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OPTIMAL BY THE CRITERION OF MINIMUM ACCELERATION ENERGY, SYSTEM OF CENTRIFUGAL PUMP HEAD REGULATION

Method of hydraulic grid head control process optimization is suggested on the base of the concept of inverse problems of dynamics combined with the minimization of local functionals of instantaneous values of energy that enables to obtain the needed dynamic accuracy of the preset path adjustment in conditions of parametric and coordinate disturbances impact.

Key words: *optimization, asynchronous electric drive, head regulation system, centrifugal pump.*

Introduction

Application of frequency regulated electric drive for the construction of automatic systems of pump installations control is economically expedient. Application of smooth regulation of pump units coordinates, besides energy saving, provides the reduction of hydraulic impacts and overpressures in the pipelines, increase of the term of pumps and elements of hydraulic grid operation [1]. High dynamic indices of the system of the electric drive coordinates regulation are achieved as a result of vector control application. Reliable squirrel-cage asynchronous motors are used as motors of greater part of electric pump drives. However, from the point of view of the control, they are non-linear and interconnected objects, this complicates the process of systems coordinates quality regulation.

To improve the quality of centrifuge pump discharge pressure while providing satisfactory energy indices the method, based on the concept of the inverse problems of dynamics in combination with the minimization of local functional of instantaneous values of energies and the observer of the field component of AM stator current is suggested. As a result, algorithms for the control of optimal system of centrifuge pump discharge pressure regulation, providing weak sensitivity to the impact on the motor, pump and hydraulic grid parametric and coordinate disturbances, are developed [2].

Aim of the research is the study the system of indirect vector control system of centrifuge pump head with the optimized by the criterion of minimum of acceleration energy, regulation laws in conditions of parametric disturbance impact, caused by the variation of active electric resistance of rotor winding of induction motor drive.

Results of the research

The system of indirect vector control of hydraulic grid discharge head contains centrifugal pump, induction motor(IM), frequency converter and discharge head sensor and sensor of three phase currents of the motor. Dynamic characteristics of hydraulic grid section during discharge head regulation are written by means of differential equation [3]:

$$\frac{T_Q}{2Q_n(a_p+a_l)}\frac{d\Delta H}{dt}+\Delta H=\frac{(1-\beta)T_Q}{2Q_n(a_p+a_l)}\frac{2H_0}{\omega_n}\frac{d\Delta\omega}{dt}+\frac{(1-\alpha)a_l}{(a_p+a_l)}\frac{2H_0}{\omega_n}\Delta\omega, \tag{1}$$

where T_Q – is the coefficient of mathematical model; Q_n – is nominal value of the supply at the nominal angular velocity of the pump in the operating point; H – is the discharge head of the pump; a_p – is the pump friction head; a_l – is the coefficient of the hydraulic grid friction head; H_0 – is the pump head $(Q=0)$ at nominal angular velocity; ω – is the angular velocity of the pump; ω_n – is nominal angular velocity.

Centrifugal pump operates in the system with the backpressure. Differential equations (2) describe equivalent two-phase model of the drive AM in synchronous system of the coordinates (d – q) during the standard assumptions:

$$\begin{cases} \dfrac{dH}{dt} + \dfrac{2Q_n(a_p + a_l)}{T_Q} H = 2\dfrac{H_0}{\omega_H}\dfrac{1}{J}\left[\dfrac{3}{2} p_n \dfrac{L_m}{L_2}\left(\left|\psi_2^*\right| i_{1q}\right)\right] + V_H; \\ \dfrac{d\omega}{dt} = \dfrac{1}{J}\left[T - T_l\right] = \dfrac{1}{J}\left[\dfrac{3}{2} p_n \dfrac{L_m}{L_2}\left(\left|\psi_2^*\right| i_{1q}\right)\right] - \left[T_0 \dfrac{\omega^2}{\omega_n^2} + (T_n - T_0)\dfrac{\omega}{\omega_n}\sqrt{\dfrac{H_0 \dfrac{\omega^2}{\omega_n^2} - H_{st}}{H_0 - H_{st}}}\right]\dfrac{1}{J}; \\ \dfrac{di_{1d}}{dt} + \left(\dfrac{R_1}{\sigma} + \alpha\beta L_m\right) i_{1d} = V_{1d} + \dfrac{u_{1d}}{\sigma}; \\ \dfrac{di_{1q}}{dt} + \left(\dfrac{R_1}{\sigma} + \alpha\beta L_m\right) i_{1q} = V_{1q} + \dfrac{u_{1q}}{\sigma}; \\ \dfrac{d\left|\psi_2^*\right|}{dt} + \alpha\left|\psi_2^*\right| = \alpha L_m i_{1d}^*; \end{cases}$$

$$V_H = 2\frac{H_0}{\omega_H}\frac{1}{J}T_l + \frac{2Q_n a_l}{T_Q}\frac{2H_0}{\omega_H}\omega \le V_H^0, V_{1d} = \omega_0 i_{1q} + \alpha\beta\left|\psi_2^*\right| \le V_{1d}^0, V_{1q} = -\omega_0 i_{1d} - \omega\beta\left|\psi_2^*\right| \le V_{1q}^0;, \quad (2)$$

$$2\frac{H_0}{\omega_H}\frac{1}{J}\left[\frac{3}{2} p_n \frac{L_m}{L_2}\left(\left|\psi_2\right| i_{1q}\right)\right] > V_H^0, \frac{u_{1d}}{\sigma} > V_{1d}^0, \frac{u_{1q}}{\sigma} > V_{1q}^0,$$

where $\alpha=R_2/L_2$, $\sigma=L_1\text{-}L_m^2/L_2$, $\beta=L_m/\sigma L_2$ – are the coefficients of the mathematical model; R_1, R_2 – is active resistance of stator and rotor winding; L_1, L_2, L_m – is the inductance of stator, rotor winding and magnetic loop; u_{1d}, u_{1q} – are the components of stator voltage vector; i_{1d}, i_{1q} – are the components of stator current vector; $|\psi_2^*|$ – is the set module of rotor linkage vector; J – is the total inertia moment of the electric drive; p_n=1 – is the number of poles pairs; T_l – is loading moment; T_o – is the pump shaft moment at nominal angular velocity and $Q=0$; T_n – is nominal moment of the centrifugal pump; Hst – is static pressure during the lifting of the liquid at the required height; V_H, V_{1d}, V_{1q} – are the coordinates of the disturbance, occurring as a result of mutual impact and are undetermined and limited by the value.

The preset paths of hydraulic system $H^*(t)$ head change and module of the rotor linkage $|\psi_2^*|$ have limited the first and the second time derivatives. Algorithms of rotor flux linkage, stator current components on axes d and q and the head of centrifugal pump control provide astaticism of the first order by the control action and have such structure:

–regulator of the module of rotor linkage $|\psi_2^*|$ regulator (RL)

$$i_{1d}^{*}=\frac{\left|\psi_{2}^{*}\right|}{Lm}+\frac{d\left|\psi_{2}^{*}\right|}{dt}\frac{1}{\alpha Lm},$$
$$\left|\psi_{2}^{*}\right|=\left|\psi_{2}^{*}(0)\right|+(\left|\psi_{2n}^{*}\right|-\left|\psi_{2}^{*}(0)\right|)\sqrt{\frac{H^{*}}{H_{n}}}, \tag{3}$$
$$\left|\psi_{2}^{*}\right|>0,\ \left|\psi_{2}^{*}(0)\right|=0.02\,Вб,\ \left|\psi_{2n}^{*}\right|=0.92\,Вб;$$

– regulator of centrifugal pump head (PR)

$$i_{1q}^{*}=k_{H}(\gamma_{H}\int(H^{*}-H)dt-H); \tag{4}$$

– regulators of stator current components *i1* on the axes *d* and *q* (PCd and PCq)

$$\begin{pmatrix}u_{1d}\\u_{1q}\end{pmatrix}=\begin{pmatrix}k_{i1d}(\gamma_{i1d}\int(i_{1d}{}^{*}-i_{1d})dt-i_{1d})\\k_{i1q}(\gamma_{i1q}\int(i_{1q}{}^{*}-i_{1q})dt-i_{1q})\end{pmatrix}; \tag{5}$$

– observer of stator current field component *i1d* (OF)

$$\hat{i}_{1d}=-(\frac{R_{1}}{\sigma}+\alpha\beta L_{m})\hat{i}_{1d}+\omega_{0}i_{1q}+\alpha\beta\left|\psi_{2}^{*}\right|+\frac{u_{1d}}{\sigma},$$
$$\frac{d\varepsilon_{0}}{dt}=\omega_{0}=\omega+\frac{\alpha Lmi_{1q}}{\left|\psi_{2}^{*}\right|}+k_{o}(\gamma_{o}\int(i1d-\hat{i}_{1d})dt-\hat{i}_{1d}); \tag{6}$$
$$\varepsilon_{0}(0)=0,$$

where $\varepsilon_o(0)=0$ – is an angular location of the moving system of coordinates *(d-q)* relatively the fixed system of coordinates *(a-b)*; ω_0 – is an angular velocity of the magnetic field; $k>0$ – is the amplification factor of the regulators; $\gamma\approx(3/t_{nn})>0$ – is the coefficient that sets the desired duration of transient process of aperiodic character.

Study of the dynamic indices of the suggested system of the indirect vector control of the centrifugal pump head is performed by means of mathematical modeling during the parametric disturbances (decrease by 40 % of the active electric resistance of the rotor R_2. winding).

Asynchronous motor (AM) of 4A90L2Y3 type has the following parameters: P_n=3 kW, ω_n=300.65 rad/sec, U_{1n} =380 V, f_{1n} =50 Hz – nominal power, angular velocity, linear voltage and voltage frequency; R_1=2.535 ohm, R_2=1.628 ohm – active resistance of the stator and rotor; L_1=0.394 H, L_2=0.398 H – inductance of the stator and rotor; L_m=0.387 H –inductance of the magnetized loop; *J*=0.007 kgm^2 – moment of inertia of the installation; T_l=10 Nm – loading moment.

Hydraulic grid has the length of 100 m. Fluid (water) is lifted at the height of H_{st}=65.5 m. Centrifugal pump of NMD 25/190B/A type is used, it provides fluid supply of Q_n=4.5 m^3/h and has full discharge head of *H*=71 m.

The parameters of the suggested control algorithms are the following: the coefficients of the regulators of vector components of stator current are PCd and PCq $\gamma_{i1q}=\gamma_{i1d}$=800, $k_{i1q}=k_{i1d}$=50*; the* coefficients of the discharge head regulator are PH γ_H=100, k_H=1*;* the coefficients of the flux linkage observer OS are γ_o=50, k_0=1. Initial conditions of all the variables are assumed to be zero, except $|\psi_2{}^*(0)|$=0.02 Bb.

The results and the sequence of the research execution is shown in Fig. 1:

1) at the moment of time t=0 s the rotor of AM is accelerated to nominal angular velocity on the preset path of the discharge head during 1.5 sec. In the hydraulic grid the desired discharge head of 71 m is established (simultaneously AM excites from 0.2 to 0.92 Wb);
2) at the moment of time t=2 s sharp decrease of water consumption occurs, it cause the increase of pressure Hs=4 m;
3) at the moment of time t=2.5 s water consumption rapidly increases that causes the increase of pressure with the opposite sign Hs=-4 m.

Solid line in Fig. 1 shows the graphs of the transient processes of the electric mechanical system coordinates at nominal parameters of AM, dotted line shows the graph of the transient processes in case of the impact of parametric disturbance. Errors of the hydraulic grid discharge head , presented in both cases, show that the suggested control system provides the astatic control of the discharge head with the present dynamic indices. The decrease of the dynamic resistance of the rotor by 40% leads to minor change of quality indices of the system operation, namely: the dynamic error increases during the acceleration of AM along the preset path from 0.88 to 0.92 m at full discharge head of the pump 71 m. Control quality indices in case of the compensation of the expenditures change in the system remain practically the same. Compensation time decreased from 0.046 to 0.045 s, maximal deviation of the discharge head increased from 3.997 to 3.999 m.

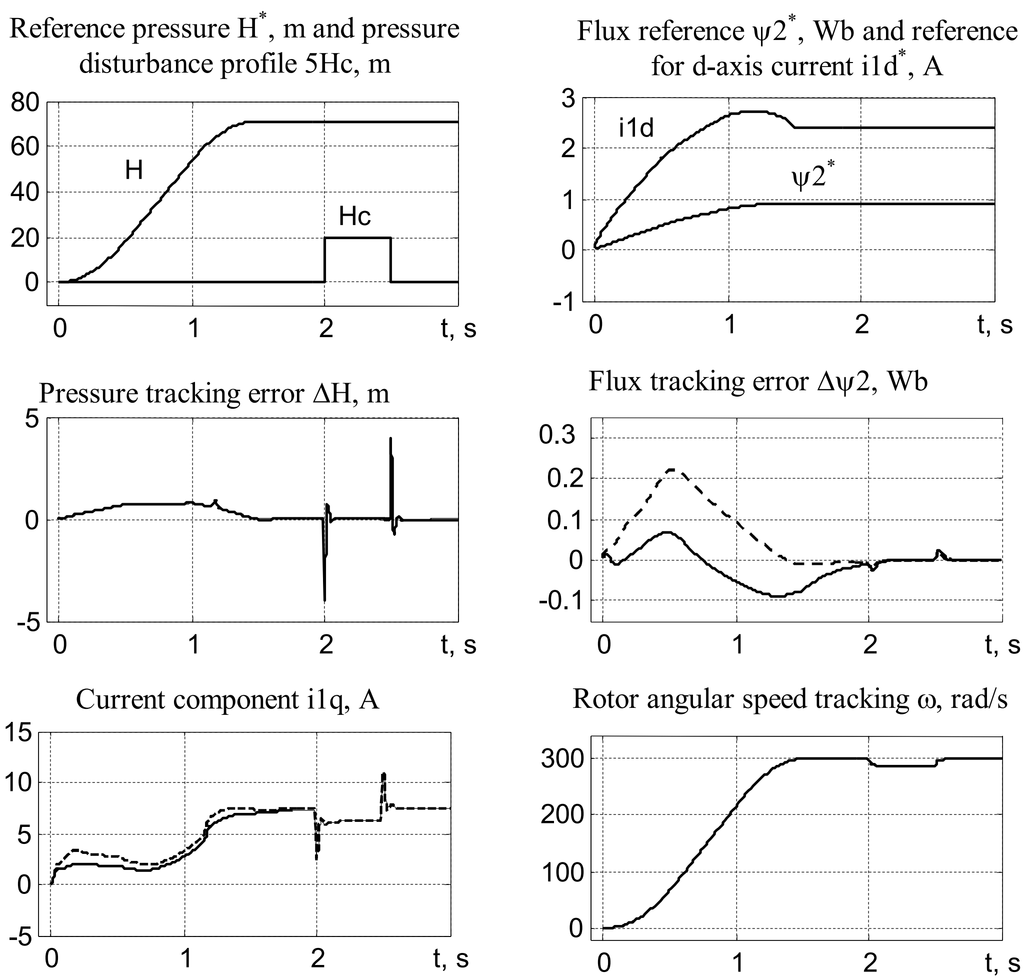

Fig. 1. Graphs of the preset paths and transient processes of the control system coordinates of centrifugal pump discharge head

As it is seen in Fig. 1, the considerable degradation of transient processes of electrical mechanic coordinates is not present in the system during the parametric disturbance. In the process of motor acceleration maximum increase of stator current component value on the axis q is 1.4 A and maximum increase of the rotor flux linkage modulus – 0.013 Wb (1.4% relatively the set value 0.92 Wb). Angular velocity of AM rotor changes during the set path exercise of the pump discharge head and operation of the parametric and coordinates disturbances smoothly, without regulation and oscillations.

Conclusions

Optimal by the criterion of the minimum acceleration energy the presented system of indirect vector regulation of centrifugal pump discharge head provides the desired control quality in static and dynamic modes during the impact of destabilizing factor (reduction of stator winding active resistance by 40% from nominal). The system provides the preset astatism of the first order by the control action and the absence of static errors by the discharge head during fluid consumption change.

Ease of practical realization of the regulation algorithms, that does not contain differentiation operations, shows the advantage of the suggested method.

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