Method for determining the sealing forces in a shut-off valve

Yu I Belogolov, V K Pogodin, V E Gozbenko, S K Kargapol'tsev, V A Olentsevich and A M Gladkih

1 Irkutsk State Transport University, 15, Chernyshevskogo str., Irkutsk, 664074, Russia
2 Angarsk State Technical University, 60, Chaykovskogo str., Angarsk, 665835, Russia
3 Irkutsk National Research Technical University, 83, Lermontova str., Irkutsk, 664074, Russia

E-mail: belogolov_vui@irgups.ru

Abstract. The developed method for determining the sealing forces in a shut-off valve takes into account the design features of its components and their elements, which affect the amount of sealing pressure. The components and assemblies of the shut-off valve that provide the creation of sealing pressure are referred to the fastening system or the sealing system. Dependences for determining the forces acting in these systems are analytically revealed. The values of forces are determined when tightening fasteners, when increasing and releasing pressure, as well as when they are exposed to temperatures. The calculation of the specific structure of the shut-off valve shutdown showed that the forces in the sealing system of the check valve prototype are 1.4 times higher than the values obtained using known calculation methods, and the forces in the mounting system of this check valve are 1.2 times higher than the calculated values. The magnitude of the discrepancy between the calculated and actual values of the forces for different designs of shut-off valves may differ and depends on the number of components included in the station shut-off valve. The proposed method for determining the sealing forces in the shut-off valve makes it possible to determine not only the forces in the shut-off valve, but also the optimal number of components and connections that will ensure safe operating conditions. It is shown that the method of calculating the forces in the station shut-off valve, used in practice, is a special case in which the stiffness coefficient of the station shut-off valve is equal to unity. The proposed method for determining the sealing forces in the shut-off valve makes it possible to more accurately determine the forces acting on the shut-off valve, the sealing conditions and the stress-strain state of the components. To implement the developed methodology for determining the sealing forces in the shut-off valve of the stop station in the shut-off valves, it is necessary to develop regulatory documents formalizing the application of this method.

1. Introduction
Ensuring reliable operation of shut-off valves is an important aspect of design [1, 2]. For this, special design methods are used, such as methods for calculating the strength of components, calculating forces for valve sealing (seat valve plug) and packing gland [3, 4]. The practice of designing and researching stop valves has shown that the determination of the sealing forces of a valve gate is mainly determined by calculation using simplified methods [5-7], developed on the basis of analytical or experimental studies of a particular gate valve. However, the study of the sealing conditions that determine the values of the forces that excludes the occurrence of leakage in the valve gate, exceeding the standard values,
remains an urgent task. In the existing calculation methods, the sealing conditions were mainly determined in the models of gate valves, since to determine the sealing conditions in real designs of stop valves, it is necessary to create a model taking into account their operating conditions [8-9].

Comparative analysis of the existing methods for calculating the forces acting in the shut-off valve showed that they do not take into account the conditions for the interaction of the components of the shut-off valve structure with each other, as well as the correspondence of the components and their elements [10, 11].

The exclusion of these factors from the calculation is the reason that in the calculations of the forces in the check valves, made in accordance with well-known methods, the value of the forces required to seal the check valve when used in service, often does not match the design. This article discusses a technique for determining the sealing forces in a shut-off valve, taking into account its design features and deformation of all parts and their elements. The use of this technique will eliminate the discrepancies between the calculated and real values of the forces and avoid design errors.

During the development of the methodology, the following well-known concepts were taken into account:

- a component – a product made of the material of the same brand without the use of assembly operations (welding, soldering, gluing, screwing);
- an element of the component – a part of the component intended to perform its definite (specific) characteristic function, for example, a sealing surface, a threaded surface, a supporting surface, etc.
- a station – a set of components interconnected by assembly operations in a structure designed to work together.

The introduction of the new concept “Station Shut-off Valve (SVS)” allows for more complete consideration of design features, component flexibility and disconnection of their valve elements (Figure 1), when determining the sealing forces. The station shut-off valve (SVS) includes not only the components of the gate valve (seat-gate valve), but also, in contrast to the existing design models, the components and their elements that affect its sealing ability at different stages of interaction of these components.

![Figure 1. The shut-off valve SVS diagram for high operating parameters: 1 – valve housing; 2 – post; 3 – spindle; 4 – threaded sleeve.](image)

2. Results and discussion

To determine the forces in the shut-off valve according to the proposed method, the values of $\alpha$ are determined at values of $Q_f$ and $Q_{sj}$. To do this, we define the movement values included in formula (11):

1. The axial movement of the spindle under pressure is determined by the formula:
where $E$ is the modulus of elasticity of the spindle material; $F = \frac{\pi d^2 p}{4}$ is the spindle sectional area.

In the considered design of the shut-off valve: for $Q_f$ the value is $\delta_{sp} = 0.0737 \text{ mm} = 73.7 \mu \text{m}$; for $Q_{sj.t}$ the value $\delta_{sp} = 0.117 \text{ mm} = 117 \mu \text{m}$.

2. Full axial movement of the most loaded thread turn is defined as the sum of its individual components [12, 13]:

$$
\delta_{th} = \delta_b + \delta_r + \delta_c + \delta_{\mu},
$$

where $\delta_b$ is the axial movement from the bend of the turn; $\delta_r$ is the axial movement from radial movements of the turns of the threaded joint; $\delta_c$ is the deformation of the microroughness of the contacting surfaces with a roughness of $R_z$ when exposed to contact pressures $p(H)$; $\delta_{\mu}$ is the axial component from the lateral deformation of the spindle body due to a change in its length:

$$
\delta_b = 2 \frac{p(H)}{E} \rho \cdot (1 \pm 0.3 f_f),
$$

$$
\delta_r = \frac{p(H)}{E \cdot P} \frac{t_2 \cdot d_2}{d_0^2 - d_2^2} \left( (\tan \frac{\alpha}{2} - f_f) \cdot \tan \frac{\alpha}{2} \right),
$$

$$
\delta_c = 0.371 \cdot (1 + 0.0353 R_z) \cdot p(H)^{0.66} \cdot \cos \frac{\alpha}{2},
$$

$$
\delta_{\mu} = \mu \frac{2 Q}{\pi \cdot E \cdot d_2} \cdot \tan \frac{\alpha}{2},
$$

where $P$ is the thread pitch; $f_f = 0.2$ is the coefficient of friction in a threaded pair (for steel threaded joints); $t_2$, $d_2$ are a height and an average diameter of the thread profile; $d_0$ is the outer diameter of the female part of the threaded joint, $\alpha$ is the angle of the sectional profile of the metric thread ($\alpha = 60^\circ$); $R_z$ is the roughness of the contacting surfaces of the thread turns; $\mu$ is the Poisson’s ratio; $E$ is the elastic modulus of the material of threaded components.

In the above formulas, the relationship between the normal pressure $p(H)$ and the axial force adopted in the works [14, 15] is used:

$$
p(H) = Q \cdot \frac{V}{f},
$$

where $f = \pi d_2 \cdot t_2$ is the projection of the lateral surface of a thread turn of a height $t_2$ on a plane perpendicular to the axis of the threaded joint; $Q$ is the axial load acting on a threaded joint;

$$
\nu = \sqrt{\frac{3.7 (P/d) \cdot (1 + 1.2 \cdot (P/d))}{1.86 + 0.35 (d/P)}}
$$

is the dimensionless coefficient.

When determining $\delta_b$, the upper “+” sign should be used under load, the lower sign “−” when unloading a threaded joint.

In accordance with the studies [15, 16] for threaded joints of the shut-off valve at $p(H) = 250 \text{ MPa}$, the values $\delta_b$ can be taken: for thread M16x1.5 – $\delta_{bs} = 24.5$ microns; for thread M36x2 – $\delta_{bs} = 33 \mu \text{m}$; for thread M64x6 – $\delta_{bs} = 63.1 \mu \text{m}$.

3. Microroughness deformation values in the connection of steel flat sealing surfaces with roughness $R_z = 9.6 ... 40 \mu \text{m}$ when exposed to contact pressures $q_1$ in the range from 0 to 300 MPa were determined in accordance with [15, 17] using the formula:

$$
\delta_p = 0.3711 (1 + 0.0353 \cdot R_z) \cdot q_1^{0.66}.
$$

When experimentally determining the compliance of components and joints, the researchers [15] recommend using the values obtained after 3-5 loading cycles in the calculations.
In the “rod–housing seat” sealing joint, the movements determined by this relationship with $q_{ld} = q_{H} = 250$ MPa can have the following values: at $R_{z} = 9.6$ μm the value of $\delta_{s,p} = 19$ μm; at $R_{z} = 40$ μm, the value $\delta_{s,p} = 34.237$ μm.

After substituting in the expression (11) the displacement values $\delta_{ts,sp} = 24.5$ μm, $\delta_{ts,pp} = 33$ μm; $\delta_{tr,hf} = 63.1$ μm, $\delta_{s,p} = 19$ μm $\delta_{pp}$, the value $\alpha = 0.565$ was obtained. Then the forces acting in the sealing system and the mounting system, determined in accordance with dependences (7) and (8) at $\alpha = 0.565$, $Q_{ms,t} = Q_{st} = 3579$ kgf, $Q_{d} = 1695$ kgf and $p_{w} = 150$ MPa, have the following values:

$$Q_{s,p} = Q_{ms,t} - 0.565 Q_{d} = 2651 \text{ kgf},$$
$$Q_{ms,p} = Q_{ms,t} - (1 - 0.565) Q_{d} = 4316.32 \text{ kgf}.$$ 

The values of the forces acting in the sealing system and the mounting system of the shut-off valve differ from the values determined in accordance with the existing calculation procedure [3, 4], namely $Q_{s,p}$ is 1.41 times higher than the values of $Q_{t}$, and $Q_{ms,p}$ is 1.2 times greater than $Q_{ms,t}$.

These differences can be explained by the fact that with the current design practice [3, 4], the value of the stiffness coefficient is taken equal to $\alpha = 1$, at which $Q_{s,p} = Q_{ms,t} - Q_{d}$ and $Q_{ms,p} = Q_{ms,t}$. This condition is acceptable only when the movements in the sealing system are completely absent ($\sum \delta_{tsj} = 0$) or very small compared to movements in the mounting system.

Based on the analysis, when designing prospective models of shut-off valves and determining the forces in the memory, one should take into account the structural features of its components and their elements, as well as the mechanism of their interaction by determining the stiffness coefficients $\alpha$ and the transformation coefficients of force effects $\psi$.

**Figure 2.** The diagram of a shut-off valve with a SVS, a replaceable nozzle and a split spindle: 1 – rod; 2 – spindle; 3 – half rings; 4 – outer ring; 5, 6 – supports; 7 – replaceable nozzle; 8 – housing; 9 – threaded sleeve; 10 – post; 11 – coupling nut.

In the design of the shut-off valve (Figure 2), when using SVS components and elements that differ from the design shown in Fig. 1, it is necessary to additionally introduce the ductility coefficients of the joints: “support-rod”, “support-spindle”; threaded joints: "nut-housing" and joints: "replaceable nozzle-nut" when determining the stiffness coefficient $\alpha$ (10). Design features should also be taken into account when using replaceable seats and replaceable nozzle assemblies in the shut-off valve.

3. **Conclusion**
1. A new method is proposed for determining the sealing forces in a stop valve, based on consideration of the stop station valve in its design, which includes a sealing system and a fastening system.
2. The method takes into account the design features of the stop valve and includes determination of the conformity of components, sealing of threaded connections and their elements included in the stop valve of the station.

3. It is shown that the method of calculating the forces in the station shut-off valve used in practice has a limitation - the stiffness coefficient of the station shut-off valve is equal to one.

4. The proposed method for calculating the sealing forces in the shut-off valve makes it possible to eliminate the large error in calculating the forces acting in the shut-off valve, sealing conditions and the state of stress deformation of components.

5. The developed method for calculating the sealing forces in the shut-off valve makes it possible to determine the optimal combination of components and connections that will ensure safe operating parameters of the shut-off valve.

6. To implement the developed methodology for determining the sealing forces in the shut-off valve of the stop station in the shut-off valves, it is necessary to develop regulatory documents formalizing the application of this method.

References

[1] Suslov K V, Solonina N N and Smirnov A S 2014 Distributed power quality monitoring Proc. of Int. Conf. on Harmonics and Quality of Power, ICHQP

[2] Buryanina N, Korolyuk Y, Koryakina M, Lesnykh E and Suslov K 2019 Algorithm of Current Protection Based on Three Instantaneous-Value Samples Proc. of 2019 IEEE PES Innovative Smart Grid Technologies Europe, ISGT-Europe 8905542

[3] Suslov K, Solonina N and Gerasimov D 2018 Assessment of an impact of power supply participants on power quality Proc. of Int. Conf. on Harmonics and Quality of Power, ICHQP pp 1-5

[4] Vdovin K N, Feoktistov N A, Sinitskii E V, Gorlenko D A and Durov N A 2015 Production of high-manganese steel in arc furnaces. Part 1 Steel in Translation 45(10) 729-732

[5] Shestov V V, Antipov V V and Ryabov D K 2017 Corrosion Resistance and Mechanical Properties of Layered Structural Material Based on Aluminum Alloy and Fiberglass Thin Sheets Metallurgist 60(11-12) 1191-1196

[6] Ryabov D K, Antipov K V, Fiesenko T V and Dynin N V 2017 Influence of cobalt alloying on structure and long-term strength of Al–Cu–Mg–Ag alloy system Inorganic Mater.: Appl. Res. 8(1) 159-165

[7] Ryabov D K, Shestov V V, Buznik V M and Antipov V V 2016 Design concept of multifunctional layered composite materials for operation in arctic regions Inorganic Mater.: Appl. Res. 7(4) 547-553

[8] Kuzmin O V and Orkina K P 2006 Building error-correcting codes using a Pascal-type triangle Bull. of Buryat State University 13 32-39

[9] Kolosov A D, Gozbenko V E, Shtayger M G, Kargapoltsvev S K, Balanovskiy A E, Karlina A I, Sivtsov A V and Nebogin S A 2019 Comparative evaluation of austenite grain in high-strength rail steel during welding, thermal processing and plasma surface hardening IOP Conf. Ser.: Mater. Sci. Eng. 560 012185

[10] Guseva E A, Kargapoltsvev S K, Balanovskiy A E, Karlina A I, Shtayger M G, Gozbenko V E, Konstantinova M V and Sivtsov A V 2019 Comparative evaluation of corrosion resistance of wheel and rail steels in various media IOP Conf. Ser.: Mater. Sci. Eng. 560 012181

[11] Karlina Yu I, Kargapoltsvev S K, Gozbenko V E, Karlina A I and Leonovich D S 2020 Overview of electro physicochemical methods for deburring small-sized high-precision details of coaxial radio components IOP Conf. Ser.: J. of Phys. 1582 012041

[12] Karlina Yu I, Kargapoltsvev S K, Gozbenko V E and Karlina A I 2019 Removal of burrs from small-size high-precise parts for SHF electronics IOP Conf. Ser.: Earth Env. Sci. 378(1) 012015

[13] Nekrasov I V, Sheshukov O Y, Metelkin A A, Sivtsov A V, Tsymblast M M and Egiazar’yan D K 2015 Ensuring Consistent Foamability in Electric-Furnace Slags Metallurgist
59(3-4) 300-304

[14] Kopylova T A and Mikhailov A Yu 2016 Evaluation of the functioning of intermodal nodes of urban passenger transport Transport systems of Siberia. The development of the transport system as a catalyst for the growth of the state economy. Int. sci. and pract. conf. pp 528-532

[15] Chriqui C and Robillard P 1975 Common bus lines Transportation Sci. 9 115-121

[16] Lebedeva O A and Kripak M N 2016 Modeling freight transportation in the transport network Bull. of Angarsk State Technical University 10 182-184

[17] Sazonov V N and Zagitov E D 2008 Russian Railways need modern effective solutions, not lightweight theories World Railways 4