Dynamic loads control in a pump complex with adjustable pipeline valves

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***Abstract*—An electromechanical system of dynamic loads reduction in pump complex pipeline network is developed on the basis of locking and regulating stopcock variable-frequency electric drive. It is proved that irregular rate of pipeline valves control is an efficient way of dynamic loads reduction. An adjustable valve pipeline network model taking into account wave processes in the pipeline and stopcock hydraulic resistance nonlinear dependence on the relative rate of its opening is offered.**

Keywords—electromechanical system, controlled electric drive, locking and regulating valves, dynamic loads, irregular rate of control

I. INTRODUCTION

Pipeline valves are the most significant element of pump complexes (PC) technological equipment and function as protective, safety and regulating means. PC valves control influences the character of transient processes in the hydrosystem. Frequent shutting (opening) of pipeline valves without observation of the required rate and duration of control, check valve abrupt response at PC sudden power supply outage are accompanied by occurrence of surges in the communication network, increased vibrations of the pump unit walls and flowing channel, pipeline network pressure rush 5-7 times as large as the admissible values. Such conditions result in decrease of the pipeline valves and pumping equipment life time and significant material expenditure on breakdown consequences elimination.

Sufficient attention is paid to the problem of surges, research of wave processes in pressure pipeline systems [1–5]. Papers [2, 5] contain comparative characteristics of surge-proof valves used in pipeline networks. The main faults of such control means include:

bulkiness of the structure and impossibility of considerable decrease of pressure oscillation amplitude when air chambers, receivers, drain valves etc. are installed;

absence of the possibility of flow rate smooth variation taking into consideration the valve hydraulic resistance coefficient nonlinear dependence on the relative rate of its opening;

valves uncontrollability at sudden pump station power supply outage.

II. METHOD AND RESEARCH RESULTS

To exclude increased dynamic loads under such conditions an electromechanical system of decreasing dynamic loads (ESDDL) has been developed on the basis of variable-frequency electric drive (ED) of locking and regulating stopcock with a standby power supply (Fig. 1). Such a system can be used for valves control under both usual (operating) conditions, when head or capacity are regulated according to the current water consumption, and under emergency conditions connected with sudden electric power outage, occurrence of surges.

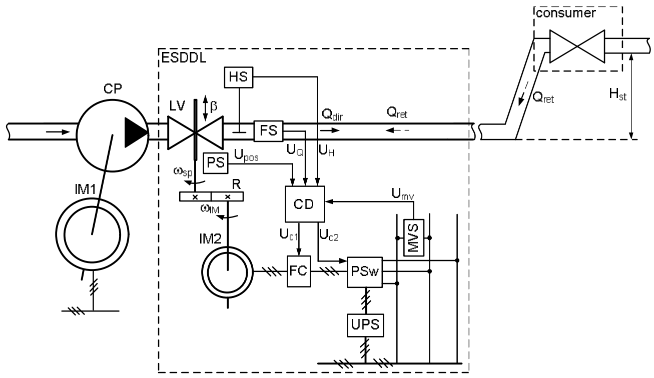

Fig. 1 ESDDL functional diagram

This system includes: locking and regulating valves LV installed at the centrifugal pump CP output with a drive induction motor IM1; a frequency converter FC connected to valves drive induction motor IM2 whose shaft is connected with valves spindle through reducer R; head sensors HS and flow sensors FS installed in the pump discharge tube; pipeline valves locking device LV position sensor PS; mains voltage sensor MVS; uninterruptible power supply UPS; power switch PSw; control device CD.

To reduce dynamic loads in PC at sudden power supply outage the system switches the power of the stopcock variable-frequency electric drive to a standby power supply.

Formation of an irregular rate of stopcock opening (shutting) is an efficient way of reducing dynamic loads in PC

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

This rate takes into consideration the hydraulic resistance coefficient ξ_v nonlinear dependence on pipeline valves opening relative rate β

$$\xi_v(\beta) = A((1/\beta) - 1)^C + B((1/\beta) - 1)^D + \xi_0. \qquad (2)$$

In (1) and (2): n – valves control intensity coefficient ($n \geq 1$); t, t_{sh} – current time and time of valves complete shutting, respectively, s; A, B, C, D – approximation coefficients depending on the pipeline valves type; ξ_0 – hydraulic resistance coefficient when valves are completely open (β=1).

To research dynamic processes in a pipeline network a mathematical model with wave processes presented by a system of telegraph equations was used [6]. The system was solved by means of finite elements method enabling presentation of a hydrotransport system as a finite number of sections with equal parameters [7].

Fig. 2 shows head $H_p(t)$ time variable curves at pump output and at stopcock $H_v(t)$ at abrupt (1), smooth (2) and time variable (3) rates of its shutting.

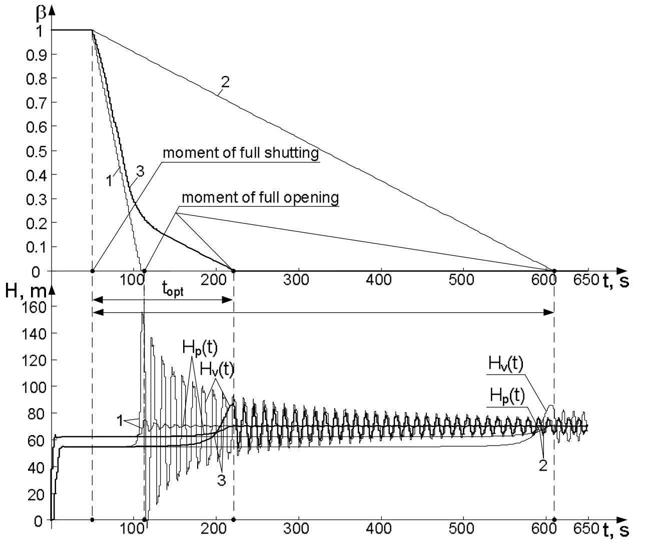

Fig. 2 Schemes of head variation transient processes at abrupt (1), smooth (2) and time variable (3) rates of valves shutting

Parameters of PC used in modeling: nominal pump head $H_n=60$ m, operating liquid flow rate $\upsilon=1$ m/s, consumer hydraulic resistance $R_c=40.65$ s^2/m^5, length $L=3000$ m and diameter $d=1.2$ m of the pipeline, number of pipeline sections N=20, surge velocity $c=1000$ m/s.

It can be seen from the analysis of the obtained curves that abrupt rate of stopcock control (curves 1, Fig. 2) is accompanied by rapid growth of pressure at the stopcock; its value 2.5 times as large as the pump nominal head. Decrease of supply voltage frequency results in reduction of the head up to the value of $0.7H_n$ and increase of valve control time up to maximum value of t_{max} (curves 2, Fig. 2). When valves are controlled with variable rate (curves 3, Fig. 2), valve shutting time t_{opt} reduces by several times, which is especially important in emergency conditions connected with sudden electric power outage in PC and occurrence of liquid backflow. In this case the pressure in the pipeline network does not exceed the value of $0.7H_n$.

When closed ESDDL were created and optimal trajectory of pipeline valve control was determined, a quality criterion was offered. It provides minimization of dynamic loads in hydrosytem and operative control of pipeline valves in emergency (contingency) situations:

$$J = \int_0^{t_{sh}} \left(\nu(t)\Delta h(t) + k\Delta t\right)dt \rightarrow min \qquad (3)$$

where $\nu(t)$ – relative frequency of valve electric drive rotation; $\Delta h(t)$ – relative head increase in the pipeline network; Δt – relative time of valves shutting; $k=0...1$ – weighting coefficient taking into account the value of Δt component; t_{sh} – time of valve shutting , s.

To solve this problem a dynamic programming method was used. It enabled determination of the optimum law of pipeline valves electric drive control.

Fig. 3 shows time variable curves of pressure in pipeline network for a stopcock with non-retractable spindle of the diameter $d=1200$ mm, nominal head of $H_n=100$ m, equipped with a controlled induction motor of the nominal power of $P_n=2.4$ kW and a reducer with reduction ratio $i=91$.

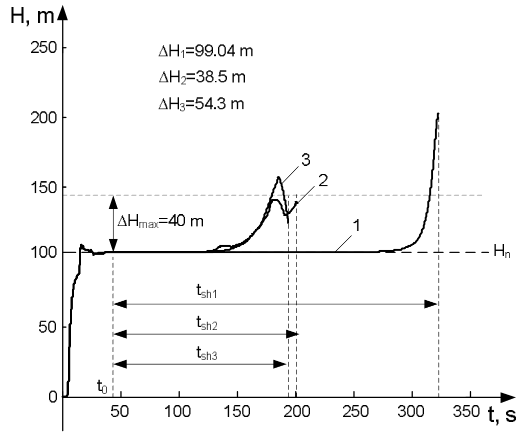

Fig. 3 Time variable curves of pressure in the pipeline network in open (1) and closed (2, 3) ESDDL

The use of pipeline valves non-controlled ED (curve 1, Fig. 3) is accompanied by the highest excess of the head $\Delta H_1=99.04$ m in the hydraulic network with the maximum valve shutting time $t_{sh1}=320$ s. At the optimum law of stopcock ED control (curve 2, Fig. 3) the least pressure increase is observed $\Delta H_2=38.5$ m with more rapid valve shutting $t_{sh2}=190$ s. If the control law is intermediate, different from the optimum one (curve 3, Fig. 3), ΔH increases by 35.7% compared with ΔH_2; in this case the time of stopcock control does not practically change.

The results of modeling ESDDL operation in PC are confirmed by experimental research on the basis of pump assembly physical model.

III. Conclusions

An approach to reduction of dynamic loads in a pump complex under both operating and emergency conditions by means of forming an irregular rate of locking and regulating valves control has been offered.

A structure of electromechanical system of dynamic loads decrease in a pipeline network on the basis of locking and regulating stopcock variable-frequency electric drive with the use of uninterruptible power supply has been grounded. The system makes it possible to exclude inadmissible pressure increase in the hydraulic network when the pipeline valves are closed at the quickest rate.

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