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ELECTRIC DRIVE SETTING TORQUE CALCULATION METHOD IN ELECTRIC DRIVE SHUT-OFF VALVE SYSTEM WITH RECTILINEA DISPLACEMENT OF THE VALVE CLOSURE

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A new method for calculating the setting torque magnitude of the electric drive in the electric drive shut-off system as the main elements ensuring the safety of oil pipelines and main gas pipelines is presented. The method allows to calculate a sufficient value of the torque of the drive adjustment with a minimum volume of input information about the system elements characteristics (electric drive, shut-off valve, control system) and to ensure that the actual torque is met when the system is completely stopped by the calculated torque specified by static methods. Clarification of the tuning parameters is carried out by means of experimental determination of environmental leaks with a step-by-step decrease in the torque within the regulation of the electric drive. The use of the technique at the design stage allows, during the operation of the systems, to reduce undesirable loads arising in the shut-off valves from the side of the electric drive, ensuring reliable operation of pipeline systems transporting mineral raw materials.

Key words: electric shut-off valves; force calculation method; reliability; quality

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Introduction. Currently, more than 30 % of the mineral raw materials (bulk of oil and gas) are transported in Russia by pipeline transport. The Russian gas transportation system is the largest in the world and is more than 165 thousand km long. The length of the main oil pipelines intended for transportation of oil from areas of their extraction or storage to places of consumption exceeds 70 thousand km. An essential part of the pipeline system is a shut-off valve. It is designed to cut off the pipeline section during an accident or repair work. On the linear part of the pipeline shut-off valves are installed every 10-30 km.

The vast majority of pipeline valves are remotely controlled by an electric drive. This makes it possible to use electric shut-off valve systems in the longest and most complicated pipelines. Characteristics that determine the possibility of technical alignment of the electric drive and stop valves within the system are the power parameters: torque and forces.

The methods of force calculations for hand-operated valves of various domestic manufacturers are based on unified principles formulated by the classics of valve construction D.F.Gurevich in the early 1960s [3]. They are time-tested and united by the standards of CDBVC (Central Design Bureau of Valve Construction, St. Petersburg). Unfortunately, in these documents there are no methods for calculating electric drives.

In accordance with the standards for electric drives, the closing torque ($M_{\text{close,ED}}$) is assumed to be equal to the torque calculated for manual reinforcement, increased by the safety factor [7]:

$$M_{\text{close,ED}} = K_{\text{mf}} M_{\text{manual.close}}, \quad (1)$$

where K_{mf} – margin the factor for the required torque on the drive, for the electric drive $K_{\text{mf}} = 1,1 \div 1,25$.

This approach, in our opinion, is incorrect. It leads to a decrease in the reliability of electric drives and the safety of enterprises operating this type of equipment [1, 9, 15].

Hand valve, in the first approximation, is a static system, the calculation of which can be carried out using static methods. Electric drive armature, in most cases including an asynchronous electric motor, is an electrodynamic system. When the valve with the rectilinear movement direc-



tion of the locking element (valve, gate) is closed, processes similar to the «short circuit» mode appear in the system. The currents at the time of closure of the system can exceed the nominal value by 5-10 times, respectively, and the torque at closing for a short period of time increases many times. The longer the «time delay» when the motor control system triggers, which in practice can reach 100 ms, the higher the torque value [8, 16]. As a result of the increase in torque in the stop valves on the side of the electric drive, significant loads occur that reduce the reliability of the systems during operation [11, 14].

Therefore, the actual task is to develop a technique for power calculation of electric drives. The purpose of the work is to determine the magnitude of the tripping electric drive torque, which, taking into account the electrodynamic processes, will ensure reliable locking of the armature, i.e. will ensure the compliance of the actual torque with the complete shutdown of the system to the estimated torque established by static methods and confirmed by many years of operation experience.

Main provisions of the methodology. The basis of the methodology was the following:

1. Electric drive valve is a technical system that includes in its structure three main elements: electric drive, shut-off valve and electric motor control system. Changing the parameters of any of their elements leads to a change in the output characteristics of the system as a whole [4, 5].

2. The static closing torque ($M_{\text{close,ED}}$) is the basic value that ensures reliable operation of the objects operating the system. Therefore, the torque at full stop of the system must correspond to the $M_{\text{close,ED}}$.

3. The methodology should take into account the minimum set of the most important characteristics of elements that affect the output characteristics of the system [10, 12].

The essence of the methodology. Based on the results of numerous theoretical and experimental studies, the formula [2] is proposed for calculating the torque for setting the electric drive to trip ($M_{\text{ED,turn.off}}$), sufficient for reliable locking of the valve,

$$M_{\text{ED,turn.off}} = M_{\text{close,ED}} - 6n_{\text{ED}}K_i\Delta t\lambda, \quad (2)$$

where $M_{\text{close,ED}}$ – torque, ensuring a reliable closing of the reinforcement, determined by static methods and specified in the tests, N·m; n_{ED} – rotational speed of the output shaft of the drive, prm; λ – system stiffness, N·m/deg; K_i – empirical coefficient, time-dependent delay Δt of control system (CS) and defined by the following formula

$$K_i = 1.1^i, \quad (3)$$

where i – sequence number of time delay.

The parameters for assigning the corrective empirical delay coefficient are as follows:

i	0	1	2	3	4	5	6	7
$\Delta t, s$	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08

The formula (2) takes into account the main characteristics of each of the elements combined in the technical specification (TS) and at the design stage it is possible to calculate the torque of the electric drive shut-off at known values of all the main system parameters: the rotational speed of the output drive shaft of the electric drive n_{ED} , response time of the control system Δt .

System stiffness λ – is the damping component [13]. Increasing the stiffness increases the actual torque value [6]. It should be noted that to the present time there are no methods for calculating the rigidity of electric drive reinforcement. To determine the value of this parameter, you can use the data in Table 1.

Table 1

Dependence of the system stiffness on the nominal torque and the drive adjustment range

Electrical drive torque adjustment range, N·m	M_{nom} , N·m	System stiffness is average (minimum; maximum), N·m/deg
40-120	80	10 (6.3; 16)
100-250	175	25 (16; 40)
200-500	350	63 (40; 100)

Table 1 shows the results of the analysis, which made it possible to establish a relationship between the rigidity of the system and the range of adjustment of the electric drive (ED) by torque for controlling various shut-off valves. The average stiffness value (Table 1) can also be determined from the nominal torque of the ED (M_{nom}) within the specified range of the tuning range.

If the calculated moment $M_{close,ED}$ significantly less or more than M_{nom} , then the least or greatest rigidity should be applied from a number of preferred values indicated in parentheses (Table 1).

Rotational speed of the output shaft (n_{ED}) is determined in accordance with the technical specifications (TS) for the electric drive. The influence of this parameter on the output characteristics of the vehicle is quite weighty. With increasing speed, the actual torque value, fixed when the system is completely stopped, increases almost directly in proportion.

Time delay of control system operation (Δt) is defined as the sum of the delays of all CS components. The value of this parameter is limited by standards and should not exceed 100 ms (0.1 s).

The values of the torque of the drive adjustment calculated in accordance with the formula (2) at the test stage of the prototypes must be confirmed and, if necessary, corrected. The simplest and most reliable method for clarifying the real torque of switching off the ED is the «leakage method». It can be used both at the stage of testing prototypes, and for adjusting the values $M_{close,ED}$ serially produced valves already in operation.

The algorithm of the proposed method can be represented in the following form:

- 1) to make a preliminary calculation of the value $M_{ED,turn.off}$ by the formula (2);
- 2) adjust the system in accordance with the calculated design torque $M_{ED,turn.off}$;
- 3) to install electric drive armature on the test stand, connect the power supply and supply the working medium under pressure (Fig. 1);

- 4) start the system and complete five complete cycles. A full cycle is understood as the execution by the closing body of a move from the position «closed» to the «open» and backward;

- 5) after five complete cycles, stop the system and determine the air leakage in the shutter. Leakage is determined by counting the number of air bubbles emerging from the nozzle, connected to the outlet fitting of the armature and immersed in a container of water, according to formula

$$q_{air} = \frac{N_{ab}V_{ab}}{\tau}, \quad (4)$$

where q_{air} – leakage in the gate, cm^3/min ; N_{ab} – measured number of air bubbles; V_{ab} – the volume of the air bubble (indicated in table. G.7 depending on the inner diameter of

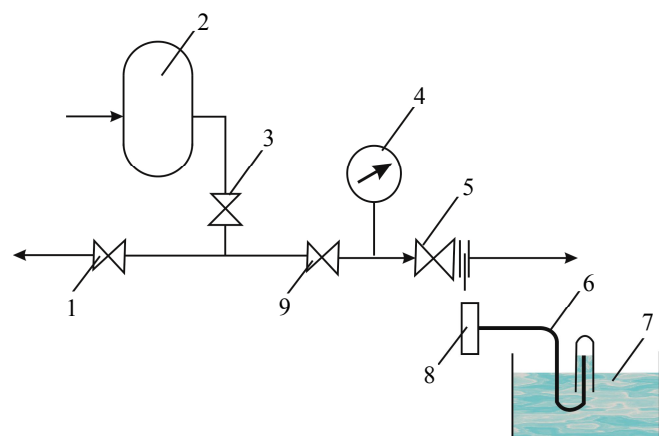


Fig. 1. Schematic diagram of the test stand

- 1, 3, 9 – shut-off valve; 2 – pressure source;
4 – measuring pressure device; 5 – tested electric drive valve; 6 – beaker;
7 – water tank; 8 – blank plug

the nozzle – GOST R 53402-2009 «Pipeline valve. Methods of control and testing». Moscow: Standartinform, 2010, p. 54), cm^3 ; τ – measuring time, min;

6) If there is no leakage or is within the tolerance, then it is necessary to reduce $M_{\text{ED.turn.off}}$ on 5 N·m and repeat the test according to par. 2-5. The value of the system adjustment torque should be reduced until leakage occurs or until the limit value is reached by the torque limiter;

7) If after the initial setting of the system for the tripping torque $M_{\text{ED.turn.off}}$ the leakage will be fixed immediately, then it is necessary to increase $M_{\text{ED.turn.off}}$ on 5 N·m and repeat the test according to par. 2-5. The torque value of the system setting can be increased no more than 1.5 times or until the maximum limit value is reached by the torque limiter. It should be understood that in the described situation the probability of rejection of the reinforcement is great, the presence of which must be excluded.

The described algorithm allows to specify the value of the torque of the adjustment of the electro-drive, in which the system will ensure reliable locking of the medium («moment on the verge of leakage»). Given that due to process manufacturing tolerances for each system, the set value will be individual, but these differences are not critical, within $\pm 5\%$, in the product specification for the product, the value of the torque setting of the ED for shutdown must be indicated with a safety factor:

$$M_{\text{ED.turn.off}}^{\text{TS}} = 1.2M_{\text{ED.turn.off}}^{\text{ex}} \quad (5)$$

An example of the implementation of the methodology. To confirm the efficiency of the procedure, calculation and refinement of the settings of the real system of electric drive armature was performed (Fig.2).

The system included the following elements: electric drive (output shaft speed $n_{\text{ED}} = 32$ rpm, limits of torque clutch control 100-250 N·m); shut-off valve (conditional pass 50 mm, torque ensuring reliable closure of the valve, determined by static methods and specified in the current TS $M_{\text{close. ED.}} = 180$ N·m); control unit (time delay $\Delta t = 20$ ms).

The empirical coefficient, which depends on the time lag of the CS, was calculated by formula (3), in accordance with the data given $K_i = 1.1^1$.

Stiffness of the shut-off valve $\lambda = 25$ N·m/deg according to the data in Table 1.

The torque value of the ED ($M_{\text{ED.turn.off}}$) calculated according to formula (2):

$$M_{\text{ED.turn.off}} = 180 - 6 \cdot 32 \cdot 1.1^1 \cdot 0.02 \cdot 25 = 74.4 \text{ N}\cdot\text{m}.$$

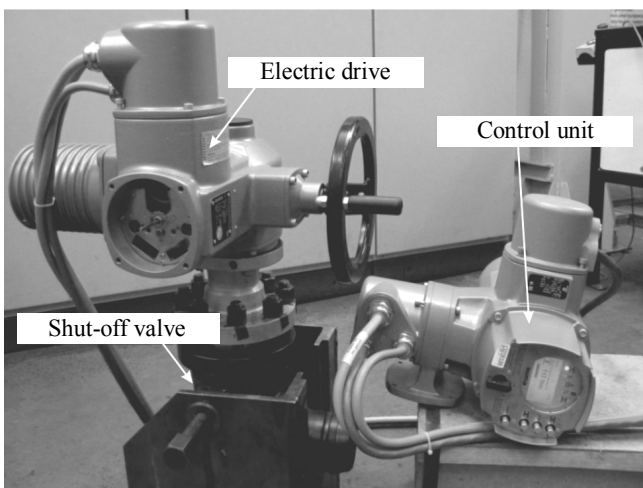


Fig.2. Electromechanical shut-off valves system

According to the calculation results, it is established that the torque specified in the current specification (180 N·m) is significantly higher than the calculated value obtained using the developed procedure.

Limits of regulation of the ED (100-250 N·m) did not allow the system to be tuned to a new estimated value ($M_{\text{ED.turn.off}} = 74.4$ N·m) for specification of parameters by carrying out of tests on leaks. For the purity of the experiment, the ED of the real system was tuned to the tripping torque corresponding to the limiting minimum value (100 N·m). In addition, tests were car-

Table 2

ried out for a new system with identical characteristics, but with smaller limits of torque limitation (40-120 N·m), which made it possible to approach the torque value obtained by calculation in the process of testing. The test results are shown in Table 2. According to the specification, the maximum permissible leakage in the valve for this type of valve is 30 cm³/min.

Analyzing the results obtained (Table 2), it can be concluded that the fixed leakage values in the valve gate do not exceed the set value. This proves the operability of the proposed technique and the possibility of reducing the timing of the adjustment of the ED in the system of electric drive with rectilinear motion of the shut-off element without loss of tightness of the gate of the shut-off valve.

Leakage of electric shut-off valve, sm³/min

Amount of cycles	ED limits of regulation, N·m	
	100-250	40-120
250	0	0
750	0	0
1250	0	0
1750	1.2	0
2000	4.8	0
2250	6.0	0
2500	8.7	0
2750	9.1	0.7*
3000	11.0	3.2**

* From the 2501st to the 2700th cycles of ED tuning of agreed with $M_{ED,turn.off}^{ex} = 90 \text{ N} \cdot \text{m}$.

** From the 2701st to the 3000th cycles of ED tuning of agreed with $M_{ED,turn.off}^{ex} = 80 \text{ N} \cdot \text{m}$.

Conclusion

1. A new technique for determining the magnitude of the torque of the electric drive for adjusting the system of electric drive armature with rectilinear movement of the shut-off body (piston, valve) is developed.

2. The method allows for a minimum amount of input information on the characteristics of the system elements (electric drive, shut-off valve, control system) to calculate a sufficient torque value of the drive adjustment and ensure that the actual torque corresponds to the total stop of the system with the calculated torque established by static methods.

3. To refine the settings of the systems being designed or in operation, an experimental method is proposed, the «leakage method». The method is based on the test procedure for tightness of shut-off valves with a step-by-step reduction in the torque of the electric drive to the limit value – the minimum torque limited by the limits of the regulation of the electric drive.

4. The use of the technique at the design stage allows, during the operation of the systems, to reduce undesirable loads that arise in the shut-off valve on the electric drive side, ensuring reliable operation of pipeline systems transporting mineral raw materials.

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