to stabilize the flow along the wall of the diffuser. It plays the same role as the muffler or the flow rotation.

The valves without the screen show the lowest pressure loss. They appear to have greater uneveness of the velocity and the pressure field or step changes in the pressure.

The screen helps to balance the velocity and the pressure fields in the valve. It is the source of the pressure loss, which may be 0.2 ÷ 0.5 % of the input pressure.

The screen with the directional holes for the air rotation has better aerodynamic properties than the screen with the drilled holes.

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