DOI: https://doi.org/10.30932/1992-3252-2020-18-22-49

Theoretical Method for Controlling the Flow Rate of the Pumped Medium by Positioning Locking Elements of the Pipe Fittings




Alexander S. KRAVCHUK **Anzhelika I. KRAVCHUK** **Arnold P. MIKHIEVICH** **Nikolay Yu. GAYS**

Kravchuk, Alexander S., *Research Polytechnic Institute, a branch of Belarusian National Technical University, Minsk, Belarus.*
Kravchuk, Anzhelika I., *Belarusian State University, Minsk, Belarus.*
Mikhievich, Arnold P., *Belarusian State University, Minsk, Belarus.*
Gays, Nikolay Yu., *JV CJSC International Business Alliance, Minsk, Belarus*.*

ABSTRACT

Any object located in the pipeline, including the flow meter, leads to a drop in pressure in the pipeline and the need to increase the power of the pumps. Therefore, it seems promising to reduce energy consumption for pumping fluid in the pipeline by reducing the number of flow meters installed after shut-off and control valves and to predict the flow rate of the pumped medium by the position of the locking element in the valve. This will also lead to a reduction in the cost of transporting media by reducing the number of metering devices. In order to solve this complex problem in pipeline transport, the article solves a number of regional problems of hydromechanics based on the finite element method. In order to simplify the acquaintance with these solutions, as well as their practical application by engineers, the article proposes «parametric stationary vortex flow models in such types of shut-off and control valves as a ball valve, butterfly valve, wedge gate valve, angle valve. Without prejudice to generality of the technique, water is considered as an example of a pumped medium. The analysis was performed using FLOTRAN CFD software of ANSYS10 ED program».

The article describes in detail the capabilities of both the graphical interface and the command line. Creating models is accompanied by full comments on the actions, which allows any user to master these models. All stages of building models are considered in detail: construction of a solid-state model, selection of elements, appointment of properties of the pumped media, appointment of boundary conditions, as well as solving the problem and viewing the results. «It has been established that the flow rate of the medium is affected both by the geometry of the considered types of shut-off and control valves», and the position of the locking element. The technique can be applied to any designs of pipe fittings associated with calculation of movement of a viscous fluid.

Keywords: *fluid viscosity, vortex flow, stationary flow, incompressible fluid, parametric modeling, shut-off and control valves, ANSYS, FLOTRAN.*

---

*Information about the authors:
Kravchuk, Alexander S. – D.Sc. (Physics and Mathematics), associate professor, leading researcher of the laboratory of Systems Dynamics and Materials Mechanics of Research Polytechnic Institute, a branch of Belarusian National Technical University, Minsk, Belarus, ask_belarus@inbox.ru.
Kravchuk, Anzhelika I. – Ph.D. (Physics and Mathematics), associate professor of the department of web technologies and computer modeling of Belarusian State University, Minsk, Belarus, anzhelika.kravchuk@gmail.com.
Mikhievich, Arnold P. – Ph.D. student of the department of bio- and nanomechanics of mechanics and mathematics faculty of Belarusian State University, Minsk, Belarus, fakel.arnold@gmail.com.
Gays, Nikolay Y. – engineer-programmer, JV CJSC International Business Alliance, Minsk, Belarus, craderua@gmail.com.

Article received 22.07.2019, revised 12.12.2019, accepted 15.01.2020.

For the original Russian text of the article please see p. 22.

This article was written based on the master's thesis by A. P. Mikhievich and the thesis by N. Yu. Gays, performed under the guidance of D.Sc. (Physics and Mathematics) A. S. Kravchuk.

«Until now, all hydrodynamic calculations of pipelines have been carried out using semi-empirical formulas obtained mainly for the laminar flow of the medium in the pipeline, in which experimentally determined coefficients taking into account Reynolds numbers are present. Using this approach, various effects that occur during pumping of the medium and possible occurrence of vortices and other phenomena in these cases that reduce the velocity of the medium are taken into account» [1, p. 6].

«The main weakness of these methods is intuitiveness and complexity of adequately determining the necessary values of Reynolds numbers and inability to theoretically predict the flow rate of the pumped medium through shut-off and control valves» without installing additional metering devices (flow meters), which significantly increases the cost of building and operating pipelines [1, p. 6; 2, p. 6].

In addition, since it is obvious that any metering device is an obstacle to the medium, installation of any additional equipment in the path of the pumped stream leads to a pressure drop [1; 2]. Although it is «insignificant, a lot depends on the number of metering devices along the route, which can lead to a significant increase in the cost of electricity for pumping the medium» [1, p. 6; 2, p. 6].

Accordingly, one of the obvious ways to reduce energy and resource costs for operation of pipeline transport is to maximize simplification of pipeline equipment (a significant reduction in the number of control and measuring equipment)», as well as to use of a calculation-theoretical methodology for controlling the flow of the medium and its redistribution» over flows using such modern means of analysis of the eddy flow of liquid and gas as ANSYS with FLOTRAN module» [1, p. 6; 2, p. 6].

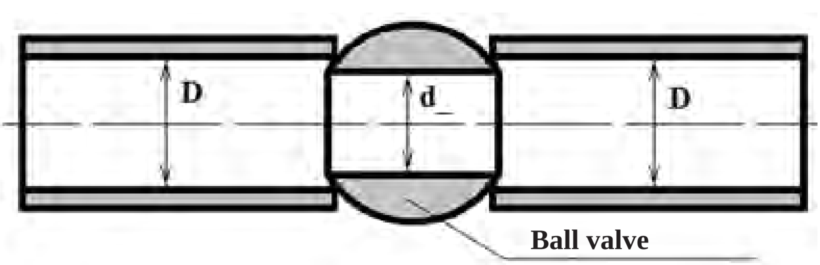
The proposed parametric models of shut-off and control valves will make it possible to refuse to install additional flow meters on the pipeline route, and to determine the flow rate of the medium by the geometric position of the locking element, which, in particular, for some structures can be determined by the angle of deviation of the handle from the axial direction of flow» [1; 2; 8].

1. A brief description of the task. «Due to the symmetry of the tasks and the need to save elements, we consider three-dimensional parametric models of the internal volume of a half ball valve, butterfly valve, valve and wedge gate valve, which are obtained by their section in the longitudinal plane. In all cases, the discarded (symmetric) part of the internal volume of the shut-off and control equipment is replaced by the corresponding boundary conditions for the flow (zero flow velocities in the direction perpendicular to the plane of symmetry).

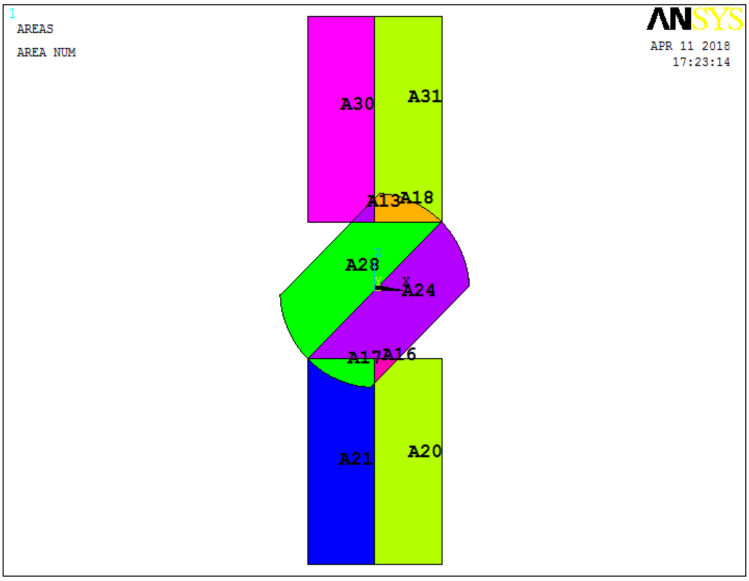
The boundary-value problem for studying the turbulent flow of the medium in shut-off and control valves was carried out taking into account the hypothesis of complete adhesion of the medium to the inner surface of the valve» [1, p. 19].

«Since all models under construction will be parametric, before starting to build any of the models, it is necessary to enter all the parameters listed in the statement of the problem with their values» [1, p. 19].

2. Creating a finite element model of the inner space of a ball valve. Ball valve is one of the most common types of shut-off and control valves. All cranes have a similar design and it is



Pic. 1. The axial section of a ball valve with a vertical plane [1; 2]. Authors' drawing.



Pic. 2. The axial section of the ball valve horizontal plane [1; 2]. Authors' drawing.

Table 1

List of commands for building a finite-element model of inner volume of a ball valve [1; 2]

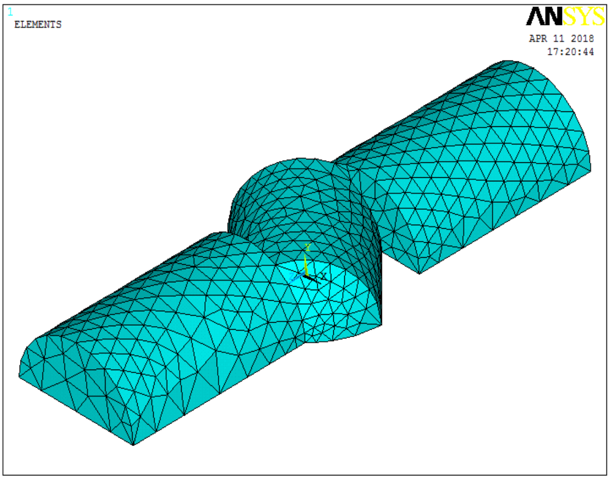
No.	Command	No.	Command
1.	/FILNAME, PipingCrane, 0	19.	CSYS, 0
2.	D = 1	20.	BTOL, 0.10E-5
3.	d_ = 0.95	21.	VADD, 1, 6, 2
4.	Fi = 45	22.	BTOL, DEFA
5.	V = 0.2	23.	AADD, 20, 21, 16, 17, 24, 28, 18, 13, 31, 30
6.	P = 3 • (1E+5)	24.	NUMCMP, ALL
7.	Pi = ACOS(–1)	25.	ET, 1, FLUID142
8.	/PREP7	26.	SMRTSIZE, 4
9.	CYLIND, D/2, 0, -D/2, –2 • D, 0, 180	27.	MSHAPE, 1, 3D
10.	CYLIND, D/2, 0, D/2, 2 • D, 0, 180	28.	VMESH, 1
11.	CYLIND, d_/2, 0, -D/2/COS(45/180 • PI), D/2/COS(45/180 • PI), 0, 180	29.	ASEL, S, AREA,, 4, 10
12.	SPH4, 0, 0, D/2/COS(45/180 • PI)	30.	DA, ALL, VX, 0, 1
13.	VDELE, 4,,, 0	31.	DA, ALL, VY, 0, 1
14.	ADELE, 17,,, 1	32.	DA, ALL, VZ, 0, 1
15.	VSBA, 3, 16,, DELETE, DELETE	33.	ASEL, ALL
16.	VDELE, 4, 5, 1, 1	34.	DA, 2, VY, 0, 1
17.	CSYS, 5	35.	DA, 3, VZ, -V, 1
18.	VGEN, 2, 6,,,, FI,,,, 1	36.	DA, 1, PRESS, 0, 1

enough to demonstrate the technique on one of the versions of the locking element. In this article, the most common ball valve currently selected [1; 2; 5; 6].

In case of constructing a model of the inner space of a ball valve (Pic. 1), the following parameters are used (Pic. 1) [1; 2]: D = 1 (m) – diameter of the inner space of the pipe [1; 2]; d_ = 0,95 (m) – diameter of the hole in the ball locking element (valve) [1; 2]; Fi = 45 (degrees) – angle between the symmetry planes of the locking element and the symmetry plane of the entrance and exit of the crane (Pic. 2) [1; 2]; V = 0,2 (m/s) – fluid transfer rate [1; 2]; P = 3 • (1E + 5) (Pa) – gauge pressure in the pipeline [1; 2].

In this model, the radius of the locking element (ball valve) is a calculated parameter, although the user can manually set its values if necessary [1; 2].

The list of commands for setting parameters, starting work in the preprocessor, building half



Pic. 3. The finite element model of half the internal volume of a ball valve [1; 2]. Authors' drawing.

of the internal space of a ball valve, symmetrical with respect to the longitudinal plane, is given in Table 1 [1; 2].

Line No. 1 (Table 1) defines the name of the solution PipingCrane with saving the names of open task files (error file, results, etc.) with which data will be exchanged.

Lines No. 2–6 set the values of the task parameters.

Line No. 7 sets the value of the constant π with the best accuracy for ANSYS.

Line No. 8 contains the input command to the preprocessor.

Lines No. 9–24 produce construction of the upper half of the volume of the ball valve by:

• creation of semi-cylinders (lines No. 9–11);

• creation of a ball (line No. 12);

• removal of the internal volume of the ball with preservation of its surface (line No. 13);

• removal of unnecessary hemisphere along with auxiliary lines and key points (line No. 14);

• dividing the semi-cylinder simulating the hole in the ball valve using the hemisphere built in the previous steps (command No. 15);

• removal of unnecessary volumes obtained after the last operation (command No. 16);

• changing the global coordinate system to a cylindrical (command No. 17);

• rotation of the semi-cylinder simulating the hole in the locking element by a predetermined angle FI (command No. 18);

• activation of the global Cartesian coordinate system (command No. 19);

• changing the accuracy of construction (command No. 20);

• addition of volumes (command No. 21);

• returning the accuracy of the default operations (command No. 22);

• addition of surfaces in the plane of symmetry of the crane (Pic. 2), to simplify the definition of boundary conditions (command No. 23);

• compression of the numbering of all geometric components of the model (command No. 24).

The following table 1 shows the commands No. 25–28 of creation of a finite element mesh.

Command No. 25 selects a volumetric element to simulate the flow of the medium FLUID142.

Command No. 26 sets the parameter SMRTSIZE to automatically control the accuracy of constructing a free partition.

Command No. 27 sets a parameter indicating that the partition will be performed by pyramidal elements.

Command No. 28 builds a free partition of the previously created geometric model (Pic. 3).

Commands No. No. 29–36 of setting boundary conditions end the list of commands of Table 1.

Commands No. 29–32 choose the outer surfaces of the model and set the boundary conditions of adhesion in them.

Command No. 33 cancels the selection of external surfaces.

Command No. 34 sets a boundary condition corresponding to the symmetry of the task.

Pic. 4. A large shutter with a flat-blade disc used at a hydropower plant in Japan [1; 2]. [Electronic resource]: https://commons.wikimedia.org/wiki/File: Yagisawa_power_station_inlet_valve.jpg?uselang=en. Last accessed 22.07.2019.

Commands No. 35 and 36 set the boundary conditions at the input and output of the crane.

3. Creating a finite element model of half of the internal space of a disk shutter symmetrical with respect to the horizontal plane [1; 2]. A disc shutter is a type of pipe fittings in which a locking or regulating element has the shape of a disk that rotates around an axis perpendicular to or located at an angle to the direction of flow of the working medium [1; 2; 5; 6] (Pic. 4).

To build a model of a symmetric half of the internal volume of a disk shutter (Pic. 4) with a flat-skewed disk, the following parameters are used [1; 2]: D = 1 (m) – inner passage diameter of the disk shutter and the disk itself [1; 2]; H_MAX = 0,1 (m) – maximum thickness of a flat-skewed disk in the middle [1; 2]; H_MIN = 0,03 (m) – minimum thickness of the disk at its edges [1; 2]; Fi = 45 (degrees) – opening angle of the disk [1; 2]; L = 2 • D – distance from the input section to the shutter disk and from the shutter disk to the output section in the model [1; 2]; V = 0,5 (m/s) – fluid transfer rate [1; 2]; P = 3 • (1E + 5) (Pa) – gauge pressure in the pipeline [1; 2].

Table 2

The coordinates of the points for constructing half the longitudinal section of the inner space of the disk shutter [1; 2]

KP	X-Loc	Y-Loc	Z-Loc
1	0	0	-H_MAX/2
2	D/2	0	-H_MIN/2
3	D/2	0	H_MIN/2
4	0	0	H_MAX/2

When constructing a disk shutter model, four auxiliary key points are used with the coordinates listed in Table 2 [1; 2].

The list of commands for setting parameters, starting work in the preprocessor, constructing half of the internal space of the shutter with a plane-skewed disk, symmetrical with respect to the longitudinal horizontal plane (Pic. 4), is given in Table 3 [1; 2].

Line No. 1 (Table 3) defines the name of the ButterflyValve solution file.

Lines No. 2–8 set the values of the parameters of the task.

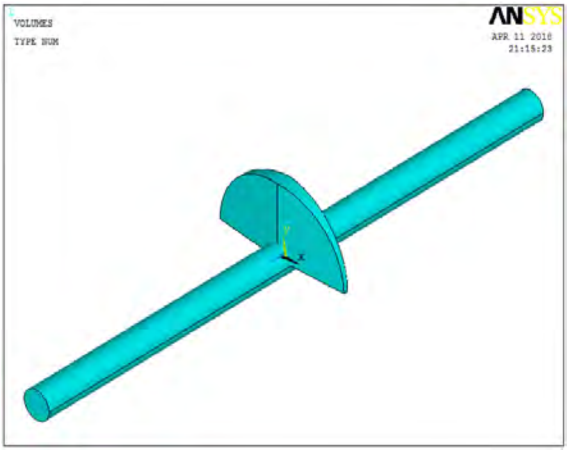
Line No. 9 sets the value of the constant π with the best accuracy for ANSYS.

Line No. 10 contains the input command to the preprocessor.

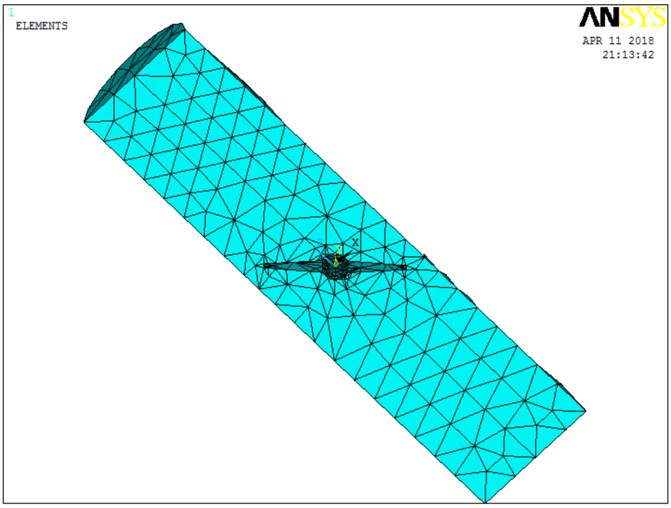
Table 3

List of commands for constructing the finite element model of the internal volume of the disk shutter [1; 2]

No.	Command	No.	Command
1.	/FILNAME, ButterflyValve, 0	33.	CSYS, 0
2.	D = 1	34.	CYLIND, D/2, 0, -L, L, 0, 180
3.	Fi = 45	35.	VSBV, 1, 2,, DELETE, DELETE
4.	H_MAX = 0.1	36.	NUMCMP, ALL
5.	H_MIN = 0.03	37.	ET, 1, FLUID142
6.	L = 2 • D	38.	SMRTSIZE, 8
7.	V = 0.5	39.	ESIZE, D/5
8.	P = 3 • (1E+5)	40.	MSHAPE, 1, 3D
9.	Pi = ACOS(−1)	41.	VMESH, ALL
10.	/PREP7	42.	ASEL, S, AREA,, 3, 12, 1, 1
11.	K, 1, 0, 0, -H_MAX/2	43.	NSLA, S, 1
12.	K, 2, D/2, 0, -H_MIN/2	44.	D, ALL, VX, 0
13.	K, 3, D/2, 0, H_MIN/2	45.	D, ALL, VY, 0
14.	K, 4, 0, 0, H_MAX/2	46.	D, ALL, VZ, 0
15.	KSYMM, X, 2, 3, 1	47.	ASEL, ALL
16.	A, 1, 2, 3, 4, 6, 5	48.	NSEL, ALL
17.	CYLIND, D/2, 0, -H_MAX/2, H_MAX/2, 0, 180	49.	ASEL, S, AREA,, 15,,, 1
18.	VOFFST, 1, -D	50.	NSLA, S, 1
19.	VSBA, 1, 11,, DELETE, KEEP	51.	D, ALL, VX, 0
20.	VSBA, 4, 10,, DELETE, KEEP	52.	D, ALL, VY, 0
21.	VSBA, 5, 8,, DELETE, KEEP	53.	D, ALL, VZ, 0
22.	VSBA, 6, 13,, DELETE, KEEP	54.	ASEL, ALL
23.	VDELE, 1, 5, 1, 1	55.	NSEL, ALL
24.	CYLIND, 0.2 • D/2, 0, -L, L, 0, 360	56.	ASEL, S, AREA,, 13, 14,, 1
25.	CSYS, 5	57.	NSLA, S, 1
26.	VGEN, 2, 1,,,, 90,,,, 1	58.	D, ALL, VY, 0
27.	CSYS, 1	59.	ASEL, ALL
28.	VGEN, 2, 1,,,, 90,,,, 1	60.	NSEL, ALL
29.	CSYS, 0	61.	ESEL, ALL
30.	VADD, ALL	62.	DA, 2, VZ, -V, 1
31.	CSYS, 5	63.	DA, 1, PRESS, 0, 1
32.	VGEN, 2, 2,,,, FI,,,, 1	64.	—-



Pic. 5. The initial position of flat-skewed shutter and its shaft [1; 2]. Authors' drawing.



Pic. 6. The finite element model of half the internal volume of the disk shutter [1; 2]. Authors' drawing.

Lines No. 11–36 produce construction of the upper half of the volume of the ball valve by:

• creation of four key points (lines No. 11–14) with the coordinates from Table 2;

• symmetric display of two points (line No. 15);

• creation of a surface at key points (line No. 16);

• creation of a semi-cylinder simulating a shutter (line No. 17);

• extraction of volume from a surface previously created at key points (line No. 18);

• dividing the semi-cylinder simulating the shutter, the side surfaces, the created volume (commands No. 19–22);

• removal of unnecessary volumes obtained after the last operations, together with their surfaces, edges and key points (command No. 23);

• creation of a cylinder (Pic. 5) corresponding to the vertical shutter shaft (command No. 24);

• inclusion of a global cylindrical coordinate system and rotation of the cylinder, simulating the shaft of the locking element at an angle of 90° (commands No. 25–28);

• activation of the global Cartesian coordinate system (command No. 29);

• addition of the constructed shutter and shaft volumes (command No. 30);

• inclusion of the global cylindrical coordinate system and turning the shutter at a given angle FI (commands No. 31 and 32);

• activation of the global Cartesian coordinate system (command No. 33);

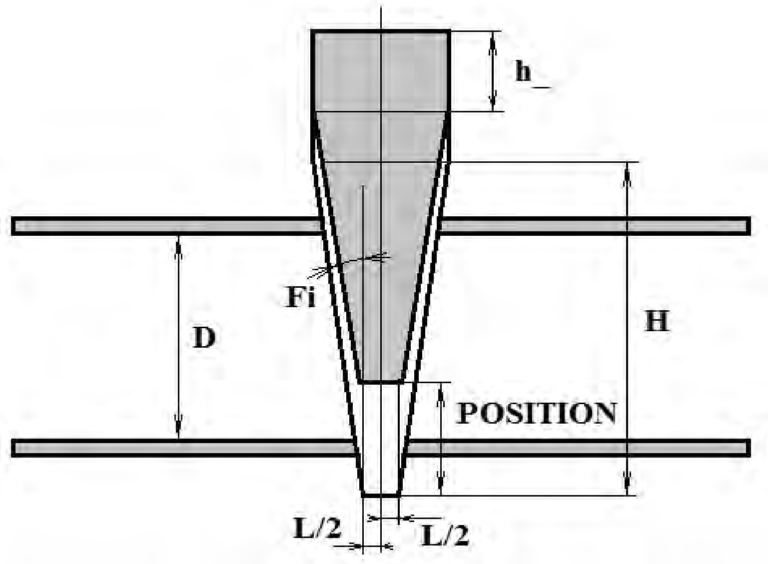
• building a semi-cylinder of internal volume (command No. 34);

• subtracting the volume simulating the shutter from the volume of the constructed cylinder (command No. 35);

• compression of the numbering of all geometric components of the model (command No. 36).

The following Table 3 shows commands No. 37–41 of creation of a finite element mesh. Command No. 37 selects a volumetric element to simulate the flow of the medium FLUID142. Command No. 38 of setting the parameter SMRTSIZE for automatic control of the accuracy of constructing a free partition (the large value of this parameter guarantees a small number of elements corresponding to the educational version of ANSYS10 ED). Command No. 39 sets the approximate size of the edge of the element relative to the value of the parameter *D* of the model. Command No. 40 sets a parameter indicating that the partition will be performed by pyramidal elements. Command No. 41 performs a partition of the constructed volume (Pic. 6).

Commands No. 42–61 setting the boundary conditions on the nodes of the finite element mesh and then two commands No. 62 and 63 setting the boundary conditions on the surfaces simulating the input and output of the model end the list of commands in Table 3.



Pic. 7. Wedge gate valve [1; 2]. Authors' drawing.

Table 4

The coordinates of the points for constructing half the longitudinal section of the inner space of the tee [1; 2]

KP	X-Loc	Y-Loc	Z-Loc
1	0	-H/2	-L/2
2	0	-H/2	L/2
3	0	H/2	L/2 + H • TAN(FI/180 • PI)
4	0	H/2	L/2 + H • TAN(FI/180 • PI)
5	0	H/2	-L/2 – H • TAN(FI/180 • PI)
6	0	H/2	-L/2 – H • TAN(FI/180 • PI)

This significantly distinguishes this model from the previous one, because in this case, the boundary conditions are specified directly on the components of the finite element decomposition, and not on the components of the geometric model.

Commands No. 42–53 select the external surfaces of the model and the nodal points of the finite element partition located on these surfaces to specify the boundary conditions of adhesion on them. Commands No. 54 and 55 deselect external surfaces and nodal points on them. Commands No. 56–58 choose the surface of the plane of symmetry and the nodal points on it to determine the boundary condition corresponding to the symmetry of the given task. Commands No. 59–61 cancel the choice of surfaces on the plane of symmetry, nodal points and elements on them. Commands No. 62 and 63 set the boundary conditions at the input and output of the disk shutter.

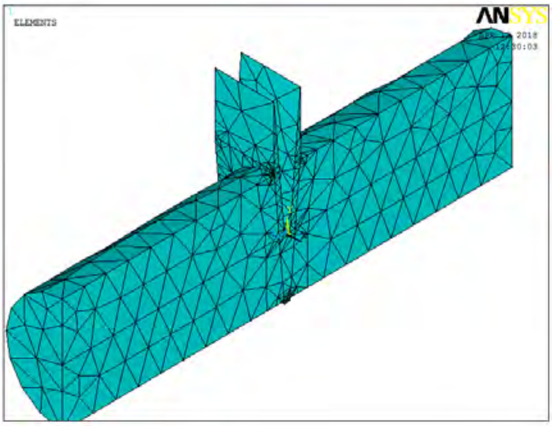
4. Creation of a finite element model of the internal space of the wedge gate valve [1; 2]. Gate valve – industrial pipe fittings, in which the shut-off element moves reciprocally perpendicular to the axis of the flow of the working medium [1–4]. It is possible to use valves for on-off (discrete) regulation of the flow of the working medium [1; 2]. Overlapping in gate valves is carried out due to the locking element blocking the flow. This article discusses a wedge gate valve (Pic. 7) [1; 2].

To build a model of the internal volume of a wedge gate valve (Pic. 7), the following parameters are used [1; 2]: D = 1 (m) – internal input and output pipe diameters [1; 2]; H = 1 (m) – height of the wedge [1; 2]; h_ = D (m) – height of the parallel part of the valve [1; 2]; POSITION = 0,5 • H (m) – valve position relative to full closure [1; 2]; L = 0,05 (m) – minimum thickness of the wedge [1; 2]; Fi = 5 (degrees) – angle of inclination of the lateral planes of the valve [1; 2]; V = 0,5 (m/s) – fluid

Table 5

List of commands for constructing a finite element model and setting boundary conditions for the internal volume of a wedge gate valve [1; 2]

No.	Command	No.	Command
1.	/FILNAME, WedgeGateValve, 0	29.	CYLIND, D/2, 0, –2 • D, 2 • D, 90, 270
2.	D = 1	30.	VADD, 1, 3
3.	H = 1.05	31.	VSBV, 4, 2,, DELETE, DELETE
4.	h_ = D	32.	AADD, 20, 19, 36, 7, 21
5.	Fi = 5	33.	ET, 1, FLUID142
6.	V = 0.5	34.	SMRTSIZE, 8
7.	L = 0.05	35.	ESIZE, D/5
8.	POSITION = 0.5 • H	36.	MSHAPE, 1, 3D
9.	P = 3 • (1E+5)	37.	VMESH, 1
10.	Pi = ACOS(–1)	38.	ASEL, S, AREA,, 32, 35, 1
11.	/PREP7	39.	ASEL, A, AREA,, 37
12.	K, 1, 0, -H/2, -L/2	40.	ASEL, A, AREA,, 5, 6, 1
13.	K, 2, 0, -H/2, L/2	41.	ASEL, A, AREA,, 1, 10, 9
14.	K, 3, 0, H/2, L/2+H • TAN(FI/180 • PI)	42.	ASEL, A, AREA,, 25, 26, 1
15.	K, 4, 0, H/2 + h_, L/2 + H • TAN(FI/180 • PI)	43.	DA, ALL, VX, 0, 1
16.	K, 5, 0, H/2 + h_, -L/2 – H • TAN(FI/180 • PI)	44.	DA, ALL, VY, 0, 1
17.	K, 6, 0, H/2, -L/2 – H • TAN(FI/180 • PI)	45.	DA, ALL, VZ, 0, 1
18.	*DO, i, 1, 5	46.	ASEL, ALL
19.	LSTR, i, i+1	47.	ASEL, S, AREA,, 23, 24, 1
20.	*ENDDO	48.	ASEL, A, AREA,, 27, 28, 1
21.	LSTR, 6, 1	49.	ASEL, A, AREA,, 2
22.	AL, 1, 2, 3, 4, 5, 6	50.	DA, ALL, VX, 0, 1
23.	VOFFST, 1, H/2	51.	DA, ALL, VX, 0, 1
24.	CYLIND, H/2, 0, -H, H, 180, 270	52.	DA, ALL, VX, 0, 1
25.	VSBA, 1, 11,, DELETE, DELETE	53.	ASEL, ALL
26.	VDELE, 2, 3, 1, 1	54.	DA, 18, VZ, -V, 1
27.	NUMCMP, ALL	55.	DA, 17, PRESS, 0, 1
28.	VGEN, 2, 1,,,, POSITION	56.	——

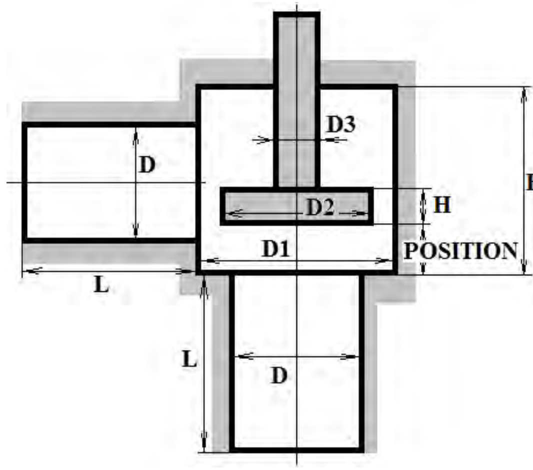


Pic. 8. The finite-element partition of the model of half the internal volume of the wedge gate valve [1; 2]. Authors' drawing.

transfer rate; P = 3 • (1E + 5) (Pa) – gauge pressure in the pipeline (Pic. 7) [1; 2].

When constructing a wedge gate valve model, six auxiliary key points with the coordinates listed in Table 4 are used [1; 2].

The list of commands for setting parameters, starting work in the preprocessor, building half of the internal space of the wedge gate valve, symmetrical with respect to the longitudinal vertical plane (Pic. 7), is given in Table 5 [1; 2].



Pic. 9. Section of the angle valve [1; 2]. Authors' drawing.

Line No. 1 (Table 5) defines the name of the WedgeGateValve solution file.

Lines No. 2–9 set the values of the parameters of the task.

Line No. 10 sets the value of the constant π with the best accuracy for ANSYS.

Line No. 11 contains the input command to the preprocessor.

Lines No. 12–32 produce the construction of half the volume of the wedge gate valve by:

• creating six key points forming the wedge gate valve profile (lines No. 12–17) with the coordinates from Table 4;

• plotting lines connecting the constructed key points using the loop operator (lines No. 18–21);

• creating a wedge gate valve profile surface along lines (line No. 22);

• pulling the wedge gate valve profile (line No. 23);

• construction of the auxiliary quarter of the cylinder (line No. 24);

• dividing the volume constructed by pulling the quarter plane of the cylinder by the lateral plane (command No. 25);

• removal of unnecessary volumes obtained after the last operations, together with their surfaces, edges and key points (command No. 26);

• compression of numbering of all geometric components of the model (command No. 27);

• creating a copy of the volume corresponding to the wedge gate valve at a given distance POSITION (command No. 28);

• building a semi-cylinder of internal volume (command No. 29);

• addition of the first and third (last) volumes (command No. 30);

• subtracting from the result of adding the second volume constructed by the shift and simulating the wedge gate valve position (command No. 31);

• addition of the lateral surfaces of the vertical section of the valve to simplify the task of boundary conditions (command No. 32).

The following Table 5 shows the commands No. 33–37 of creation of a finite element mesh (Pic. 8). Their description is fully consistent with the previous example (commands No. 37–41 of Table 3).

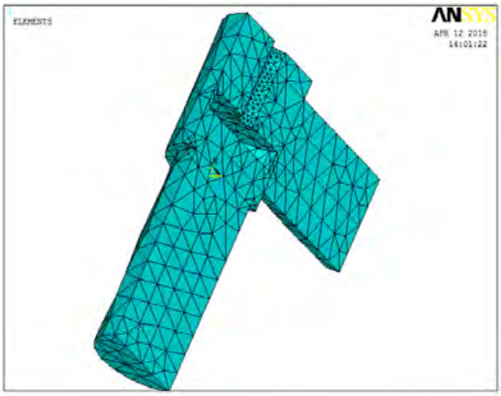
Commands No. 38–55 setting boundary conditions on the components of the geometric model end the list of commands in Table 5. Commands No. 38–45 choose the outer surfaces of the model to set the boundary conditions of adhesion on them. Command No. 46 deselects external surfaces. Commands No. 47–52 select the surfaces of the plane of symmetry to determine the boundary condition corresponding to the symmetry of the given task. Command No. 53 deselects surfaces on the symmetry plane. Commands No. 54 and 55 set the boundary conditions at the entrance and exit of the wedge gate valve.

5. Creation of a finite element model of the internal space of the angle valve [1; 2]. Valve – industrial pipe fittings in which a shut-off or regulating body moves reciprocally parallel to

Table 6

Commands for constructing the finite element model of the angle valve volume [1; 2]

No.	Command	No.	Command
1.	/FILNAME, Valve, 0	49.	D, ALL, VY, 0
2.	D = 0.5	50.	D, ALL, VZ, 0
3.	D1 = 0.6	51.	ASEL, ALL
4.	D2 = 0.55	52.	NSEL, ALL
5.	D3 = 0.1	53.	ASEL, S, AREA,, 28, 34, 6, 1
6.	H = 0.1	54.	NSLA, S, 1
7.	H1 = D+2 • H	55.	D, ALL, VX, 0
8.	L = 2 • D	56.	D, ALL, VY, 0
9.	POSITION = 2 • H	57.	D, ALL, VZ, 0
10.	V = 0.5	58.	ASEL, ALL
11.	P = 3 • (1E+5)	59.	NSEL, ALL
12.	Pi = ACOS(–1)	60.	ASEL, S, AREA,, 26,,, 1
13.	/PREP7	61.	NSLA, S, 1
14.	CYLIND, D/2, 0, L, 0, 0, 180	62.	D, ALL, VX, 0
15.	CYLIND, D1/2, 0, 0, -H1, 0, 180	63.	D, ALL, VY, 0
16.	CYLIND, D/2, 0, L, 0, 0, 180	64.	D, ALL, VZ, 0
17.	CSYS, 5	65.	ASEL, ALL
18.	VGEN, 2, 3,,,, 270,,,, 1	66.	NSEL, ALL
19.	CSYS, 0	67.	ASEL, S, AREA,, 4, 5, 1, 1
20.	VGEN, 2, 3,,,,, -(H+D/2),,, 1	68.	NSLA, S, 1
21.	CYLIND, D2/2, 0, 0, -H, 0, 180	69.	D, ALL, VY, 0
22.	CYLIND, D3/2, 0, -H/2, -L, 0, 180	70.	ASEL, ALL
23.	VADD, 1, 2, 3	71.	NSEL, ALL
24.	VADD, 4, 5	72.	ASEL, S, AREA,, 22, 23, 1, 1
25.	VGEN, 2, 1,,,,, -POSITION,,, 1	73.	NSLA, S, 1
26.	VSBV, 6, 1,, DELETE, DELETE	74.	D, ALL, VY, 0
27.	ET, 1, FLUID142	75.	ASEL, ALL
28.	SMRTSIZE, 8	76.	NSEL, ALL
29.	ESIZE, D/5	77.	ASEL, S, AREA,, 29, 30, 1, 1
30.	MSHAPE, 1, 3D	78.	NSLA, S, 1
31.	VMESH, ALL	79.	D, ALL, VY, 0
32.	ASEL, S, AREA,, 1, 3, 2, 1	80.	ASEL, ALL
33.	NSLA, S, 1	81.	NSEL, ALL
34.	D, ALL, VX, 0	82.	ASEL, S, AREA,, 16, 19, 3, 1
35.	D, ALL, VY, 0	83.	NSLA, S, 1
36.	D, ALL, VZ, 0	84.	D, ALL, VY, 0
37.	ASEL, ALL	85.	ASEL, ALL
38.	NSEL, ALL	86.	NSEL, ALL
39.	ASEL, S, AREA,, 17, 18, 1, 1	87.	ASEL, S, AREA,, 33,,, 1
40.	NSLA, S, 1	88.	NSLA, S, 1
41.	D, ALL, VX, 0	89.	D, ALL, VY, 0
42.	D, ALL, VY, 0	90.	ASEL, ALL
43.	D, ALL, VZ, 0	91.	NSEL, ALL
44.	ASEL, ALL	92.	NSEL, ALL
45.	NSEL, ALL	93.	ESEL, ALL
46.	ASEL, S, AREA,, 15, 20, 5, 1	94.	DA, 2, VZ, -V, 1
47.	NSLA, S, 1	95.	DA, 12, PRESS, 0, 1
48.	D, ALL, VX, 0	96.	——



Pic. 10. The finite-element partition of the model of half the internal volume of the angle valve [1; 2]. Authors' drawing.

the axis of the flow of the working medium (Pic. 9) [1; 2; 5; 6]. Until 1981, the valve, in which the locking element is moved by means of a screw pair and controlled manually, was usually called a valve [1; 2]. Now the term «valve» is not allowed for use by GOST [7].

To build a model of the internal volume of the angle valve (Pic. 9), the following parameters are used [1; 2]: D = 0,5 (m) – inner diameter of the pipe [1; 2]; D1 = 0,6 (m) – diameter of the valve chamber [1; 2]; D2 = 0,55 (m) – diameter of the locking element of the valve [1; 2]; D3 = 0,1 (m) – diameter of the rod of the locking element [1; 2]; H = 0,1 (m) – height of the locking element of the rod [1; 2]; H1 = D + 2 • H – chamber height [1; 2]; POSITION = 2 • H – position of the locking element relative to the extreme lower state is «completely blocked» [1; 2]; L = 2 • D – pipe length [1; 2]; V = 0,5 (m/s) – fluid transfer rate [1; 2]; P = 3 • (1E + 5) (Pa) – gauge pressure in the pipeline [1; 2].

The list of commands for setting parameters, starting work in the preprocessor, building half of the internal space of the angle valve (Pic. 9), symmetrical with respect to the longitudinal vertical plane, is given in Table 6 [1; 2].

Line No. 1 (Table 6) defines the file name of the Valve solution.

Lines No. 2–11 set the values of the parameters of the task.

Line No. 12 sets the value of the constant π with the best accuracy for ANSYS.

Line No. 13 contains the input command to the preprocessor.

Lines No. 14–26 produce construction of half the volume of the wedge gate valve by:

• creation of three semi-cylinders (lines No. 14–16);

• switching to a cylindrical coordinate system (line No. 17);

• turning one of the semi-cylinders (line No. 18);

• returning to the global Cartesian coordinate system (line No. 19);

Table 7

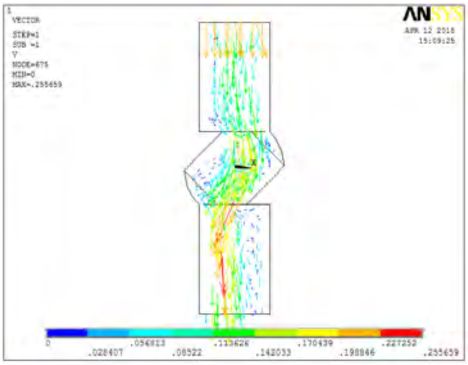
List of commands setting properties of the medium [1; 2]

No.	Command
1.	FLDATA7, PROT, DENS, CONSTANT
2.	FLDATA8, NOMI, DENS, 1000
3.	FLDATA7, PROT, VISC, CONSTANT
4.	FLDATA8, NOMI, VISC, 0.000894
5.	FLDATA7, PROT, COND, CONSTANT
6.	FLDATA8, NOMI, COND, –1
7.	FLDATA7, PROT, SPHT, CONSTANT
8.	FLDATA8, NOMI, SPHT, –1
9.	FLDATA15, PRES, REFE, P

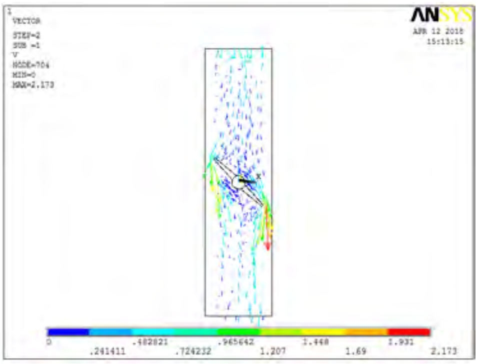
Table 8

List of commands for determining the parameters of the solver and solving the task [1; 2]

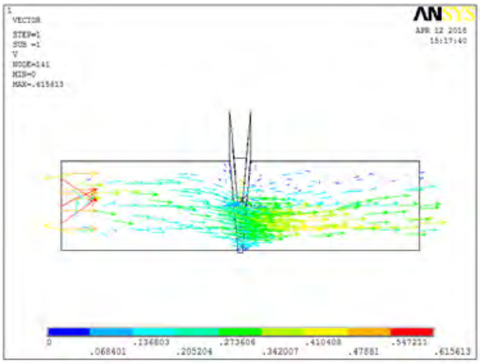
No.	Command
1.	FLDATA1, SOLU, TRAN, 0
2.	FLDATA1, SOLU, TEMP, 0
3.	FLDATA1, SOLU, TURB, 1
4.	FLDATA1, SOLU, COMP, 0
5.	FLDATA24, TURB, MODL, 3
6.	FLDATA37, ALGR, SEGR, SIMPLEN
7.	FLDATA2, ITER, EXEC, 500
8.	FLDATA34, MIR, MOME, 0.35
9.	FINISH
10.	/SOL
11.	SOLVE
12.	FINISH



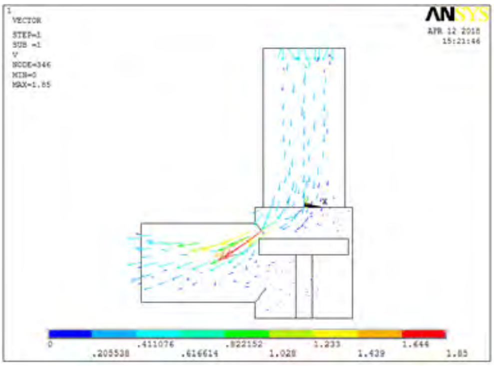
a)



b)



c)



d)

Pic. 11. The velocity field in parametric models of shut-off and control valves [1; 2]: a) ball valve, b) disc shutter, c) wedge gate valve, d) angle valve.

• displacement of the rotatable semi-cylinder (line No. 24);

• creation of two auxiliary semi-cylinders that simulate a locking element on the shaft (commands No. 21–22);

• addition of the first three semi-cylinders imitating the internal volume of the angle valve (command No. 23);

• addition of the last two semi-cylinders imitating a locking element and a shaft (command No. 24);

• shifting the locking element to POSITION (command No. 25);

• subtracting the volume of the locking element from the internal volume of the valve (command No. 26).

The following Table 6 shows the commands No. 27–31 of creation of a finite element mesh (Pic. 10). Their description is fully consistent with the previous example (commands No. 37–41 of Table 3).

Commands No. 32–93 setting the boundary conditions on the nodes of the finite element mesh end the list of commands of Table 6 and then there are two commands No. 94 and 95 setting the boundary conditions on surfaces that simulate the input and output of the valve. Note that the description of commands No. 32–93 (Table 6) fully corresponds to the description of commands No. 42–61 of Table 3. Moreover, setting boundary conditions by commands No. 94 and 95 from table 6 was repeatedly commented on in the previous examples.

6. Setting the physical properties of an incompressible fluid for all designs of shutoff valves. The physical properties of the fluid are set using the commands for setting the fluid properties, as well as gauge pressure from Table 7 [1; 2]. In particular, commands of Table 7 indicate the density of 1000 kg/m^3 and viscosity 0,000894 Pa • s of liquid [1; 2; 8].

Setting the thermodynamic characteristics of the undisturbed flow is carried out by default. Using command No. 9 of Table 7, the required gauge pressure P is indicated.

7. Preparatory measures before solving the boundary value tasks of fluid flow and solving the task [1; 2]. The task of the fluid flow model must be carried out using commands 1 to 5 [1; 2]. In line 6 of Table 8, the command for selecting the algorithm for solving the vortex task is given [1; 2].

Although the stationary task is being solved, iterative algorithms are used in FLOTRAN, therefore, before starting the solution of the task, it is necessary to limit the number of iterations. The number of iterations is assigned using the command given in line 7 of Table 8.

When solving the task, an error may occur indicating that negative elements are obtained in the matrix being solved at a certain iteration. You can get around this error using command 8 in Table 8 (you need to set MIR parameter to 0,35). This completes the preparation of any of the tasks considered for the solution, and to run the solution algorithm, it is necessary to use commands 10–12 from Table 8.

8. Reading the results of solving the task at the last step and displaying them [1; 2]. Since vortex problems (even stationary ones) are solved iteratively, in order to gain access to the solution results, it is necessary to read the most recent decision data [1; 2]. This is done using the menu item: Main Menu> General Postproc> Read Results> Last Set [1; 2].

To display the results in vector form, it is necessary to use the menu item Main Menu> General Postproc> Plot Results> Vector Plot> Predefined [1; 2]. In the window that appears, select the required results in the list and, if necessary, resize the flow velocity vectors (Pic. 11) [1; 2].

Conclusion. In order to solve the complex task of management and resource saving in pipeline transport, the article proposes parametric stationary vortex flow models in such types of shut-off and control valves as a ball valve, disc shutter, wedge gate valve, angle valve [1; 2].

Without prejudice to generality of the technique, water is considered as an example of a pumped medium [1; 2].

The analysis was performed by means of FLOTRAN CFD of program ANSYS10 ED [1; 2].

It was established that the flow rate of the medium and its pumping rate can be determined by the position of the locking element [1; 2].

It was established that the nature of the flow and the flow rate of the medium is influenced both by the geometry of the considered types of shut-off and control valves and the flow rate [1; 2].

The proposed models and methods can be applied to any reinforcement designs related to calculation of the motion of a viscous fluid [1; 2].

To improve quality of the results obtained on the proposed models, it is only necessary to indicate in the given lists of commands a value that improves partition of parameters [1; 2].

REFERENCES

1. Mikhievich, A. P. Modeling of the vortex fluid flow in pipelines taking into account the design features of shut-off valves, as well as metering and control devices for flow parameters in ANSYS ED10. Master's thesis in specialty 1-31.80.03 «Mechanics» [*Modelirovanie vikhrevogo potoka zhidkosti v truboprovodakh s uchetom osobennostei konstruktsii zapornoi armatury, a takzhe priborov ucheta i kontrolya parametrov potoka v ANSYS ED10. Magisterskaya dissertatsiya po spetsialnosti 1-31.80.03 «Mekhanika»*]. Minsk, BSU, 2018, 59 p.

2. Gays, N. Yu. Modeling of the vortex fluid flow in pipelines taking into account the design features of shutoff valves, as well as metering and control devices for flow parameters in ANSYS ED10. Thesis on the specialty 1-31.80.03 «Mechanics» [*Modelirovanie vikhrevogo techeniya zhidkosti v truboprovodakh s uchetom osobennostei konstruktsii zapornoi armatury, a takzhe priborov ucheta i kontrolya parametrov potoka v ANSYS ED10. Diplomnaya rabota po spetsialnosti 1-31.80.03 «Mekhanika»*]. Minsk, BSU, 2019, 68 p.

3. Chass, S. I. Hydromechanics in examples and problems [*Gidromekhanika v primerakh i zadachakh*]. Yekaterinburg, UGGU publ., 2006, 216 p.

4. Kovalnogov, N. N., Kovrizhnykh, E. N. Fundamentals of hydraulics [*Osnovy gidravliki*]. Ulyanovsk, UVAU GA, 2004, 86 p.

5. Eremkin, A. I., Bakanova, S. V., Kanakina, O. N. Shut-off and control valves in heating systems [*Zaporno-reguliruyushchaya armature v sistemakh otopleniya*]. Penza, PGUAS, 2013, 88 p.

6. Novikov, V. T. Fundamentals of design and equipment of enterprises of organic synthesis. Part 1. Pipe fittings [*Osnovy proektirovaniya i oborudovanie predpriyatii organicheskogo sinteza. Chast' 1. Truboprovodnaya armatura*]. Tomsk, Publishing House of Tomsk Polytechnic University, 2013, 292 p.

7. GOST 24856-81 (ISO 6552-80) Industrial pipe fittings. Terms and Definitions [*GOST 24856-81 (ISO 6552-80) Armatura truboprovodnaya promyshlennaya. Terminy i opredeleniya*]. [Electronic resource]: http://docs.cntd.ru/document/1200011740. Last accessed 05.03.2019.

8. Kravchuk, A. S., Tarasyuk, I. A. Modeling of stationary turbulent flow around a cylindrical obstacle by a stream of viscous incompressible fluid in a stepped pipe [*Modelirovanie statsionarnogo turbulentnogo obtekaniya tsilindricheskogo prepyatstviya potokom vyazkoi neszhimaemoi zhidkosti v stupenchatoi trube*]. *Mechanical Engineering: network electronic scientific journal*, 2017, Iss. 2, pp. 26–31. [Electronic resource]: http://indust-engineering.ru/issues/2017/2017-2.pdf. Last accessed 05.03.2019.

9. Shabarov, V. V. Application of ANSYS system to the solution of hydrodynamic problems [*Primenenie sistemy ANSYS k resheniyu gidrogazodinamicheskikh zadach*]. Nizhny Novgorod, NNSU, 2006, 108 p.