20th International Conference
ENGINEERING MECHANICS 2014
Svratka, Czech Republic, 12 – 15 May 2014

EXPERIMENTAL VALIDATION OF THE AERODYNAMIC FORCE ACTING ON A CONE OF A BALANCED CONTROL VALVE

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Abstract: *This is the description of an experiment focused on the determination of the aerodynamic force acting on a cone of a balanced control valve. The force determined from the pressures is compared with the force acquired from the strain gauge measurement. Two variants of the operating characteristics of a turbine are considered. A force conversion measured on a model to the forces acting on a real design of a valve is stated.*

Keywords: Turbine, Valve, Aerodynamic Force.

1. Introduction

The force required to separate a cone of a control valve off a saddle is proportional to the pressure difference on a cone and a contact surface. The valve stem, apart from the aerodynamic force, is also affected by own weight of movable parts of a valve, by the force from a pressure spring and by the friction force from sealing elements. There is a certain type series of actuators. If operating parameters of a turbine require valves with the power parameters exceeding the capacity of an actuator, it is necessary to implement a higher number of unbalanced valves or to use a balanced control valve.

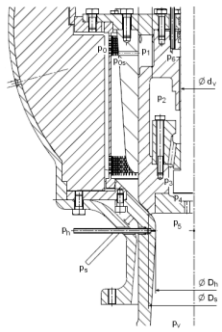

Fig. 1: Scheme of a control valve.

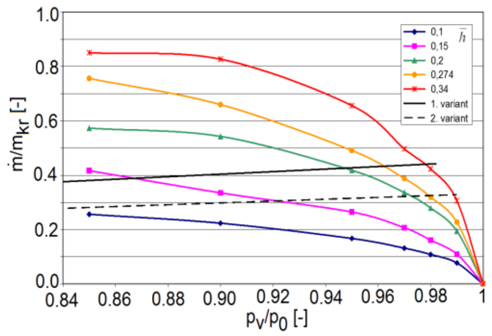

Fig. 2: Flow characteristics of a valve without the screen.

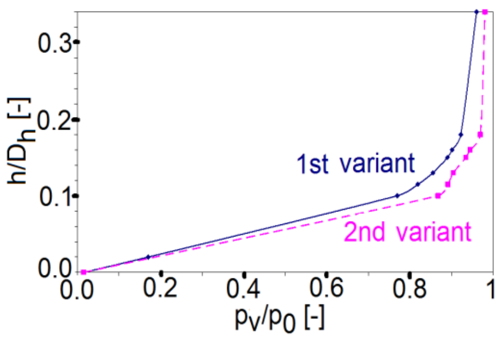

Fig. 3: Operating characteristics of a turbine.

A balanced valve comprises an inner bypass valve enabling to decrease the contact pressure acting on a cone and facilitating a cone to be separated off a saddle. A steam flow to the bypass valve is enabled through a ring slit, which reduces the pressure in the space under the slit. The aim is to ensure the chambers under the bypass cone, when the stem being separated off a saddle, to be emptied faster than the chambers out of this area. In order to be able to validate a design variant of a valve, a model in scale 1:1 was created.

2. A Model of a Balanced Valve

A design of a balanced valve is shown in the Fig. 1. Through the apertures in a guiding sleeve the steam also flows to the inner space to a bypass valve. There is the pressure p_1 above the part of a cone. After

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flowing through the slit the pressure is reduced to the value p_2. In the vicinity of the bypass valve the pressures p_3 and p_4 are set up. The pressure p_5 acts on the bottom of a large cone. The output pressure in the diffuser is shown as p_v. All above said pressures, with the exception of the pressure p_5, may be directly measured on a model of a valve. Apart from the above said pressures, there is also a tendency to record the pressures in the diffuser throat p_h and on the wall of a saddle p_S. In case of a higher elevation of a large cone an input slit opens and the pressures p_1 and p_2 become equal. However, at the same time the steam supply to a cone of a bypass valve closes. Then it is also reasonable to measure the pressure p_6. In such a case the pressures p_3, p_4 and p_6 should be similar to the pressure p_5. On a model of a valve by using strain gauges the contact force of a cone to the stem as well as the aerodynamic force acting on the stem is measured. A valve is connected to the suction of an aerodynamic tunnel. By changing the speed of the compressor the required pressure at the outlet from a valve is set up. The pressure ratio is fluctuating in the range $p_v / p_0 = 0.3 \div 1$. The input pressure is similar to the barometric pressure. However, the input pressure is much higher on the piece of work. In order to determine the total mass flow of a valve, a diaphragm being a part of an aerodynamic tunnel is used.

3. Findings from the Experiments

For a certain type and geometry of a valve there is a general flow characteristics shown in the Fig. 2, which is universal for the various media (the air and steam) as well as for the different dimensions of a valve. Only an entire geometric similarity is required. The results were confirmed by the calculations (Hajšman, 2011) as well as by the experiments. A general flow characteristics shows the dependence of a proportional mass flow $q = \dot{m}/m_{kr}$ on the pressure ratio $\varepsilon_v = p_v / p_0$ (a note: m_{kr} is a theoretical critical mass flow considered for the diffuser throat behind a valve, p_v is the pressure behind a valve and p_0 is the input pressure). Given values belong to constant $\overline{h_p} = h/D_h$, which is a real elevation of a large cone related to a diameter of the diffuser throat D_h.

A steam turbine creates one unit with a control valve. According to the required performance of the turbine, on the valve using the elevation of a stem a certain mass flow and the pressure ratio is set up. By this the pressure before the turbine itself is set up too. In the Fig. 2 there are also shown two variants of an operating characteristics of the turbine. The first variant ensures a higher mass flow, but the lower pressure before the turbine. However, in the valve itself the higher contact force of a large cone is applied on the stem. The other variant shows at full valve opening a higher proportional pressure p_v / p_0, thus a lower loss in the turbine. However, the contact force on the movable parts of a valve is lower. There is a unified product series of valves due to which it is always necessary to decide whether it is better to choose bigger dimensions of a valve with the higher output pressure or smaller dimensions of a valve with the bigger contact force and bigger losses. In the Fig. 3 there is shown an elevation of a cone of a valve $\overline{h_p} = f(\varepsilon_v)$ for a considered operating characteristics of the turbine. In the conditions close to the certain operation of the turbine a small change of the pressure ratio corresponds to a big change of setting a large cone. A wide range of the change of the turbine performance (it concerns particularly starting and approaching the performance) occurs at the small range of the cone elevation.

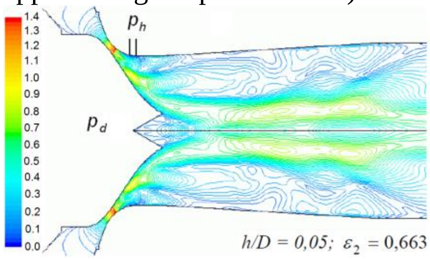

Fig. 4: Valve with a shaped cone.

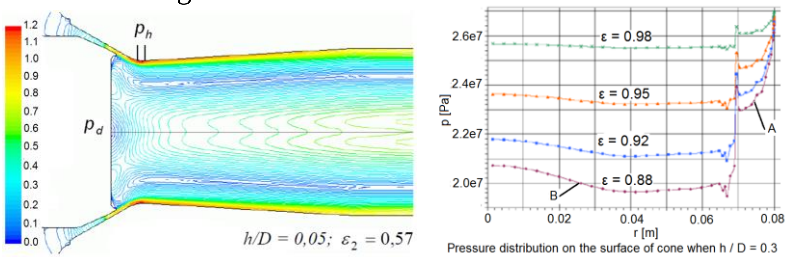

Fig. 5: Valve with cone with flat bottom.

A big emphasis is placed on the operational reliability of the valves. A correct function must be guaranteed also in case the gravitational forces act against the aerodynamic force acting on a cone of the valve. A step change of the position of a cone against a stem may cause the change in a flow area and due to this a step change of the turbine performance. Therefore, the contact force from the pressures on the surface of a cone is required to be in all modes of a turbine reasonably higher than a relevant gravitational force is. The gravitational force is permanent, but the aerodynamic force depends on the turbine operation A minimum contact aerodynamic force occurs under the nominal operation conditions of the turbine. A contact aerodynamic force may be influenced by an appropriate shaping of the cone bottom and by controlled distribution of the pressure on its surface (Matas et al, 2010; Hajšman et al, 2011; Jirka, 2007). A shaped cone shows the highest contact force. This is shown by the Fig. 4. If an expanding steam adheres to the surface of a cone, the pressure decreases on its surface and due to this the contact force gets higher. A drawback of this shaping is the existence of a ring Laval nozzle. Under the above-critical pressure conditions continuing under the low elevation of a cone, the unsteady flow, with the occurrence of shock waves accompanied by intense vibrations, arises. Even the destruction of pipelines may occur. The better reliability is shown by cone with flat bottom, which is shown by the Fig. 5. Cone with flat bottom enables to stabilize the flow conditions under the cone, however, there is a lower contact force. The lowest pressure is not on the cone bottom, but in the place of the wall of the diffuser throat.

A certain instability may occur within the transition from the subsonic to transsonic field of flowing. It is related to the occurrence of shock waves and to a possible separation of the flow off the surface of a cone Fig 6 shows how the force acting on the cone with the flat bottom in a balanced valve being designed according to the Fig. 1, under the permanent elevation $\bar{h} = 0.115$ and a fluent change of the pressure ratio $\varepsilon_v = p_v / p_0$ changes. The friction forces between a guide sleeve and a cone appear to act on a cone too. A cone loading is, therefore, organized so that the loading force could increase gradually. Evaluation of dependencies was carried out only from one branch of the loading characteristics. The effect of shock waves after the occurrence of the transonic flow on a cone with the flat bottom is transferred. The influence of vibrations of an aerodynamic tunnel as well as possible resonance between own frequencies of the suspension of a valve with the frequencies from the compressor speed and the gear box of a sucking system of an aerodynamic tunnel shows up.

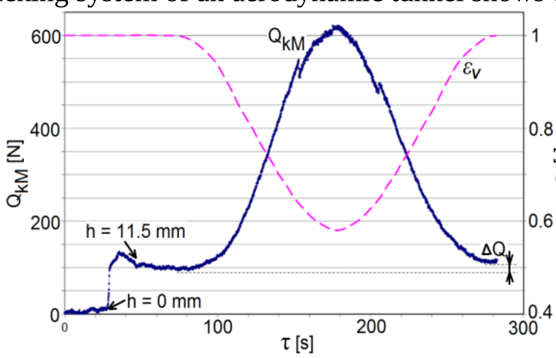

Fig. 6: Force on a cone with the flat bottom.

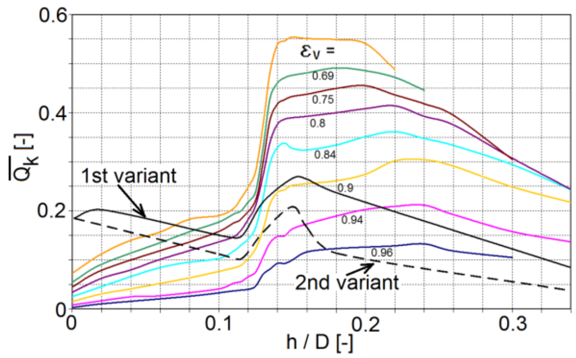

Fig. 7: General force characteristics of a valve.

The dimensionless force acting on a cone is the function of the relative elevation and the pressure ratio.

$$\overline{Q_k}(\varepsilon_v, \bar{h}) = \frac{Q_k}{p_0 s_s} \tag{1}$$

whereas $Q_k = f\,(h, p_0, p_v, S_S)$ is a real force acting on a cone, p_0 is the input pressure, p_v is the output pressure, h is an elevation and S_S is an area of a saddle.

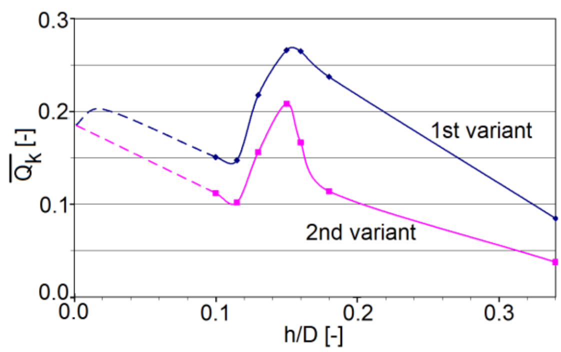

Fig. 8: Operational force characteristics.

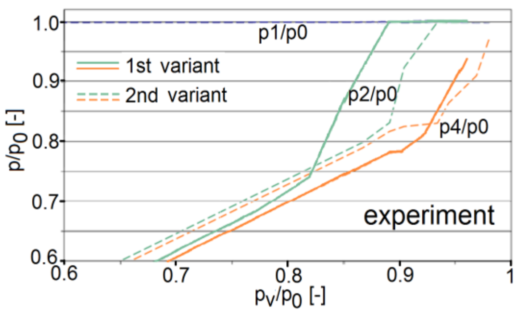

Fig. 9: Pressure ratios in inner chambers of a balanced valve.

In order to be able to determine the contact force of a cone for a particular operational variant of a valve and its dimensions, it is required to specify a general dimensionless force characteristic, which is for a certain valve specified in the Fig. 7. The operating characteristics for both chosen variants of the turbine operation are described in the Fig. 8. The transition from an area when a valve works as balanced one to the area of an unbalanced valve is highly evident. The pressure distribution in inner parts of a valve is shown in the Fig. 9.

The distribution of the pressure ratios shows three characteristic parts. An initial phase of the valve opening is influenced by shortening the length of the slit, which is finished by its entire opening. The pressure p_2 is gradually equalizing with the pressure p_1. The other pressures are similar to the pressure p_2. Under the further movement of a cone the inflow of the steam to the bypass valve begins to close down. The pressures p_3 up to p_6 are getting to be equal. After the entire closing of the flow, the pressures p_3 up to p_6 are practically the same. In the first variant the bigger differences of the pressures p_1 and p_4 occur, which proves the higher contact force. In the other variant the difference of the pressures acting on a cone decreases.

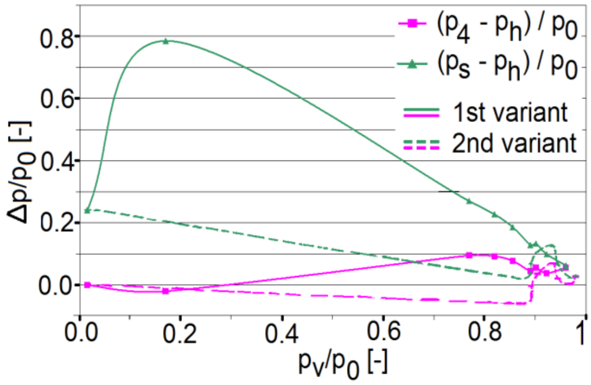

Fig. 10: Pressure differences around a saddle and the diffuser throat of a valve.

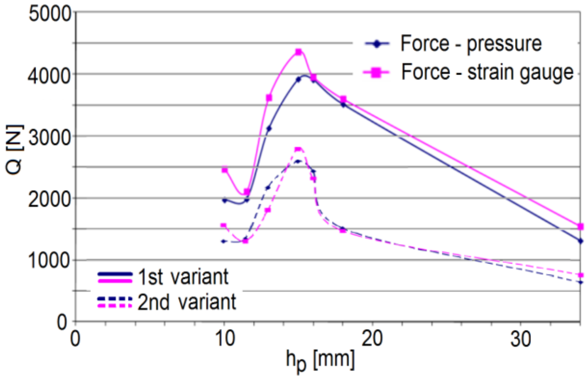

Fig. 11: Contact forces acting on a cone of a balanced valve.

The experiment does not allow to measure directly the pressure p_5 acting on the bottom of a cone. However, from the carried out calculations (Hajšman, 2011) it is known to be comparable with the pressure p_4, which is measured. On the model of a valve the pressure loss on the perforated wall is recorded as well as the pressures in the diffuser throat and in the part of a saddle. Their changes depending on the operation pressure ratio p_v / p_0 are shown for both variants in Fig. 10. The pressure in the place of a throat is the lowest when the pressure bypasses without being separated off the wall. The pressure in the diffuser throat p_k may be measured easily. By using the diagrams in the Fig. 10 the pressure on the bottom of a cone as well as in other modifications of valves may be estimated. The result of the comparison of the measured and calculated contact forces on a cone from recorded pressures is shown in the Fig. 11. The comparison was carried out for input parameters of the steam considered for the regulation of the turbine performance installed in a laboratory, which is p_0 = 14 bar. Experimentally determined data are converted into these parameters. The forces calculated from the measured pressures acting on the certain area of a valve are considered. This determined contact force corresponds to the contact force directly measured by strain gauges.

4. Conclusions

- A tested valve fulfils the requirements for the decrease of the contact force at the start of a turbine.
- By choice of a valve from a unified production series the pressure loss on a valve as well as the size of a contact force on a cone may be influenced.
- In transition from the subsonic to transsonic area a valve is sufficiently stable.
- The forces determined from the pressures correspond directly to the measured forces.

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