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Automated parameter selection for throttling control valves

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Автоматизований вибір параметрів дросельних регулюючих органів

Summary. *When designing new systems for automatic control of technological processes, there is a need to choose the type and calculate the parameters of throttle regulating bodies (RO). Therefore, the throughput (ideal) characteristic of RO in working conditions is called the consumption (real) characteristic. Selection of throttle RO parameters requires a certain theoretical training and practical skills from the designer, which should be acquired using specialized programs from manufacturers. These programs allow designers of automatic control systems to develop skills in the selection of valves and actuators, to correctly place orders for the manufacturing company.*

Резюме. *При проектуванні нових систем автоматичного керування технологічними процесами виникає необхідність вибору типу і розрахунку параметрів дросельних регулюючих органів (РО). Вибір параметрів дросельних РО потребує від проектувальника певної теоретичної підготовки і практичних навичок, які доцільно набути, використовуючи спеціалізовані програми від фірм-виробників. Дані програми дозволяють сформувати у проектувальників систем*

автоматичного керування навички з вибору клапанів та виконавчих механізмів, коректно скласти замовлення для фірми-виробника.

Throttling regulating valves (RV), for example, valves or dampers, are designed to change the flow rate of the substance entering the technological unit in proportion to the amount of the control action of the regulator. Throttle RVs are part of the pipeline network, which also includes pumps, pipes, elbows, shut-off valves and other local resistances. They have their own typical dependence of pressure loss depending on flow rate [1].

The pump head depends on the flow rate, which decreases when the flow rate increases. Pump manufacturers usually indicate this relationship in their manuals. In liquid transport systems, the pump size is selected to operate at maximum efficiency at rated flow rates. Under conditions of minimum flow, the pump pressure is higher, and under conditions of maximum flow, the pressure is lower than optimal. This change is manifested in a change in the pressure drop $\Delta P = P_1 - P_2$ at the RV when the flow rate Q in the network changes (Fig. 1). At rated flow rates, the control valve typically accounts for approximately one-third of the total system pressure loss [1].

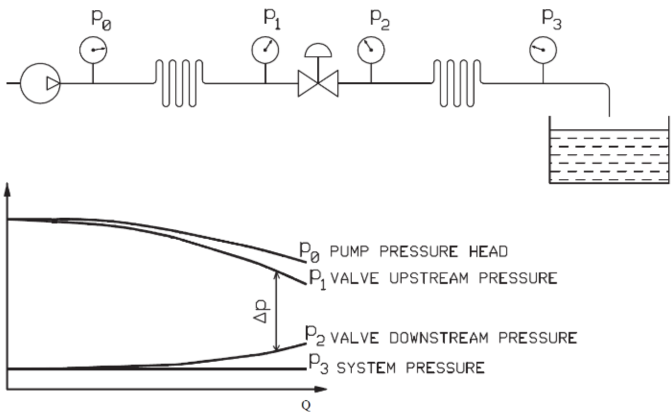


Fig. 1. Pressure loss in the pipeline network [1]

From a hydraulic point of view, the throttle RV is a complex variable local resistance. When passing through it, the flow of matter undergoes compression, expansion, rotation, separation and subsequent merging (Fig. 2, *a*).

During operation, not only the live cross-section of the passage and its geometry changes, but also the flow speed; in addition, the density of the substance, its viscosity and temperature may change. All noted factors complicate the analytical calculation of the parameters of throttle control valves.

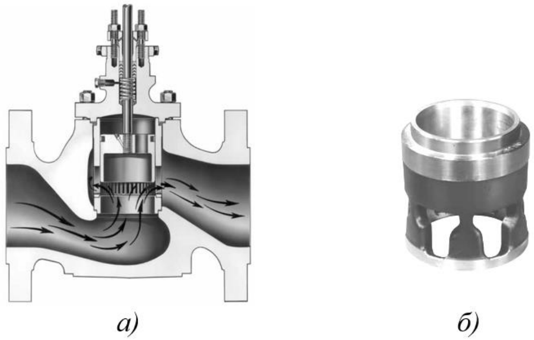


Fig. 2. Example of RVs designs from Fisher [2]:
a) – cell valve with noise reduction; *b)* – a cage which provides a linear throughput characteristic of the valve

In throttling valves, a change in their hydraulic resistance ΔP and flow capacity k_V occurs due to a change in the flow area depending on the linear h or angular α stroke of the movable part of the valve, consisting of a seat and a plunger [3].

In the technical documentation, manufacturers indicate the flow capacity k_V, m^3/h of the regulatory valve as the water flow through it with a density of ρ=1000 kg/m^3 under the influence of a pressure difference ΔP=0.1 MPa (1bar). At the maximum stroke (conditional stroke) of the rod h_S (or a_S), the k_V value is maximum and is called the conditional capacity k_{VS} [3].

The documentation also indicates the throughput characteristics of the valve. In dimensionless form, this is the dependence of the relative flow capacity k_V/k_{VS} on the degree of opening h/h_S (or α/α_S) [3]. It can be, for example, linear or equal percentage (Fig. 3), which mainly depends on the design of the seat and plunger (Fig. 2, *b*).

To understand the physical meaning of the k_v parameter, one should recall the Weisbach formula for local resistance. Let us first write it for idealized conditions, when water with density ρ_V=1000 kg/m^3, speed V_V, m/h and flow Q_V, m^3/hour flows through a valve with local resistance ξ and inlet area S, m^2 under the influence of a pressure difference ΔP_V=1 bar:

$$\Delta P_v = \xi \frac{\rho_v V_v^2}{2} = \xi \frac{\rho_v Q_v^2}{2S^2}.$$

Similarly, for another liquid that flows through the same valve, you can write:

$$\Delta P_1 = \xi \frac{\rho_1 V_1^2}{2} = \xi \frac{\rho_1 Q_1^2}{2S^2}.$$

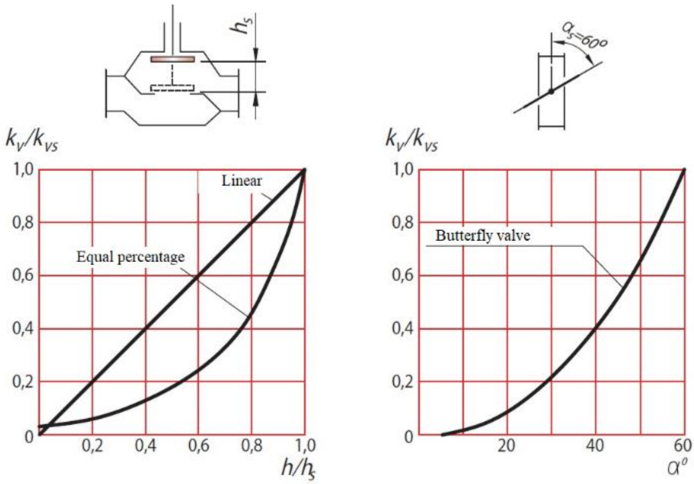


Fig. 3. Throughput characteristics of regulatory valves [3]

Then

$$\frac{\Delta P_1}{\Delta P_v} = \frac{\rho_1 Q_1^2}{\rho_v Q_v^2},$$

from where, taking into account the definition of the flow capacity, you can get the expression for the k_V of another liquid [4, 5]:

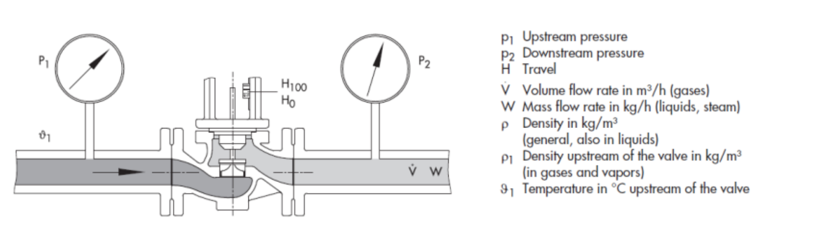
$$k_v = Q_v = Q_1 \sqrt{\frac{\Delta P_v}{\Delta P_1} \cdot \frac{\rho_1}{\rho_v}} = Q_1 \sqrt{\frac{\rho_1}{1000 \cdot \Delta P_1}}.$$

A similar expression is given, for example, in the reference table [5], which also contains formulas for calculating the flow capacity of a valve that changes the flow rate of gas or water vapor.

Examples of flow capacity calculation are given in [1, 3, 4].

In the American calculation system, C_V is used instead of k_V, which is equal to the flow of water through the valve in gallons per minute at a pressure drop of 1 psi and a water temperature of 60 °F. The ratio of k_V and C_V values is as follows: k_V=0,86·Cv.

Dependencies listed in the reference table in Fig. 4 are approximate and valid only under certain conditions. More detailed dependencies and conditions of their use are given in the standard ISA-75.01.01-2007 (IEC 60534-2-1 Mod) [6].



Medium / Pressure drop	Liquids		Gases		Steam
	m³/h	kg/h	m³/h	kg/h	kg/h
$p_2 > \frac{p_1}{2}$; $\Delta p < \frac{p_1}{2}$	$K_V = \dot{V}\sqrt{\frac{\rho}{1000\,\Delta p}}$	$K_V = \frac{W}{\sqrt{1000\rho\,\Delta p}}$	$K_V = \frac{\dot{V}_G}{519}\sqrt{\frac{\rho_G T_1}{\Delta p\ p_2}}$	$K_V = \frac{W}{519}\sqrt{\frac{T_1}{\rho_G \Delta p\ p_2}}$	$K_V = \frac{W}{31.62}\sqrt{\frac{v_2}{\Delta p}}$
$p_2 < \frac{p_1}{2}$; $\Delta p > \frac{p_1}{2}$			$K_V = \frac{\dot{V}_G}{259.5\ p_1}\sqrt{\rho_G T_1}$	$K_V = \frac{W}{259.5\,p_1}\sqrt{\frac{T_1}{\rho_G}}$	$K_V = \frac{W}{31.62}\sqrt{\frac{2v^*}{p_1}}$

where:

p_1 [bar] Absolute pressure p_{abs}
p_2 [bar] Absolute pressure p_{abs}
Δp [bar] Absolute pressure p_{abs} (differential pressure $p_1 - p_2$)
T_1 [K] $273 + \vartheta_1$
$\dot{V}_G$ [m³/h] Flow rate of gases, related to 0 °C and 1013 mbar
ρ [kg/m³] Density of liquids
ρ_G [kg/m³] Density of gases at 0 °C and 1013 mbar
v_1 [m³/kg] Specific volume (v′ found in the steam table) for p_1 and ϑ_1
v_2 [m³/kg] Specific volume (v′ found in the steam table) for p_2 and ϑ_1
v^* [m³/kg] Specific volume (v′ found in the steam table) for $\frac{p_1}{2}$ and ϑ_1

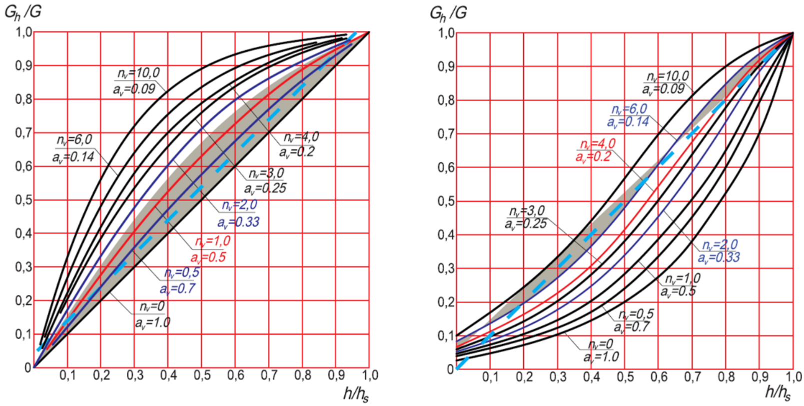
Fig. 4. Reference table for calculating k_V [4]

Next, we will consider the concept of the flow characteristic of RV. To do this, note that the total pressure losses in the pipeline network P_0 - P_3 consist of losses in the control valve $\Delta P=P_1$ - P_2 and losses in the pipeline ΔP_L (see Fig. 1). The ratio between ΔP and ΔP_L is characterized by the module n_V or valve authority a_V [3]:

$$n_v = {}^{\Delta P_L}/_{\Delta P}\ ;\ \ a_v = \frac{1}{1+n_v}.$$

During the operation of the valve, the type of its throughput characteristic usually changes significantly depending on the change in the hydraulic resistance of the network, the parameters of the substance (temperature, density, viscosity, etc.), which collectively leads to a change in the flow mode. Accordingly, the indicators n_V , a_V change, and, together with them, the appearance of the graphs of the flow characteristics of the valve (Fig. 5).

The throughput (ideal) characteristic of valve in working conditions is called the flow (real) characteristic, which is the dependence of the relative volumetric Q_h/Q_{max} or mass G_h/G_{max} flow rates of the substance from the degree of opening of the regulating valve h/h_S [3].



a) *б)*

Fig. 5. Examples of flow characteristics depending on the degree of opening at different values of the module n_V/authority a_V [3]:
a) – for a valve with a linear throughput characteristic;
b) – for a valve with an equal percentage throughput characteristic

The non-linear nature of the change in the flow characteristic naturally leads to a change in the K_{RV} transfer coefficient of the regulating valve, which in relative terms can be represented as:

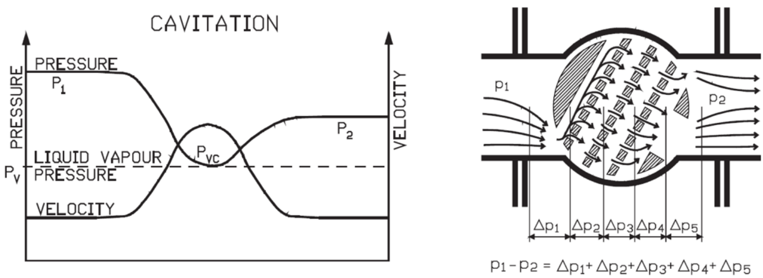
$$K_{RV} = \frac{d(Q/Q_{max})}{d(h/h_s)} = \frac{dq}{dl}.$$

In the process of operation, the throttling regulating valves must provide such a flow characteristic of the hydraulic system that the static characteristic of the control object (as a whole) is as close as possible to the linear one. Then the transmission coefficient K_O of the control object, which is the product of the transmission coefficients of the actuator K_{AC}, the regulatory valve K_{RV}, the technological unit K_{TU} and the sensor K_S, will change insignificantly, i.e.:

$$K_o = K_{AC} \cdot K_{RV} \cdot K_{TU} \cdot K_S \approx \text{const}.$$

Therefore, the designer faces the task of choosing such a valve with the transmission coefficient K_{RV} that would change minimally in the working range of the stroke of the rod $l=h/h_S$=0,2 ... 0,8. For example, if the functioning of the control system requires a linear flow characteristic, then there is an alternative: for values of the $n_V \leq 1{,}5$ one should choose a valve with a linear throughput characteristic, and if $n_V \geq 3{,}0$ then a valve with an equal percentage throughput characteristic (see Fig. 5). If an equal-percentage flow characteristic is required, then there is no alternative and one should choose a valve with an equal-percentage throughput characteristic. More detailed recommendations for choosing the type of flow characteristic are given in [3, 7].

When choosing the type and parameters of the valve, one should also take into account the possibility of harmful phenomena, namely noise and cavitation, associated with an increase in the speed of the liquid flow that flows through the valve. The result of these phenomena can be intensive wear of the surfaces of the throttling pair, the body, the rod and the sealing elements of the stuffing box, as well as a violation of the tightness in the throttling pair and flange connections. The conditions under which the listed phenomena occur are presented in fig. 6, *a* [1].



а) *б)*

Fig. 6. Phenomena of noise and cavitation in valve [1]:
a) – conditions of occurrence; *b*) –an example of valve with a gradual decrease in the pressure drop across it

An increase in the flow rate of the liquid when it passes through the valve is accompanied by a decrease in the pressure in the throttle passage and can cause the phenomena of cavitation if the pressure falls below some critical P_V threshold. Cavities (caverns) filled with vapors or gases released from the liquid appear in the liquid flow. The occurrence of cavitation is accompanied by the occurrence of vibrations and noises, erosion of the surfaces of the shutters and seats, when the cavities snort near them. However, the most undesirable consequence of cavitation is a sharp increase in the hydraulic resistance of the throttle passage and, as a result, a weak dependence of the medium flow rate on the pressure drops across the valve. To avoid erosion of valve surfaces, it is necessary [1]:

• reduce the flow rate inside the valve using multi-stage pressure drop regulation by utilizing special valve structures (Fig. 6, *b*);

• reduce surface wear due to the use of stainless and hardened materials.

Thus, the most important modern trend in the development of the structures of regulating valves should be recognized as the division of the following functions in their design: flow control and throttling, i.e. extinguishing "excess" pressure drop. Accordingly, with the appearance of these two functions of regulating valves, the content, as well as calculation and software for choosing their size, changed. The new approach consists in choosing the type and size according to the following indicators:

• according to the degree of anti-cavitation or anti-noise protection;

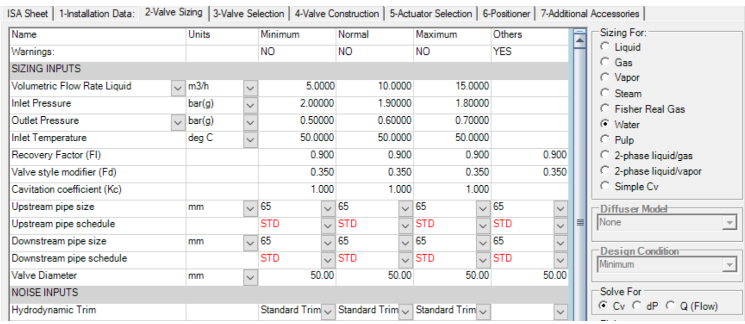
• flow capacity k_V.

In general, it should be noted that the selection of throttling valve parameters requires a certain theoretical training and practical skills from the designer, which can and should be acquired using specialized software from manufacturers.

The purpose and tasks of the research - consider using the Fisher Valve Specification Manager and Metso Nelprof programs as examples for selecting parameters of throttling valves.

Throttling control valves automated calculation of parameters using Fisher VSM and Metso Nelprof programs was chosen as the research method.

Fisher Valve Specification Manager software offers a set of tools for calculating Fisher and Baumann control valves [8]. The calculation itself is performed on the 2-Valve Sizing tab, where the initial data for the calculation is specified, for example, for three options of changing the water flow through it (Fig. 7).



ISA Sheet | 1-Installation Data: | 2-Valve Sizing | 3-Valve Selection | 4-Valve Construction | 5-Actuator Selection | 6-Positioner | 7-Additional Accessories

Name	Units	Minimum	Normal	Maximum	Others
Warnings:		NO	NO	NO	YES
SIZING INPUTS					
Volumetric Flow Rate Liquid	m3/h	5.0000	10.0000	15.0000	
Inlet Pressure	bar(g)	2.00000	1.90000	1.80000	
Outlet Pressure	bar(g)	0.50000	0.60000	0.70000	
Inlet Temperature	deg C	50.0000	50.0000	50.0000	
Recovery Factor (Fl)		0.900	0.900	0.900	0.900
Valve style modifier (Fd)		0.350	0.350	0.350	0.350
Cavitation coefficient (Kc)		1.000	1.000	1.000	
Upstream pipe size	mm	65	65	65	65
Upstream pipe schedule		STD	STD	STD	STD
Downstream pipe size	mm	65	65	65	65
Downstream pipe schedule		STD	STD	STD	STD
Valve Diameter	mm	50.00	50.00	50.00	50.00
NOISE INPUTS					
Hydrodynamic Trim		Standard Trim	Standard Trim	Standard Trim	

Fig. 7. Example of the data input in the Fisher VSM program

Next, on the 3-Valve Selection tab, the type of control valve is selected as well as its desired flow characteristics and *DN* size. At the same time, the program immediately displays possible options of the standard valve types and sizes (Fig. 8).

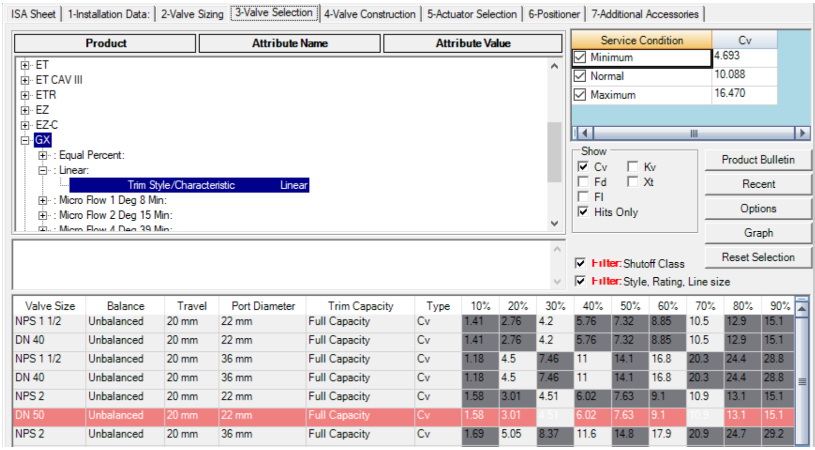
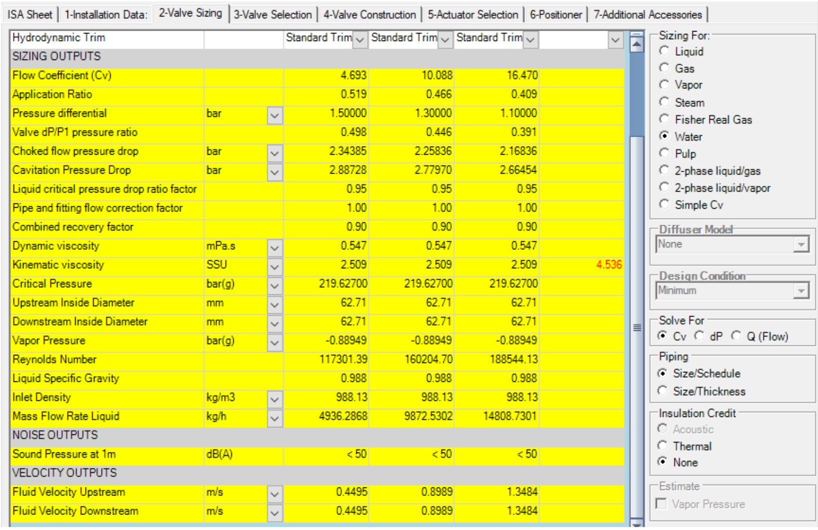


Fig. 8. Example of selecting the type of control valve
in the Fisher VSM program

For the Fisher Valve Specification Manager, control valve parameter calculations can be obtained from the 2-Valve Sizing tab after clicking the Calculate button. By far the most important parameter is the flow capacity C_V. When ordering a valve, one should take C_V for maximum flow rates, and with a margin of up to 20 %. One should also pay attention to the speed of water flow through the valve, which should not exceed 2 m/s (Fig. 9).

On the 3-Valve Selection tab of the Fisher VSM program, after clicking on the Graph button, you can get graphs of the dependence of the throughput on the stroke of the control valve stem $C_V = f(l)$ (Fig. 10). In this case, for the selected valve of the GX type with a linear throughput characteristic, the stroke of the rod exceeds the permissible limits of 20 % ... 80 %. And this is undesirable, because beyond these limits the transmission coefficient of the valve can change significantly. Therefore, under such operating conditions, one should choose a different valve size.

Metso Nelprof software is an expert system for selecting control and shut-off valves. In addition to the calculation equations, it also includes expertise in the interpretation of the results. The program analyzes the selection and gives advice on the selection of control valves [9].



ISA Sheet | 1-Installation Data: | 2-Valve Sizing | 3-Valve Selection | 4-Valve Construction | 5-Actuator Selection | 6-Positioner | 7-Additional Accessories

Hydrodynamic Trim		Standard Trim	Standard Trim	Standard Trim	
SIZING OUTPUTS					
Flow Coefficient (Cv)		4.693	10.088	16.470	
Application Ratio		0.519	0.466	0.409	
Pressure differential	bar	1.50000	1.30000	1.10000	
Valve dP/P1 pressure ratio		0.498	0.446	0.391	
Choked flow pressure drop	bar	2.34385	2.25836	2.16836	
Cavitation Pressure Drop	bar	2.88728	2.77970	2.66454	
Liquid critical pressure drop ratio factor		0.95	0.95	0.95	
Pipe and fitting flow correction factor		1.00	1.00	1.00	
Combined recovery factor		0.90	0.90	0.90	
Dynamic viscosity	mPa.s	0.547	0.547	0.547	
Kinematic viscosity	SSU	2.509	2.509	2.509	4.536
Critical Pressure	bar(g)	219.62700	219.62700	219.62700	
Upstream Inside Diameter	mm	62.71	62.71	62.71	
Downstream Inside Diameter	mm	62.71	62.71	62.71	
Vapor Pressure	bar(g)	-0.88949	-0.88949	-0.88949	
Reynolds Number		117301.39	160204.70	188544.13	
Liquid Specific Gravity		0.988	0.988	0.988	
Inlet Density	kg/m3	988.13	988.13	988.13	
Mass Flow Rate Liquid	kg/h	4936.2868	9872.5302	14808.7301	
NOISE OUTPUTS					
Sound Pressure at 1m	dB(A)	< 50	< 50	< 50	
VELOCITY OUTPUTS					
Fluid Velocity Upstream	m/s	0.4495	0.8989	1.3484	
Fluid Velocity Downstream	m/s	0.4495	0.8989	1.3484	

Fig. 9. Table of results control valve parameters calculations in the Fisher VSM program

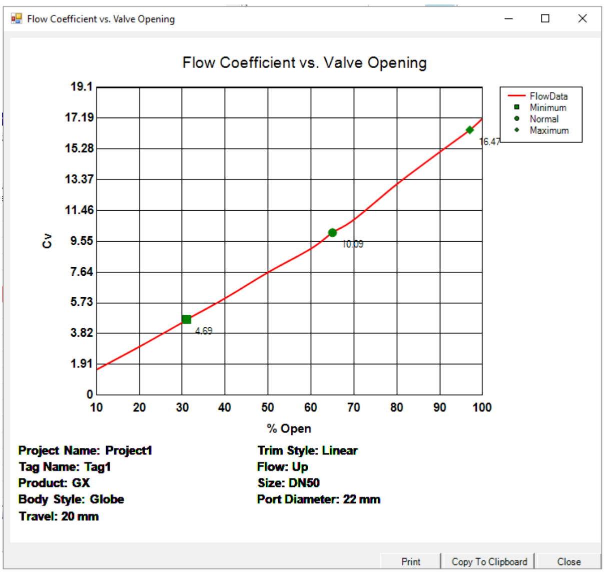


Fig. 10. Dependence graph *Cv* = *f(l)* for a linear throughput characteristic

Input data for calculations is set in the Control tab, for example, for two options of changing water flow through a valve, the type of which is selected from the list that appears after clicking on the Valve button (Fig. 11).

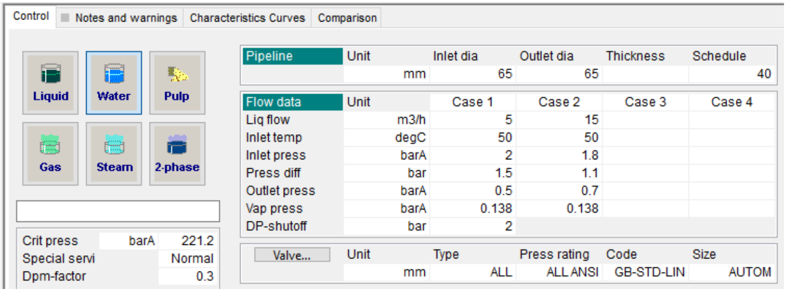
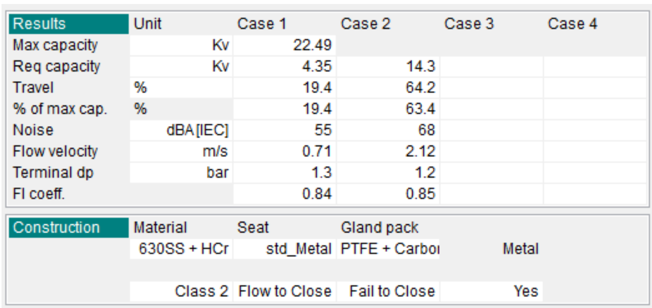


Fig. 11. Example of data entry in the Metso Nelprof program

For the Metso Nelprof program, calculation results can be obtained by clicking on the Calculate button (Fig 12).



Results	Unit	Case 1	Case 2	Case 3	Case 4
Max capacity	Kv	22.49			
Req capacity	Kv	4.35	14.3		
Travel	%	19.4	64.2		
% of max cap.	%	19.4	63.4		
Noise	dBA [IEC]	55	68		
Flow velocity	m/s	0.71	2.12		
Terminal dp	bar	1.3	1.2		
Fl coeff.		0.84	0.85		

Construction	Material	Seat	Gland pack		
	630SS + HCr	std_Metal	PTFE + Carboı	Metal	
	Class 2	Flow to Close	Fail to Close	Yes	

Fig. 12. Table of results control valve parameters calculations in the Metso Nelprof program

When you go to the Characteristics Curves tab of the Metso Nelprof program, you can see graphs: inherent and installed characteristics of the selected GB-STD-LIN type valve (top in Fig. 13), the change in pressure and valve transmission coefficient depending on the stroke of the rod (bottom in Fig. 13).

In this case, it is noteworthy that the transmission coefficient of the selected GB-STD-LIN type valve changes insignificantly within 35 % ... 80 % of the stroke of the rod, therefore this valve can be recommended for use.

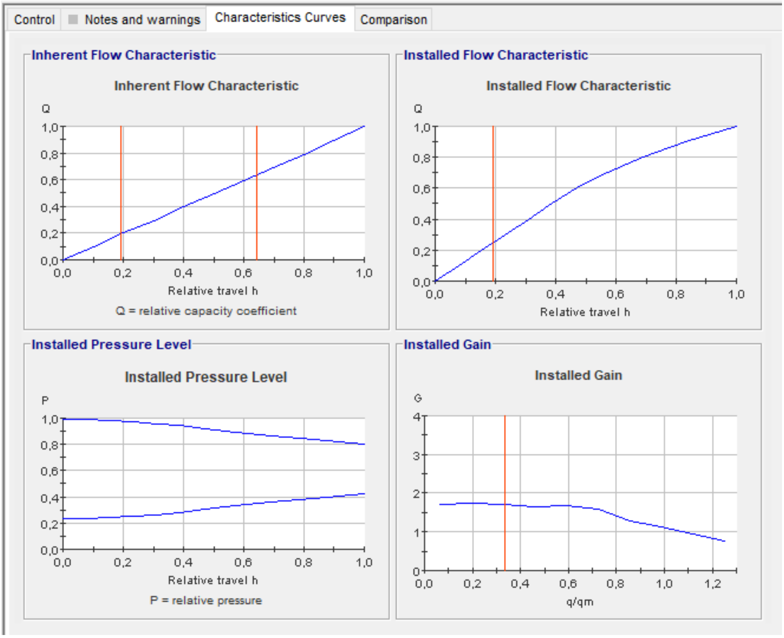


Fig. 13. Graphs of control valve characteristics in the Metso Nelprof program

Using the Fisher Valve Specification Manager and Metso Nelprof programs to select parameters of throttling RVs allows one to quickly obtain and analyze the results for several alternative options and choose the desired one.

The functionality of the Metso Nelprof program also allows one to view and select the type of actuator for the selected valve. The program is presented on the website of the manufacturer in the form of a WEB page, which simplifies its use.

The programs Fisher Valve Specification Manager and Metso Nelprof provide in a convenient form an opportunity to calculate the main parameters of throttling valves and choose a specific type that meets the technical requirements of its use, taking into account the limitations. These programs allow designers of automatic control systems to develop skills in the selection of valves and actuators, to correctly place orders for the manufacturing company.

REFERENCES
ЛІТЕРАТУРА

1. Flow control manual. Finland: Valmet Neles Finland Oy, 2020. – 169 p.

2. Control valve handbook, Fourth Edition. USA: Fisher Controls International LLC, 2005. – 297 p.

3. V. Pokotilov. Reguljujuchi klapani avtomatizovanih system teplo ta holodo postachanja. Viden: firma "HERZ Armaturen", 2017. – 232 p.

4. Handbook for control valve sizing. Technical bulletin 1-I. Italy: PARKOL S.p.A., 2016. – 24 p.

5. K_V coefficient Valve sizing. Application Notes AB 05 EN. Germany: SAMSON AG, 2012. – 2 p.

6. ISA-75.01.01-2007 (60534-2-1 Mod) Flow Equations for Sizing Control Valves. USA: ISA, 2007. – 72 p.

7. Korotkyi katakog produkzii Fisher. USA: EMERSON, 2018. – 244 p.

8. Quick Start Guide Fisher Specification Manager. USA: Fisher Controls International LLC, 2012. – 28 p.

9. NELPROF 6.2 user's guide. Finland: Metso, 2010. – 77 p.

Анотація. *При проектуванні нових систем автоматичного керування технологічними процесами виникає необхідність вибору типу і розрахунку параметрів дросельних регулюючих органів (РО). З точки зору гідравліки дросельний РО являє собою складний змінний місцевий опір. В технічній документації виробники вказують пропускну здатність РО та його пропускну характеристику. Вона може бути, наприклад, лінійною, рівнопроцентною, що в основному залежить від конструкції сідла та плунжера. У процесі роботи РО вид його пропускної характеристики звичайно суттєво змінюється залежно від зміни гідравлічного опору мережі, параметрів речовини (температури, щільності, в'язкості та ін.), що в сукупності приводить до зміни режиму руху потоку. Відповідно змінюється вигляд графіків пропускної характеристики РО. Тому пропускну (ідеальну) характеристику РО в робочих умовах прийнято називати витратною (реальною) характеристикою. Нелінійний характер зміни витратної характеристики звісно приводить до зміни коефіцієнта передачі регулюючого органу. При виборі типу і параметрів клапану*

слід також зважати на можливість виникнення шкідливих явищ, а саме шуму і кавітації, пов'язаних з зі збільшенням швидкості протоку рідини, яка протікає крізь РО. Результатом цих явищ може стати інтенсивне зношування поверхонь дросельної пари, корпусу, штока і ущільнювальних елементів сальника, а також порушення герметичності в дросельній парі і фланцевих з'єднаннях. В цілому слід зазначити, що вибір параметрів дросельних РО потребує від проектувальника певної теоретичної підготовки і практичних навичок, які доцільно набути, використовуючи спеціалізовані програми від фірм-виробників. Програмне забезпечення Fisher Valve Specification Manager пропонує набір інструментів для розрахунків регулюючих клапанів Fisher і Baumann. Програмне забезпечення Metso Nelprof – це експертна система вибору регулюючих та запірних клапанів. Використання програм Fisher Valve Specification Manager та Metso Nelprof для вибору параметрів дросельних РО дозволяє швидко отримати та проаналізувати результати для декількох альтернативних варіантів та обрати бажаний. Функціонал програми Metso Nelprof дозволяє також розглядати та обирати тип виконавчого механізму для обраного клапану. Програма представлена на сайті фірми-виробника у вигляді WEB-сторінки, що спрощує її застосування. Програми Fisher Valve Specification Manager та Metso Nelprof у зручній формі надають можливість провести розрахунки основних параметрів дросельних клапанів та обрати конкретний тип, який задовольняє технічним вимогам його використання з урахуванням обмежень. Дані програми дозволяють сформувати у проектувальників систем автоматичного керування навички з вибору клапанів та виконавчих механізмів, коректно скласти замовлення для фірми-виробника.