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Estimation of dynamic loads in an electrohydraulic complex at different laws of supply voltage frequency variation

***Abstract**. It is shown that direct start of electrohydraulic complex pump units is characterized by essential surges of current, dynamic torque and head. An electrohydraulic complex mathematical model for research of supply voltage frequency variation law influence on transient processes in the system is proposed. It is shown that transient processes behavior in the electrohydraulic complex is influenced by the time of acceleration/braking, pipeline geometry, presence of static head at particular sections of the hydraulic network, the method of the technological mechanism start-up. It is proved that the use of smooth start/stop of the pump unit makes it possible to decrease dynamic loads on the motor, eliminate occurrence of oscillations in the head and flow rate signals, reduce power losses at the start. Basic recommendations as to the choice of the law of input impact generation are formulated.*

Streszczenie.** Wykazano, że **b**ezpośredni start system elektrohydraulicznego charakteryzuje się istotnymi przetężeniami prądowymi oraz dynamicznym momentem. Zaprezentowany został złożony model matematyczny zjawisk elektrohydraulicznych do badania wpływu zasilania napięciowego na procesy przejściowe w systemie. Pokazano, że przebiegi procesów przejściowych w układach elektrohydraulicznych zależą od czasu przyspieszania/hamowania, geometrii rur, obecności statycznej głowicy w poszczególnych sekcjach systemu oraz od metody technologicznej do rozpoczynania procesu, Wykazano, że użycie łagodnego startowania/hamowania pompy czyni możliwym dynamicznego obciążenia silnika, wyeliminować oscylacje głowicy I sygnałów przepływowych, jak również zredukować straty mocy przy starcie, sformułowano podstawowe rekomendacje co do wyboru zasady generacji impulsów wejściowych. **(Estymacja obciążeń dynamicznych w systemie elektrohydraulicznym przy różnych zasadach zmiany częstotliwości zasilania napięciowego)

Keywords: electrohydraulic complex, transient processes, smooth start/stop, dynamic loads.
Słowa kluczowe: system elektrohydrauliczny, procesy przejściowe, gładki start/stop, obciążenia dynamiczne

Introduction.

Frequent direct starts of pump units (PU) as parts of electrohydraulic complexes (EHC) of industrial and public water supply and disposal are characterized by a number of essential drawbacks related to undesirable influence on electric motor, actuator (pump), pipeline system [1–3].

So, in transient processes at induction motor (IM) direct start peak current surges are 5–6 times as large as the rated ones. It results in premature wear of insulation and decrease of the electromotor operation resource [1]. Presence of sign-changing dynamic moments exceeding the rated values by 4–5 times is accompanied by increased vibrations of electromechanical equipment. Due to generation of considerable pressure waves at the start, surges appear in the pipeline system, which results in additional loads on the pipes joints and possible breaks of the pipeline [1–3]. The crack tip opening displacement test has been become a common method of measuring the real mechanical properties of used base materials [7].

When PU is stopped by direct disconnection of the electric drive (ED) from the power grid, considerable problems also occur due to extremely rapid stop of the electric machine. Because of a high flow of liquid mass in the pipeline the pumped medium continues to move with the same speed for some time, then it changes its direction. It causes essential pressure surges, provides high mechanical overloads in the pipeline and negatively influences the operation of the pump unit.

To prevent the mentioned drawbacks of PU direct start/stop it is necessary to perform smooth acceleration/braking of the electric motor with the assigned law of increase/decrease of the input voltage. It will allow reduction of dynamic loads in the hydrosystem, extension of the resource of electrohydraulic equipment operation.

Taking into account the above said, the purpose of the paper consists in substantiation of the choice of the law of generation of the input impact on the PU electric drive that will enable reduction of dynamic loads and energy losses in EHC transient conditions.

Research method

To research transient processes in EHC a mathematical model is proposed. It includes a block of generation of an input impact (BGII) on the frequency convertor, IM, a centrifugal pump, a pipeline system with a consumer at the end point. Mathematical description of the EHC operation is given in [4]. A pumping plant with the following parameters was chosen as a modeling object: motor $P_n = 800$ kW, $U_n = 6000$ V, $\omega_n = 157$ s^{-1}, $I_n = 94.5$ A, $M_n = 2547.8$ Nm; pump $Q_p = 0.75$ m^3/s, $H_p = 80$ m and pipeline system $d = 1.2$ m, $L = 5000$ m, $H_{st} = 20$ m, $n = 20$. BGII assigns a step (I), linear (II), smooth with limitation of the start current (III) and changing by parabolic law (IV) variation of input supply voltage frequency for the start or stop of the pump IM.

In the considered case time t_s of PU start is 5 s, and time t_f of the stop is 7 s.

Variation curves for electromechanical and technological parameters of EHC during generation of input impact of different form are shown in Figs. 1–4.

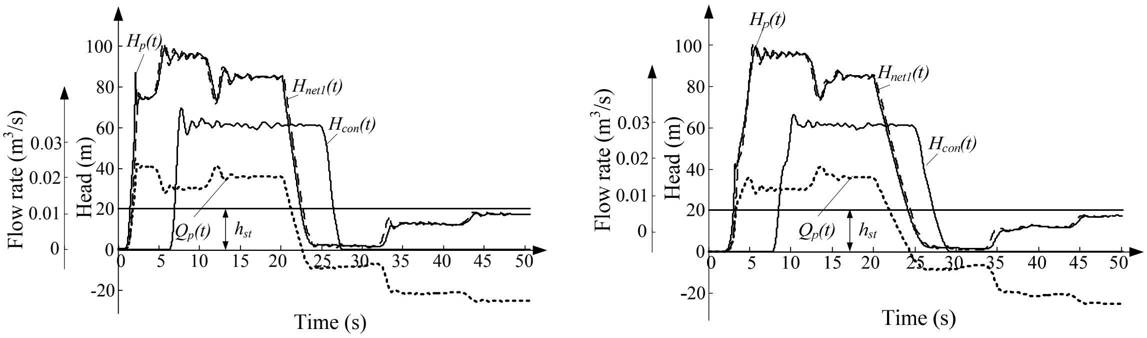
Analysis of the obtained curves revealed (Figs. 1, 2, a), that direct start of the pump on the open stopcock results in occurrence of increased start currents of the order of 0.75 I_n and torques – 0.6 M_n, and is accompanied by the head surge up to 0.1 H_p.

At time moment t = 20 s there occurs a sharp stop of the pump (e.g. because of electric power failure), which results in appearance of liquid counterflow, head reduction both at PU output and, at pipeline sections with their following increase up to the value of counterpressure h_{st} = 20 m. At the linear law of supply voltage variation the surges of current, head and flow rate (Figs. 1, 2, b) are essentially lower than at the step law.

A smooth start of PU with the function of start current limitation is a more efficient method in comparison with the previous ones, as there occurs a gradual (without surges) change of electric, electromechanical and technological parameters (Figs. 3, 4, a).

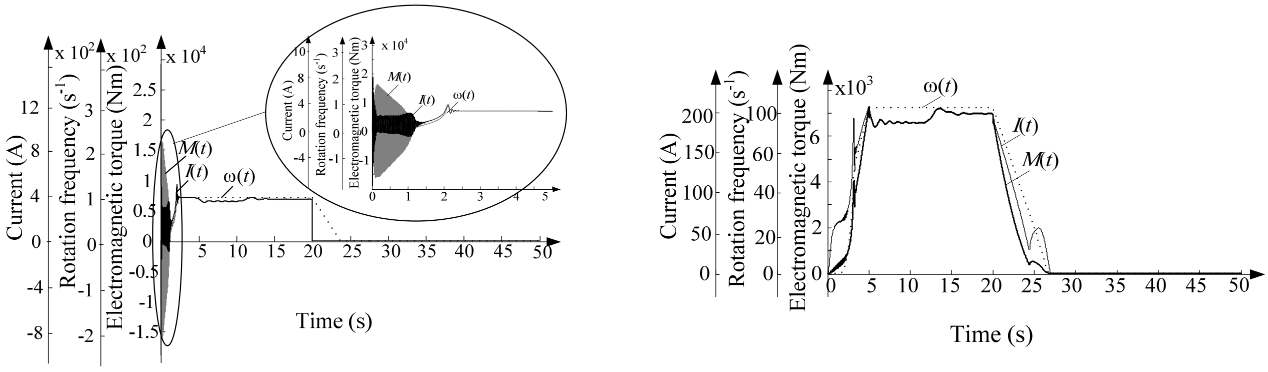
At the parabolic law of variation of the input impact (curves in Figs. 3, 4, b) the presence of insignificant surges of the start current and torque (of the order of 10–15 %), excess of the pump head (up to 10 %) at the start and smooth reduction of electric and mechanical parameters are noticed.

EHC functioning is accompanied by a continuous transformation of the parameters of power condition: electric power into mechanical one, then into hydraulic power of the pump, pipeline system and consumer [5].



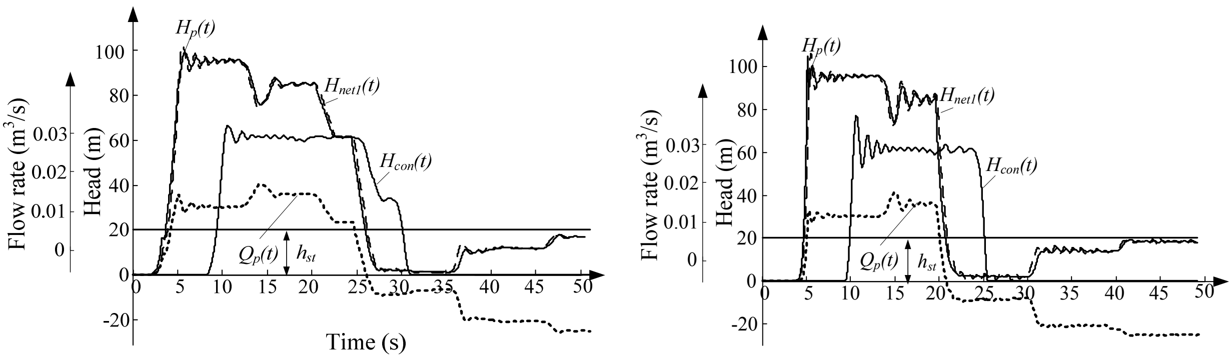
a) b)

Fig.1. Curves for head variation at the pump output $H_p(t)$, at the output of the first section of the pipeline system $H_{net1}(t)$, at the consumer $H_{con}(t)$ and for flow rate $Q_p(t)$ at the pump output at step (a) and linear (b) laws of supply voltage frequency variation



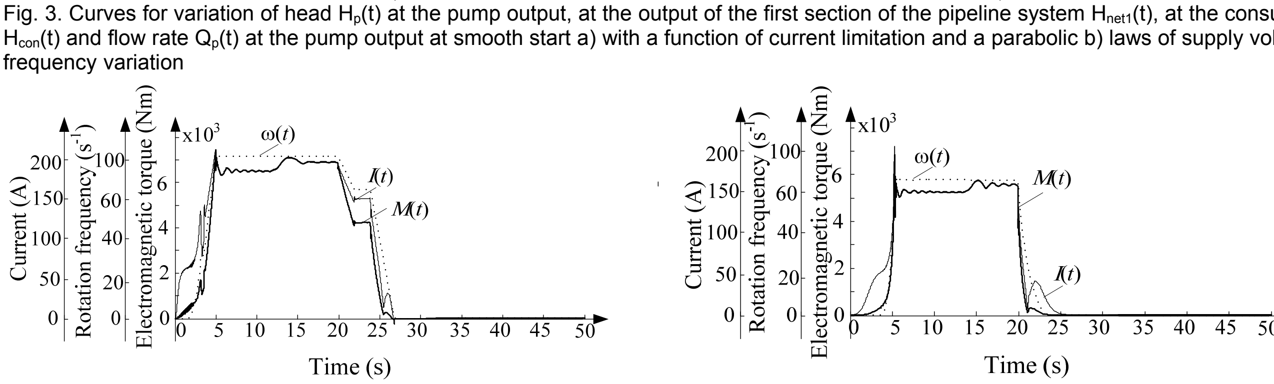
a) b)

Fig. 2. Curves for variation of rotation frequency $\omega(t)$, current $I(t)$ and electromagnetic torque $M(t)$ of the electric motor at step (a) and linear (b) laws of supply voltage frequency variation



a) b)

Fig. 3. Curves for variation of head $H_p(t)$ at the pump output, at the output of the first section of the pipeline system $H_{net1}(t)$, at the consumer $H_{con}(t)$ and flow rate $Q_p(t)$ at the pump output at smooth start a) with a function of current limitation and a parabolic b) laws of supply voltage frequency variation



a) b)

Fig. 4. Curves for variation of angular frequency $\omega(t)$ of rotation, current $I(t)$ and electromagnetic torque $M(t)$ of the electric motor at smooth start a) with a function of current limitation and parabolic b) laws of supply voltage frequency variation

Thus, electric power supplied to IM stator windings:

(1) $$p_{el}(t)=u_{1u}(t)i_{1u}(t)+u_{1v}(t)i_{1v}(t)$$

where $u_{1u}(t)$, $i_{1u}(t)$, $u_{1v}(t)$, $i_{1v}(t)$ – voltages and current according to $u,v,0$-coordinates, respectively.

Hydraulic power at PU output:

(2) $$p_{hp}(t)=\rho g Q_p(t)H_p(t)$$

where ρ – density of the pumped liquid, kg/m^3; g = 9.81 m/s^2 – acceleration of gravity.

Hydraulic power at the i-th section of the pipeline:

(3) $$p_{hnet\,i}(t)=\rho g Q_{net\,i}(t)H_{net\,i}(t).$$

Hydraulic power at the consumer:

(4) $$p_{con}(t)=\rho g Q_{con}(t)H_{con}(t).$$

Power losses at the j-th element of EHC in transient conditions are determined from expression:

(5) $$\Delta p_j=\frac{1}{t_{tp}}\int_0^{t_{tp}}\Delta p_j(t)dt$$

where t_{tp} – time of the transient process flow, s; $\Delta p_j(t)$ – time dependence of power losses at the j-th element of EHC.

The analysis of transient processes in EHC at different laws of variation of the input voltage frequency enabled determination of the indices of the quality of the pump ED start conditions (table 1). It is determined that with the aim of prevention of current and dynamic loads in EHC it is expedient to use the linear law of voltage generation.

Use of PU controlled start is an energy-saving measure. The above said is confirmed by reduction of power losses at the start. So, at the linear law electric power losses in transient modes are half as large and hydraulic power losses are the same as for step input impact; at a smooth start with the function of current limitation electric and hydraulic power losses reduce by 3.4 and 2 times, respectively; at parabolic law – by 4 and 3.3 times, respectively.

Experimental verification

The obtained theoretical results are confirmed by experimental research on the basis of EHC physical model whose description and technical characteristics are given in [6]. Experimental curves for variation of electromagnetic torque and head at the pump output and in the pipeline system at the step and parabolic laws of supply voltage frequency variation are shown in Figs. 5,6, respectively.

It is obtained that surges of the starting torque at PU direct start make almost 100 % of the head rated excess – about 20 % of the nominal one and electric power losses at PU start – 70 % of $\Delta p_{el\,n}$; when the parabolic law of supply voltage frequency variation is used, the starting torque surges make 76 % of the rated one, head excess is practically absent and power losses are seven times less that at the step input impact.

Table 1. Indices of the quality of the pump ED start conditions

Excess of start current, % of I_n	Excess of start torque, % of M_n	Excess of the pump head, % of H_n	Electric power losses at PU start, % of $\Delta p_{el\,n}$	Hydraulic power losses at PU start, % of $\Delta p_{hp\,n}$
Direct start on an open stopcock				
76	56	17	57	23
Direct start on a closed stopcock				
74	53	9	39	24
Smooth start according to the linear law				
3.38	3.84	5.38	27	21
Smooth start with limitation of the start current				
6.98	6.7	5.88	17	12
Smooth start according to the parabolic law				
14.29	13.3	13.35	14	7

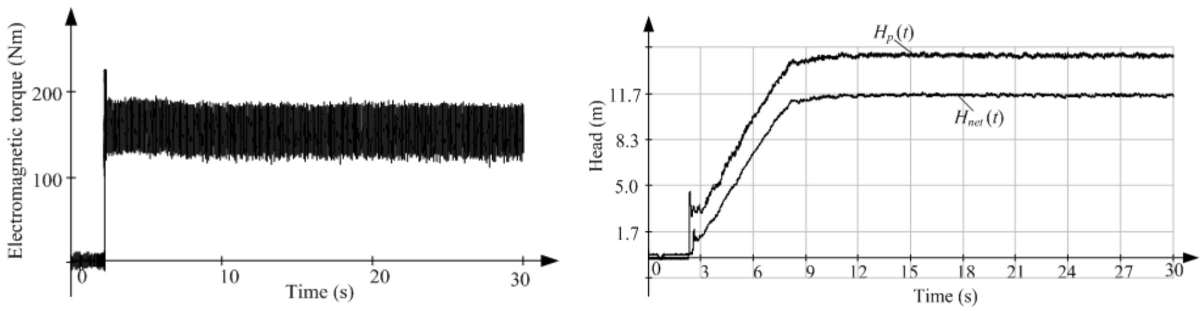


Fig. 5. Curves for variation of electromagnetic torque M(t) a) pump electric drive, head $H_p(t)$ at the pump output and in the pipeline system $H_{net}(t)$ b) at the step law of supply voltage frequency variation

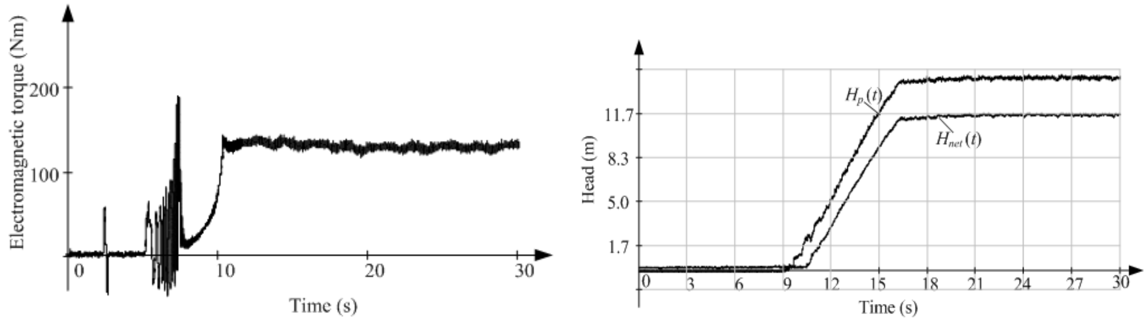


Fig. 6. Curves for variation of electromagnetic torque $M_d(t)$ a) pump electric drive, head $H_p(t)$ at the pump output and in the pipeline system $H_{net}(t)$ b) at the parabolic law of supply voltage frequency variation

Conclusions

It has been shown that electrohydraulic complexes are characterized by essential dynamic loads at direct start of the technologic mechanism, which results in premature breakdown and wear of pump and pipeline equipment. To reduce dynamic loads in transient modes it has been proposed to use systems of smooth start of the pump unit with different laws of variation of supply voltage frequency. Controlled start of the pump unit makes it possible to eliminate excess of head and flow rate, extend the service life of electrohydraulic equipment.

It has been determined that direct start of the pump unit on an open stopcock in the pipeline system is characterized by availability of increased stating current and electromagnetic torque, surges of the head and flow rate both at the pump output and at the consumer. At the smooth law of supply voltage frequency variation there occurs a gradual (without surges) variation of electric, electromechanical and technological parameters.

Direct stop of the pump unit in the hydraulic network with counterpressure is accompanied by a sharp reduction of electromagnetic torque and current, which, in its turn, results in the change of direction of the liquid flow in the pipeline. So, it is expedient to choose such supply voltage frequency variation law that will enable decrease of dynamic and electric loads in the pump unit, provide minimum fluctuation of parameters with the aim of elimination of hydraulic surges in the pipeline.

The developed model of electrohydraulic complex takes into account the processes of power transformation in the elements of power channel at different laws of input voltage frequency variation. It has been obtained that at direct start of the pump unit on an open stopcock (the hardest way of start as to dynamic loads) electric power losses make 57 % of the rated value and hydraulic losses – 23 %. Reduction of power losses in transient conditions in the pump unit electric drive is possible by means of controlled start and stop. The performed analysis of power variation and power losses in the elements of electrohydraulic complex revealed that the parabolic law of input voltage frequency generation is the most energy-saving one: power losses at the start and stop of the pump unit are almost seven times less.

Taking into account the above said, when working out the systems of management and control of electrohydraulic complexes, there appears a necessity for generation of such a law of variation of supply voltage frequency on the pump controlled electric drive that will provide a smooth (without surges) variation of electric and technological parameters, minimum power losses in transient conditions, which will prolong the service life of electrohydraulic equipment.

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REFERENCES

[1] Karassik I.J., Messina J.P., Cooper P., Heald C.C., Pump handbook, McGRAW-HILL, 2001, 600 p.

[2] Firago, B.I., Calculations on the drive industrial machinery: study guide, Tekhnoperspektiva, Minsk, 2012 – 639 p. [in Russian].

[3] Bergant A. Water Hammer Analysis of Pumping Systems for Control of Water in Underground Mines / A. Bergant, A. R. Simpson // Proceedings of Mine Water Congress Ljubljana. – 1991. – PP. 9–20.

[4] Zagirnyak M., Kovalchuk V., Korenkova T. “Identification of electrohydraulic complex parameters using instantaneous power component”, Przeglad Elektrotechniczny (Electrical review), no. 12b, pp. 286–289, 2013.

[5] M. Zagirnyak, V. Kovalchuk, and T. Korenkova, “Estimation of electromechanical systems power controllability according to instantaneous power component”, Proceedings of International IEEE Conference IEPS 2014, Kyiv, Ukraine, pp. 266–272, IEEE Catalog Number CFP1405X-PRT, ISBN 978-1-4799-2266-6, 2014.

[6] M. Zagirnyak, D. Rodkin, and T. Korenkova, **“**Estimation of energy conversion processes in an electromechanical complex with the use of instantaneous power method**”,** 16-th International power electronics and motion control conference and exposition, PEMC, Antalya, Turkey, pp. 319–326, ISBN 978-1-4799-2062-4, 2014

[7] Z. Praunseis, M. Toyoda, T. Sundararajan, **“**Fracture behaviours of fracture toughness testing specimens with metallurgical heterogeneity along crack front. Steel research, Vol.71, No. 9, pp. 366-373, ISSN 0177-4832, September 2000