IMPROVED CONTROL OF DYNAMIC LOADS WITHIN HYDRAULIC SYSTEMS BY CONSIDERING NONLINEAR PROPERTIES OF PIPELINE FITTINGS

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It is shown that the existing methods and technical means of reducing dynamic loads in hydraulic systems do not allow to significantly reduce pressure fluctuations in the hydraulic network. It does not take into account the real hydraulic characteristics of pipeline fittings. The paper is devoted to the development of a method of reducing dynamic loads in the hydraulic systems by forming a non-uniform control law of the variable-frequency electric drive of pipeline fittings, which takes into account the nonlinear dependence of the coefficient of hydraulic resistance on the relative degree of opening of the valve's working body.

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I Introduction

During the operation of hydraulic systems (HS), processes occur in the hydraulic system, which are accompanied by increased dynamic loads in the form of surges, pressure drops and vibrations of technological equipment. They are caused by pressure fluctuations in the pipeline. The mentioned phenomena are due to a number of reasons: emergency shutdowns of power supply of pump units, rapid closing/opening of safety or shut-off and regulating fittings, etc. [1]–[4].

This situation is related to the absence of reliable and effective means of protection against surges and pressure pulsations [1]–[4]. Their main drawbacks include the impossibility of significant reduction of the amplitude of pressure fluctuations when installing air caps or liquid discharge valves, the stepwise control of pipeline fittings without taking into account its non-linear hydraulic characteristics; uncontrollability of the armature in the event of sudden interruptions in HS power supply, sensitivity to sudden changes in pressure fluctuations in the hydraulic system, triggering in the event of an accident. As a rule, an unregulated electric drive is used in HS to perform uniform or discrete closing in several stages, which does not provide ensuring the change of dynamic loads in the hydraulic system within permissible limits.

Therefore, a topical task consists in finding ways to reduce HS accident rate, one of which is to control the speed of closing/opening of pipeline fittings by using a variable-frequency electric drive (ED).

II Research method and results

The main pipeline fittings hydraulic characteristic affecting the nature of the flow of transient processes in the HS is the dependence of hydraulic resistance coefficient ξ on relative degree β of its opening (Fig. 1).

It can be described by the analytical dependence of the form:

$$\xi = A\left(\left(1/\beta\right)-1\right)^{C} + B\left(\left(1/\beta\right)-1\right)^{D} + \xi_0 \tag{1}$$

where *A, B, C, D* – the approximation coefficients that depend on the type of pipeline fittings; ξ_0 – the coefficient of hydraulic resistance when the valve is fully opened (ξ=1).

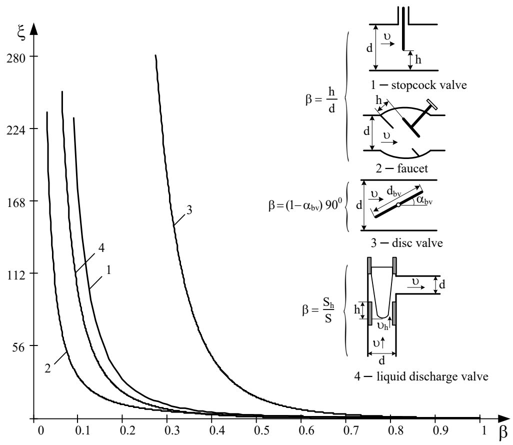

Figure 1: Dependences of hydraulic resistance coefficient ξ on relative degree β of its opening

The law of controlling the stopcock valve when it is closed is described by the expression:

$$\beta(t) = 1 - (t/t_{sh})^{1/n} \tag{2}$$

where n – the coefficient of pipeline fittings control intensity ($n \geq 1$); t, t_{sh} – the current time and the time of complete valve closure, respectively, s.

In order to reduce dynamic loads in HS pipeline network, it is proposed to form a non-uniform control law of the stopcock valve variable-frequency ED taking into account the non-linear dependence (1) on the entire interval of movement of its working body.

To study the dynamic processes in the hydraulic network with different laws of pipeline fittings control, a mathematical model of HS with a stopcock valve variable-frequency induction ED was developed, which takes into account the propagation of water hammer in the hydraulic network. Modeling parameters: rated pump pressure $H_{pn} = 100$ m, the flow rate of the working medium $\upsilon_n = 1$ m/s, shock wave propagation speed $c = 1000$ m/s, pipeline length $L = 5000$ m, diameter $d = 1.2$ m, number of pipeline sections $N = 20$, the power of the stopcock valve drive induction motor 5.2 kW, opening/closing time 4.6 min., gear ratio r_g – 80.

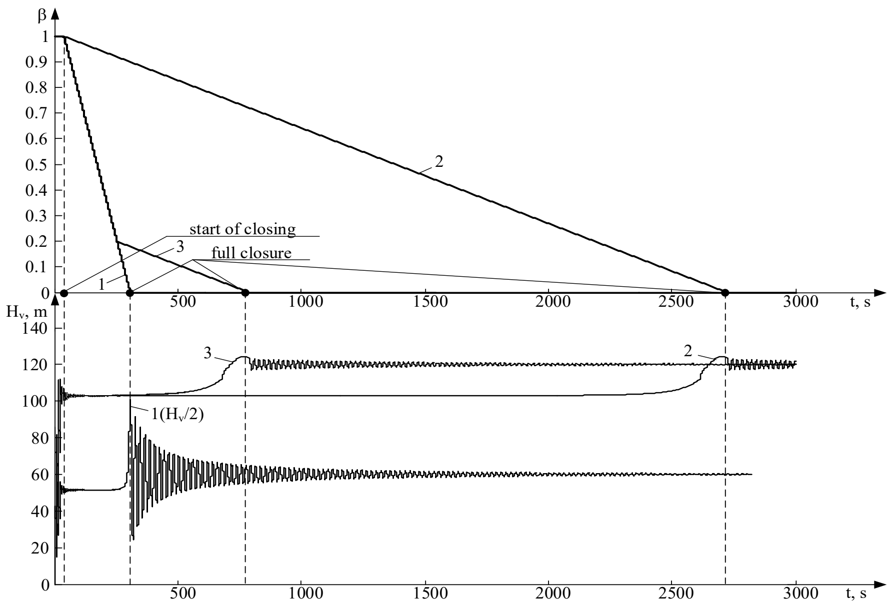

Figure 2: Graphs of transient processes in HS with the stopcock valve uniform (1, 2) and non-uniform (3) control

Fig. 2 shows the time-variable curves of changes of the head $H_v(t)$ in the pipeline network at the stopcock valve and the relative degree $\beta(t)$ of the valve opening during uniform (Fig. 2, curves 1 and 2) and non-uniform (Fig. 2, curve 3) control. Uniform control corresponds to the stopcock valve closing at a constant supply voltage frequency of 50 Hz and 5 Hz, respectively. With uneven control, the stopcock valve is closed with a supply voltage frequency of 50 Hz in the area, where β>0.2 and 5 Hz – where β≤0.2 respectively.

The analysis of the curves of pressure change near the stopcock valve shows that control at a constant frequency of the supply voltage equal to 50 Hz is accompanied by a rapid increase in pressure in the hydraulic network (Fig. 2, curve 1), the value of which is twice as high as the rated pressure of the pump. The largest decrease in the pipeline pressure is observed both when the value of the frequency of the supply voltage is reduced (Fig. 2, curve 2) and when the stopcock valve is unevenly controlled (Fig. 2, curve 3). However, with uneven control, the stopcock valve closing time is reduced tenfold, which is especially important in emergency modes associated with the sudden disappearance of power supply in the HS and the occurrence of liquid counterflow.

The adequacy of the obtained theoretical results is confirmed by experimental research performed on a laboratory installation of a hydraulic transport complex with a controlled stopcock valve.

III Conclusions

It has been determined that the conventional methods and technical means of reducing dynamic loads, which are used in practice, do not provide significant reduction of the amplitude of pressure fluctuations in the pipeline network and do not consider the task of controlling the electric drive of pipeline fittings in order to minimize dynamic loads in the hydraulic system. They do not take into account the real hydraulic characteristics of the valve and are based on increasing the closing time with uniform control or forming a stepped closing trajectory of the shut-off and regulating valve by using an unregulated electric drive.

It has been proven that in order to reduce dynamic loads in the pipeline network of the hydraulic system, it is necessary to form a non-uniform control law of the stopcock valve electric drive, taking into account the non-linear dependence of the hydraulic resistance coefficient on the relative degree of opening, which makes it possible to exclude dangerous pressure fluctuations in the pipeline, which can result in an emergency situations in the hydraulic system.

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