Journal of Urban and Environmental Engineering, v.12, n.2 , p.231-235

ISSN 1982-3932

doi: 10.4090/juee.2018.v12n2.231235

Journal of Urban and Environmental Engineering

www.journal-uee.org

HYDRAULIC CHARACTERISTICS OF TAP VALVE WITH A FLAT CLOSURE MEMBER

Alexander P. Svintsov[1*] and Nikolay A. Konoplev[2]

[1,2,3]*Department of Architecture & Civil Engineering of Academy of engineering, Peoples' Friendship University of Russia (RUDN University), Russian Federation*

Received 27 February 2018; received in revised form 06 September 2018; accepted 16 September 2018

Abstract: Valves with high regulating capacity can significantly reduce the loss of tap water. The hydraulic characteristics of liquid discharge through orifice in the form of a "curved drop" made in thin walls of tap valve closure member are determined by theoretical and experimental studies. The relationship of the change in water flow rate for tap valves with orifice in the form of a "curved drop" to varying pressure is established. The comparison of flow characteristics for tap valves with closure members having a different shape of through hole is made. The obtained hydraulic coefficients allow to design the valves with a high regulating capacity. The results of the study are of interest for theoretical and practical tasks of designing and manufacturing valves for water supply. The use of closure members with a hole in the shape of a "curved drop" allows to reduce the loss of tap water of drinking quality. The study is ongoing.

Keywords: Water fittings; valve; water flow; discharge; closure member; disc pair; hydraulic characteristic

* Correspondence to: Alexander P. Svintsov.
E-mail: svintsovap@rambler.ru

INTRODUCTION

Improvement of the hydraulic characteristics of valves is an important task in reduction of water loss and efficient use of water resources. Fittings for water supply with high regulating ability reduces the loss of tap water by eliminating its unproductive runoff.

Hydraulic characteristics of valve closure member are important for ensuring economical use of tap water. The basis of determining hydraulic characteristics of valves are experimental studies or the use of methods of mathematical modeling.

Study of hydraulic characteristics of liquid outflow by methods of mathematical modeling allow us to determine the local resistance coefficient ζ, coefficient of velocity φ, coefficient of contraction ε, coefficient of flow μ with certain accuracy (Deo, 2013; Posohin *et al.*, 2016; Hussain *et al.*, 2014). Formal parameters are the central part of the mathematical model of a hydraulic process. The main difficulty of mathematical study lies in the fact that accurate formal presentation of the studied physical process requires information on the distribution of velocity and pressure at the inlet and outlet of the local resistance (Posohin *et al.*, 2012; Kondrat'ev, 2010). Addition of a specifying component to the mathematical model does not always lead to the increase of its adequacy for the studied hydraulic process.

Experimental studies allow to identify the change of hydraulic characteristics of liquid outflow through holes and nozzles, depending on their geometric features (Zvyagincev, 2016; Barringer *et al.*, 2013; Saha *et al.*, 2014), which form their hydraulic parameters (Kuznecov *et al.*, 2014; Dey, 2014). Researchers have presented hydraulic characteristics of water outflow through round holes with different features of their geometric parameters (Hussain *et al.*, 2016; Hashid *et al.*, 2015). In external cylindrical nozzles and pipes the relationship between the hydraulic characteristics of liquid outflow and the geometric parameters of the holes of non-circular shape in a thin wall is revealed (Dey, 2014; Ghahremanian *et al.*, 2014). The study of liquid outflow through holes of non-circular shape (Pil'gunov & Efremova, 2015) establishes that their throughput is on average 10% higher than the throughput of round holes. The results of the study of water flow through holes with a smoothly changing shape and in the shape of a "curved drop" are presented in articles (Svintsov *et al.,* 2015, 2016). However, quantitative assessment of the influence of the hole shape of valve closure members on the hydraulic coefficients are not presented.

Currently, the behavior of liquid outflow from holes of round, square, triangular, rectangular, cruciform shape has been well studied. However, the hydraulic operation of closure member with a hole in the shape of a "curved drop" in the modern scientific literature is not presented.

The aim of the study is to determine the relationships and quantitative values of the hydraulic characteristics of liquid outflow through a hole in the shape of a "curved drop", made in a thin wall of tap valve closure member.

MATERIALS, EQUIPMENT AND METHODS OF RESEARCH

Hydraulic characteristics of the valve and its closure members are determined on the basis of the analysis of the results of the experimental study. Mathematical models, which were used to study the hydraulic characteristics of the holes of a flat closure member:

(a) for the local resistance coefficient ζ:

$$h_f = \xi \frac{v^2}{2g} \qquad \Delta p = \xi \frac{v^2}{2} p \tag{1}$$

(b) for the coefficient of velocity φ:

$$\varphi = \sqrt{\frac{1}{1+\xi}} \tag{2}$$

(c) for the coefficient of contraction ε,

$$\varepsilon = \mu\sqrt{1+\xi} \tag{3}$$

where h_f –head loss in the section of the closure member hole, m; Δp –pressure loss in the hole section, MPa; v – fluid velocity through the hole, m/s; g – gravitational acceleration, m/s^2; μ – flow coefficient; $\mu = f(h,q)$; q – water flow rate, L/s.

To determine the numerical values and the patterns of variation of the local resistance coefficient ζ, the coefficient of contraction ε, the velocity coefficient φ, the flow coefficient μ and the flow rate of water q through a hole in the shape of a "curved drop" an experimental study was performed on hydraulic test stands with the possibility of maintaining pressure from 0.000 01 MPa to 1.0 MPa.

The discs with the hole in the form of sectors, of a segment and a "curved drop" are considered as closure members in the study (**Fig. 1**). The disc pair is installed in a specifically made coupler with a hole diameter of 15 mm. Rubber seals installed in the sockets provide tightness of discs' connection. Counterpart fixed in the mounting socket can be rotated about the longitudinal axis to an angle of 180°. Circular scale with divisions

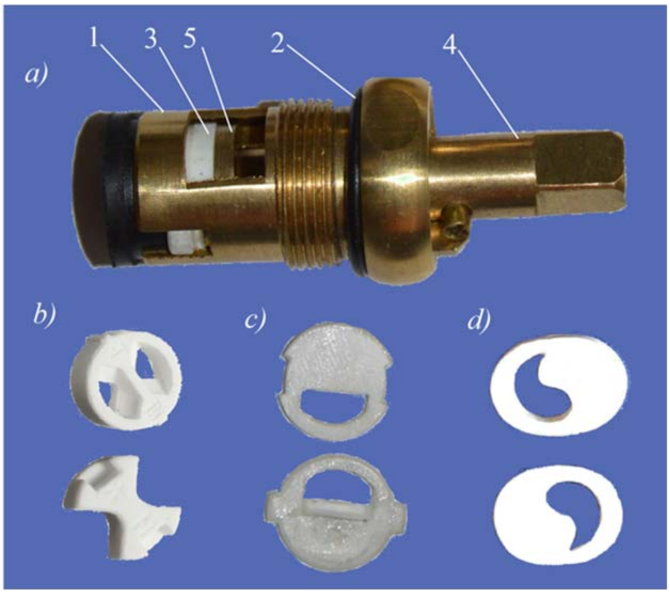

Fig. 1 Appearance of the disc pairs with a different shape of through hole a) tap valve; 1 - casing; 2 –casing seal; 3 –disc pair; 4 – stem knob; 5 – stem; b) sectors; c) segment; d) "curved drop".

of 1° is attached to the coupling to determine the rotation angle. Coupling with the disc pair under analysis is mounted on a laboratory stand.

The tests on the disc pairs are performed at constant pressures of 0.01; 0.05; 0.1; 0.3; 0.6 MPa. A constant pressure of 0.01 MPa was provided by filling a pressure tank to the level of overflow device. Measurement of pressure head was carried out by piezometers with a scale division of 1 mm. Measurement of pressure was performed by a pressure gauge with a scale division of 0.01 MPa. A Measuring container with the volume of w=1*l* and a chronometer with divisions τ=0.1 s were used to determine water flow rate at pressures less than 0.01 MPa.

Constant pressure of 0.05; 0.1; 0.3; 0.6 MPa was maintained by the means of a pump and control valves. The water flow rate is determined on rotameters ∅40 mm and ∅15 mm.

The change of cross-sectional area of the through hole in the closure member is accomplished by turning the handle of the movable disc around its longitudinal axis from 0° to 180° in 10° increments. In the experiments on disc pairs with a passing hole in the form of sectors the handle turn was produced to an angle of 90° in 10° increments.

The minimum number of measurements was determined at each step of the study, in accordance with the plan of the experiment. The method of confidence intervals with reliability γ=0.95 is the basis for determining the sample size. Mathematical processing of the measurement results is accomplished by the methods of mathematical statistics. The empirical mathematical models are developed on the basis of least squares method for regression of a pair of variables. The use of the specified devices, elements and methods of research allowed to obtain statistically significant and reliable data about the change of the hydraulic characteristics of the flat closure member with a through hole in the form of a "curved drop" for water supply fittings.

RESULTS OF EXPERIMENTAL STUDY

The local resistance coefficient from fluid flow through a hole is determined by hydraulic parameters and geometric characteristics. The ratio of the cross-sectional area of closure member through hole ω to the cross-sectional area of the pipe ω_o is taken as the geometric factor:

$$n = \frac{\omega(\alpha)}{\omega_0} \tag{4}$$

ω –cross-sectional area of closure member opening, cm^2; α – the angle of rotation of the disc around central axis.

The particularity of the through hole in the form of a "curved drop" is that its area ω is always smaller than the area of the pipe ω_0, in which it is located. This property must be taken into account in the analysis of the results of the experimental measurements and their comparison with data of classical hydraulics. **Table 1** contains the values of the local resistance coefficient of the hole in the form of a "curved drop" determined experimentally. Experiments have established that the local resistance coefficient changes from ζ_{min}=24 when the passage hole is fully open (n=0.22) to ζ_{max}=165 787 for the minimum area of the through hole (n=0.01).

The coefficient of velocity φ takes into account the pressure loss due to flow of fluid through the hole, characterized by the local resistance coefficient ζ. The coefficient of velocity φ is associated with the local resistance coefficient ζ by a mathematical function **Eq. (2)**. **Table 2** contains the values of the coefficient of velocity φ depending on the relationship ω / ω_{mp} .

The coefficient of velocity changes from φ_{min}=0.0025 for the minimum area of the through hole (n=0.01) to φ_{max}=0.199 at full opening (n=0.22).

It is known from Classical hydraulics that the coefficient of contraction depends on the shape of the hole and the pressure before it. The coefficient of contraction at pressure P=0.05 MPa varies from ε_{min}=0.171 at full opening (n=0.22) to ε_{max}=0.771 at minimum area of through hole.

Diagram of a function of coefficient of contraction for the through hole in the form of a "curved drop" versus Reynolds number is presented in **Fig. 2**.

Table 1. Values of the local resistance coefficient

ω/ω_o	0.01	0.03	0.05	0.08	0.1	0.12	0.14	0.16	0.18	0.2	0.22
ζ	165787	7161	1661	433	229	87	60	43	43	32	24

Table 2. Values of the coefficient of velocity

ω/ω_o	0.01	0.03	0.05	0.08	0.1	0.12	0.14	0.16	0.2	0.22
φ	0.0025	0.012	0.025	0.048	0.066	0.086	0.106	0.128	0.175	0.199

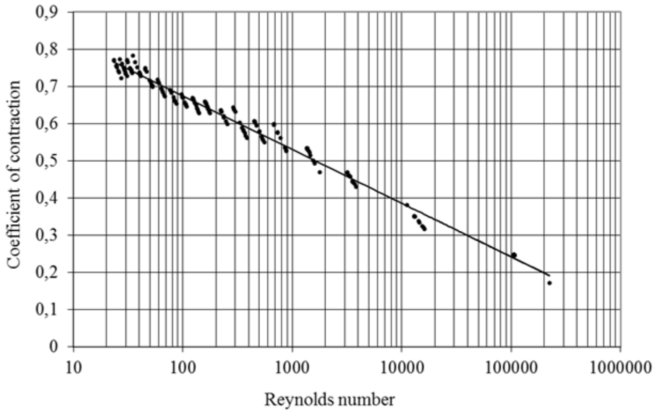

Fig. 2 The relationship of coefficient of contraction ε to Reynolds number.

The flow coefficient μ is one of the most important parameters for analyzing flat closure members. The discharge coefficient μ changes depending on the pressure P and the form of the through hole (Al'tshul', 1982). An experimental study found that at the pressure P=0.05 MPa and fully opened passage hole (n=0.22) μ_{max} equals to 0.205. Flow coefficient μ_{min} equals to 0.011 at minimum area of through hole (n=0.01). The values of flow coefficients are determined through experimental study of the flow at different pressures and constant area of through hole. A diagram of flow coefficient at different values of Reynolds number is presented in **Fig. 3.**

The water flow rate is the main hydraulic characteristic of the tap valve. Valves are designed such that at a given pressure and fully opened through hole of the closure member the required flow rate is provided. However, consumers usually regulate the flow choosing their own preferred discharge. During the configuration process, water is typically not used and is drained to the sewage system. This is loss of water in terms of unproductive consumption. The more time is spent on regulation, the greater the water loss. Therefore, the main characteristic of the closure member is not only discharge, but also its adjustment in the regulatory process. This determines the regulating capability of the valves.

The changes in flow rate through the closure member as a function of the degree of valve opening that was calculated by the developed method is shown in **Fig. 4.**

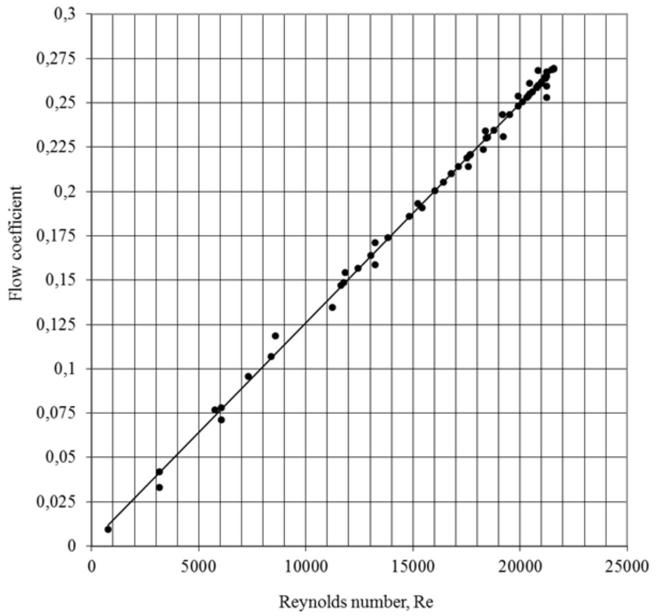

Fig. 3 The relationship of the flow coefficient μ to Reynolds number.

When designing through holes of the disc pairs, attention was paid to ensuring minimal water flow rate at fully opened valve and the pressures of 0.05 MPa and 0.3 MPa.

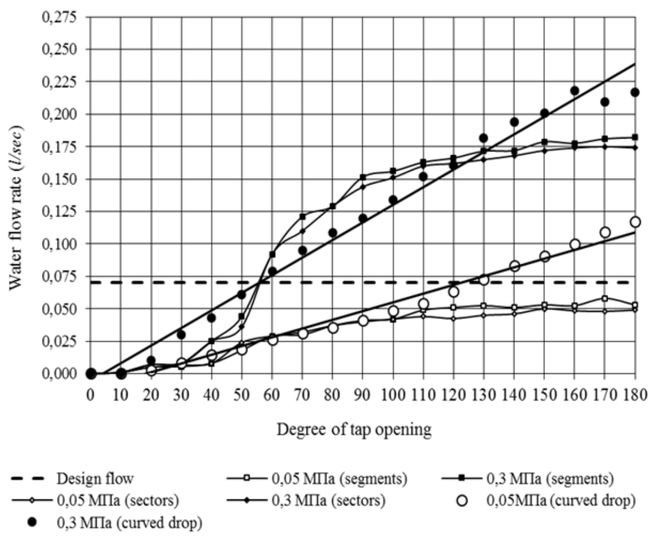

Fig. 4 Water flow rate depending on the degree of tap opening and at different pressures before the valve.

Analysis of the diagrams shows that the estimated discharge of water for disc pairs with through holes in the form of sectors and segment is below the required value on average by 24%. An interval of turning the valve handle from closed position to the point when, the water discharge is very small, is a characteristic feature of the discs. We called this interval "dry-running", which is about 20° of the handle rotation, after which water discharge varies in a regular quadratic pattern. The presence of so-called "dry run" and an abrupt transition to the square-law increase in water flow rate as the valve opens has a negative effect on the regulating capability of the valves. The authors attribute this to the fact that a consumer turns the knob and waits for the flow of water, but in the initial period the water is not received. As a result, one spends more time adjusting than if the water flow rate could vary linearly (or similar to it). This leads to wasteful spending, which increases with pressure.

Estimated flow rate of water through the orifice in the form of a "curved drop" is on average 64% higher than required by design. In the interval of rotation of the knob by the first 20° there is also the presence of "dry run". After that water flow varies according to the law close to linear. Linear change of the water flow rate depending on the rotation angle of the handle of tap valve (depending on the opening of through hole) at all pressures in the network of internal water supply systems of a building allows the user to set the desired water flow rate with the desired temperature much faster. Experimental check of the valves in operating conditions have shown their high efficiency. In a household of three persons where the tap valve with orifice in the form of a "curved drop" is used, reduction of water consumption is 12-15% per month, ceteris paribus compared to a tap valve, which is equipped with discs with the hole in the form of a semicircle or sector (Svintsov *et al*., 2016).

ACKNOWLEDGEMENT The publication was prepared with the support of the "RUDN University Program 5-100".

CONCLUSION

In terms of theoretical and experimental research the following results are obtained: (1. The numerical values of the hydraulic characteristics of liquid outflow through a hole in the shape of a "curved drop" in the closure member for water fittings is determined.

2. Computed hydraulic coefficients allow to design plumbing fittings with a high regulating capacity.3. The orifice in the form of a "curved drop" of the closure member has a high regulating capacity in contrast to the holes in the form of a segment or sector.

REFERENCES

Al'tshul', A.D. (1982). *Hydraulic resistance*. Publishing House "Nedra", Moscow, Russia.

Barringer, M., Thole, K.A., Krishnan, V., Landrum, E. (2013). Manufacturing Influences on Pressure Losses of Channel Fed Holes. *J. Turbomachinery*. **136**(5):051012-051012-10.doi: 10.1115/1.4025226

Deo, R. (2013). Comparative Analysis of Turbulent Plane Jets from a Sharp-Edged Orifice, a Beveled-Edge Orifice and a Radially Contoured Nozzle. World Academy of Science, Engineering and Technology, International Science Index 84, *Int. J. Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering*, **7**(12), 2584-2593. http://waset.org/publications/9996967

Dey, S. (2014). *Fluvial Hydrodynamics: Hydrodynamic and Sediment Transport Phenomena*. Springer-Verlag, Berlin.

Ghahremanian, S., Svensson, K., Tummers, M.J., Moshfegh, B. (2014). Hear-field mixing of jets issuing from an array of roundnozzles. *Int. J. Heat and Fluid Flow*. **47**, 84-100. https://doi.org/10.1016/j.ijheatfluidflow.2014.01.007

Hashid, M., Hussain, A., Ahmad, Z. (2015). Discharge characteristics of lateral circular intakes in open channel flow. *Flow Measurement and Instrumentation*. **46**(A), 87-92. https://doi.org/10.1016/j.flowmeasinst.2015.10.005

Hussain, A., Ahmad, Z., Ojha, C.S.P. (2014). Analysis of flow through lateral rectangular orifices in open channels. *Flow Measurement and Instrumentation*. **36**, 32-35. https://doi.org/10.1016/j.flowmeasinst.2014.02.002

Hussain, A., Ahmad, Z., Ojha, C.S.P. (2016). Flow through lateral circular orifice under free and submerged flow conditions. *Flow Measurement and Instrumentation*. **52**, 57-66. https://doi.org/10.1016/j.flowmeasinst.2016.09.007

Kondrat'ev, A.S. (2010). Leaking of Liquid form Outer Cylinder Nozzles. *Vestnik Moskovskogo gorodskogo pedagogicheskogo universiteta. Serija: Estestvennye nauki*. **2**, 14-20.

Kuznecov, V.S., Shablovskij, A.S., Jaroc, V.V. (2014). The influence of facets within the inlet edge of cylindrical probe on the discharge coefficient. *Vestnik Moskovskogo gosudarstvennogo tehnicheskogo universiteta im. N.Je. Baumana. Serija: Mashinostroenie*. **5**(98), 46-52.

Pil'gunov, V.N. & Efremova, K.D. (2015). Features of the Viscous Fluids Effluent through non-round shape edge orifices. *Nauka i obrazovanie: nauchnoe izdanie MGTU im. N. Je. Baumana*. **2**, 1-23.

Posohin, V.N., Ziganshin, A.M., Batalova, A.V. (2012). To defintion of pressure loss coefficients of disturbing elements in pipeline systems. *Izvestija vysshih uchebnyh zavedenij. Stroitel'stvo*. **9**(645), 108-112.

Posohin, V.N., Ziganshin, A.M., Varsegova, E.V. (2016). Calculation of minor losses. Report 1. *Izvestija vysshih uchebnyh zavedenij. Stroitel'stvo*. **4**(688), 66-73.

Saha, R., Mamaev, B.I., Fridh, J., Laumert, B., Fransson, T.H. (2014). Influence of Prehistory and Leading Edge Contouring on Aero Performance of a Three-Dimensional Nozzle Guide Vane. *J. Turbomachinery*. **136**(7):071014-071014-10. doi: 10.1115/1.4026076

Svintsov, A.P., Harun, M.I., Mukarzel', S.A. (2015). Valve head for water fittings with high regulatory capacity. Magazine of Civil Engineering. **6**(58), S. 8-18. DOI: 10.5862/MCE.58.2

Svintsov, A.P., Mukarzel, S.A., Kharun, M. (2016). Method of Determining the Orifice Area of Valve Head Locking Pairs of Water Fittings. *J. Urban Environ. Engng.* **10**(1), P. 57-61. DOI:10.4090/juee.2016.v10n1.057061

Zvyagincev, V.V. (2016). Optimization of the internal sizes of connecting elements of pressure pipelines according to hydraulic characteristics. *Vestnik Vostochno-Sibirskogo gosudarstvennogo universiteta tekhnologij i upravleniya (Ulan-Udeh)*. **1**, 11-14.