ON CHARACTERISTICS OF A CONTROL VALVE OPERATING IN TWO-PHASE FLOW REGIME

Michael P. Levitsky

Institute for Industrial Mathematics
4 Ha-Nachtom Str., POB 15013, 84311 Beer-Sheva, Israel

Introduction

Regulating and shut-off valves make up considerable part of the equipment for multiphase flow control in modern industry, power plants, mineral extraction, in pneumohydraulic sections of various mechanisms etc. They can be used for maintaining preset flow rates under constant high resistance as well as to modify the resistance and flow rates by moving or turning the final-control element of the system according to a given program.

Improvements in production processes and raising of the power plants capacities have brought about increase in the parameters of working media, in particular flow rates, pressures and pressure differences at which the valves operate. This have led to considerable increase in dimensions, weights of the valves and power required for their control that reduces service life. The latter is especially important when such valves operate at high hydraulic resistances. The main reason for this is that their typical design was not changed substantially in the recent decades. The developments were confined to improvements in the design of certain elements, in particular those that make the valves more leak-proof when shut, easier to manufacture, etc. But their properties that determine the control power have remained unchanged. In the case of large diameter and large pressure drop pipelines it proves to be a serious limiting factor, because it makes the equipment too bulky and consuming too much power.

Developing of small-size equipment intended for operation under severe conditions of large pressure drops that can be used with low-power drives, is vital for heat and atomic power plants, space and aircraft engines, chemical industries, gas and oil transport, shipbuilding, etc.

Analysis of the existing problems in hydraulic control equipment for high pressure and flow rate multiphase transport pipelines shows that development of a new valve capable to provide high hydraulic resistance (about 30 - 40 MPa and even more, if necessary) represents now a vital task.

The operation of hydraulic control equipment under high pressures is characterized by vibration, flow rate pulsation, erosion of the operating units, noise[1]. This reduces the valve's service life and raises the power consumption by the drive. To overcome these drawbacks the valves, using multi-stage throttling, have been designed that helps to lower the vibration and raises the valve's reliability. For example can be mentioned two-seat valve[2]. However, solutions of this kind are complex both in design and technology. Besides, such valve is not effective enough in ensuring uniform distribution of hydraulic resistance between the stages that complicates the use of the valve also as a shut-off element.

Valves for handling high pressure differences are known in which the stream is divided into a large number of streamlets throttled by a single final-control element - the so-called cassette valves. But such a design does not ensure pipeline tightness when the valve is shut. Besides, for design like this it is not easy to ensure required flow rate characteristics relative to translation or angle movement of the control element.

Last time for flow control in the above conditions were suggested valves using swirling flows, which have a number of advantages. In the paper are discussed operation parameters of such a valve and methods for improvement of its characteristics.

The hydraulic characteristics of an orifice with swirled outflow

The important feature of flow in the control valve is connected with possibility of cavitation in the throttle orifice that highly affect the device performance. To avoid the former it is necessary to analyze conditions for its appearance.

Theoretical determination of the critical cavitation number is a very complicated problem even in the simplest cases of a plane flow. For swirled outflow through orifice the cavitation characteristics have been investigated so far only experimentally.

Let us consider a swirled flow of ideal liquid through an orifice and introduce the equivalent cavitation number K_{eq}. The geometry of the flow is characterized by the radius of the supply pipeline R, the radius of the axial swirl $r_m = R - H$, where H is the radial thickness of the swirling liquid column; and the difference h between R and the radius of the outlet channel, r_n. For such a flow in the paper is received relation, connecting cavitation number, device geometry and flow parameters. The result has the form:

$$K_{\mathrm{eq}} = \frac{\Gamma^2}{V^2}\left[\frac{1}{(R-H)^2} - \frac{1}{(R-h)^2}\right] + \frac{P_{ex} - P_v}{\rho V^2 / 2} \quad (1)$$

Here P_{ex}, P_v are the exit and water vapor pressures; V – the flow velocity; Γ - the swirl intensity. As can be seen from equation (1), the swirling of flow raises the equivalent cavitation number and therefore the cavitation reserve of the orifice also grows. Equation (1) can be modified in order to introduce hydraulic parameters, usually used for characterization of flow through a valve. The final form of this relation is:

$$K_{\mathrm{eq}} = A^2\left(\frac{c^2}{\varphi'} - 1\right)^2 \varphi\varphi' + \frac{2(P_{ex} - P_v)}{\rho V_m^2}(c^2 - \varphi')^2 \quad (2)$$

$$A = \frac{R r_n}{r_{en}^2}; \quad \varphi' = 1 - \varphi; \quad c = \frac{r_1}{r_n}; \quad V_{\mathrm{m}} = \frac{m}{\rho \pi r_n^2}.$$

Here m is the mass flow rate, φ - the flow rate factor, r_{en} – the entrance radius and r_1 represents the conditional radius within the swirl, corresponding to appearance of the axial component of flow velocity.

Experimental results

The experimental investigations were carried out on a model vortex chamber with the radius R_v = 45 mm. The chamber design permitted the installation of separable inlet and outlet nozzles of various diameters. In the tests the inlet nozzles were used with radii r_{en} = 9, 11 и 12.5 mm. The cavitation characteristics were obtained for one outlet nozzle having radius r_n = 8 mm. For interpretation of experimental data the equivalent critical cavitation number K^*_{eq} was introduced analogous to K^*_V. The values of K^*_{eq}, calculated in accordance with experimental results, were K^*_{eq1} = 2.93, K^*_{eq2} = 2.94 and K^*_{eq3} = 2.88, respectively. These values were compared with the value of critical cavitation number K^*_V, found theoretically in[3] for the flow in a plane channel with protrusion on the wall. It was shown that the calculated value of K^*_{eq} is close to the theoretical value of K^*_V.

The stabilizing influence of flow swirling on the calibrated orifice characteristics was studied also for a vortex chamber with the parameters R_v = 22, r_n = 0.75 and r_{en} = 1 mm. In the tests the cavitation characteristics of device were received both for pure axial flow and for flow with swirling. To check the effectiveness of flow swirling before the orifice, the latter was made with the ratio $\frac{l}{r_n} = 20,$ whereas in the case of axial flow the same parameter value have been choused equal to 4. Here l is the length of the orifice. The tests of the vortex chamber at P_{en} = 30 MPa and atmospheric external pressure have showed the absence of cavitation in the swirled outflow and its presence in the case of pure axial flow to the orifice. This result confirms stabilizing influence of flow swirling, while the relations received permits to estimate the effect quantitatively.

CONCLUSION

1. The equation, relating cavitation number and parameters of the vortex chamber has been obtained, based on the experimentally verified model for the flow structure in a vortex chamber. The experimental cavitation characteristics of vortex device confirm stabilizing influence of swirling on the outflow at high pressure differences.

2. The results of theoretical analysis and experiments have shown that the value of critical cavitation number depends only from the ratio of the orifice radius to the vortex chamber radius and grows when this ratio is increased.

3. Theoretical results and experimental data, reported in the paper, can be used at design and simulation of highly efficient valves for multiphase flow control in the modern hydraulic equipment.

REFERENCES

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