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Closed Frequency Control System of Asynchronous Motor in Irrigation Pump

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Abstract
The working regime of frequency-controlled asynchronous motor of irrigation pump in the closed system with feedback by velocity is considered. The system transmission coefficient, providing a constancy of motor overloading coefficient set value during the voltage control proportionally to frequency of control are determined.

Keywords: electric drive, asynchronous motor, regimes of a motor, frequency controlled electric drive, frequency controller, pump, pump characteristics, control system, closed control system, open control system, and feedback.

A mode of asynchronous motor (AM) in frequency controlled electric drive system is determined with mutual changes of the following parameters: input – frequency and voltage; internal – currents in stator and rotor, the flow and parameter of absolute slip; output – rotational speed and moment on the motor shaft. Quantities of input parameters – frequency and voltage must be changed so that the reaction of the internal parameters provides stated speed at any moment of resistance on the shaft. The ratio of voltage to frequency determines the law of frequency control.

Known laws of controlling the ratio of voltage to frequency are mainly investigated on the base of the principle of control in an open system. In such an open system of frequency control, the flow, the maximum torque, the stiffness of mechanical characteristics, and motor speed control range decrease as the frequency of control reduce.

In a closed control system, the ratio of voltage to frequency, as it is understood in an open system, is of no practical importance, since it ignores the real feedbacks of the system and the limitations of its amplification factor.

Let us consider the static mode of operation of a frequency-controlled AM in a closed system with a speed feedback. The transmission coefficient of AM over voltage channel will be equal to:

$$K_{M\gamma} = \frac{\Delta\omega}{U_{n\gamma}} = \frac{\omega_{on}}{U_{n\gamma}} S, \qquad (1)$$

where S - absolute slip of AM.

As can be seen from (1), the transmission coefficient KM – is variable and depends on S and the ratio of frequency to voltage.

In order to regulate the performance of an irrigation pump, it is rational to control the voltage proportionally to the frequency, in other words, γ=F. In this case, the phase switcher (PS) characteristic will be linear, and (1) will be written up in the form of $K_{M\gamma}=\omega_{on}S_n/U_n$=const. Thus, the given values of all the transmission coefficients of the system will be constant.

The frequency control channel determines the synchronous angular speed and the voltage channel determines the absolute slip of the motor. The difference ω_o-Δω presents the angular speed of the AM rotation. One of the features of this system is that the speed of rotation of the motor through the feedback circuit affects simultaneously the frequency and voltage.

It is essential to say, that generally while regulating the necessary ratio between frequency and voltage with the help of a phase switcher, both frequency and voltage can be taken as the initial parameter. However, from the point of view of the influence of disturbances in the energy supply and the load on the motor speed, a system in which the initial parameter is frequency, and the voltage is regulated as a function of frequency, will be more rational. In this type of system, the dynamic changes in rotation speed will be less, since the rotation speed of the motor depends primarily on the frequency, which is determined by the inverter's control system and does not depend on disturbances in the power supply network and the load, while the voltage is a parameter determined not only by the inverter control system, but also the entire power circuit. That is why in the given closed system the frequency is the initial parameter.

According to the figure, the angular speed of rotation of the motor will be equal:

$\omega=KU_3$,

where $K=\frac{K_f K_{\partial f}-K_{FS}K_\gamma K_{1_\gamma}}{1+(K_f K_{\partial f}-K_{FS}K_\gamma K_{1_\gamma})K_{fb}}$ (2)

K – the transmission coefficient of a closed system. Here, the given constant values of the coefficients K_f, K_γ, K_{FS}, K_{fb} can be picked up according to the conditions required by the system, and the other coefficients are constant.

Let us determine the value of the transmission coefficient of a closed system with speed feedback, that will provide the value of AM overload coefficient of the system in the operating range of pumping plant rotation speed control from F_{min} to F=1 being not lower than the nominal overload coefficient (λ_n) of the motor in its natural switching circuit. The minimum frequency and minimum torque of the motor must be calculated in advance.

For irrigation pumps, a decrease in the rotation speed in order to control the productivity is possible up to a certain minimum value, at which the pump head (H) becomes equal to the static head (H_{st}). The pump efficiency (Q) then drops to zero. Based on this condition, we determine, up to slip, the minimum control frequency:

$f_{min}=\sqrt{H_{st}/H_o}$, (3)

where H_o – pump head at Q=0 and $\omega=\omega_n$.

The AM torque at the variable frequency, obtained on the basis of the T-shaped equivalent circuit, considering (2) with γ=F, will be written as:

$M=\frac{K_M r_2^{`} X_{\mu n}^2(F-\beta)}{KU_s\beta D^2}$, (4)

where $D=\sqrt{\left(\frac{r_1 r_2^{`}}{F\beta}-X_s X_r\sigma\right)^2+\left(\frac{r_2^{`}}{\beta}X_s+\frac{r_1}{F}X_r\right)^2}$, (5)

$X_s=X_{in}+X_{\mu n}$; $X_r=X`_{2n}+X_{\mu n}$ ; $\sigma=1-X_{\mu n}^2/X_sX_r$; $r`_1$ and $X`_{1n}$ – active and nominal inductive resistances of a phase of the stator winding; $r`_2$ and $X`_{2n}$ are the active and nominal inductive resistances of the phase of the rotor winding; $X_{\mu n}$ - nominal inductive resistance of the magnetizing circuit; β=FS - absolute slip parameter; $K_M=mU_n/9{,}81$; m - the number of phases.

Exploring (5) to the maximum, we obtain:

$$a\beta^2+b\beta+c=0, \qquad (6)$$

where

$$a=\left[\left(\frac{r_1}{F}\right)^2+(X_s\sigma)^2\right]X_r^2+\frac{2r_1r_2^`X_{\mu n}^2}{F^2},$$

$$b=\frac{2\left[\left(\frac{r_1}{F}\right)^2+X_s^2\right]r_2^`}{F}, \qquad c=-Fb/2.$$

From (6) we can determine the critical value of the absolute slip parameter:

$$\beta_{k1,2}=\frac{b}{2}(-1\pm\sqrt{1+2aF/b}). \qquad (7)$$

As can be seen from (7), the roots of (6) are positive. The condition for the positiveness of the real root that we need (the critical value of the absolute slip parameter is being founded) will be true when the sign in front of the radical is positive, so as:

$$\beta_k=\frac{b}{2}(-1+\sqrt{1+2aF/b}). \qquad (8)$$

By substituting this expression as β in (4), we find the maximum torque (M_k) of the motor.

The AM overload coefficient at the minimum frequency of control will be

$$\lambda_{(F=Fmin)}=M_{k(F=Fmin)}/M_n\,, \qquad (9)$$

where M_n is determined from (4) as F=1 and $\beta=S_n$.

From condition of $\lambda_{(F=Fmin)}=\lambda_n$, we get:

$$k=\frac{S_nD_n^2[Fk(F=F\,min)_{min}[]]}{\gamma_s\lambda_n(1-S_n)D^2_{(F=F\,min)}\beta_{k(F=F\,min)}} \qquad (10)$$

where $\gamma=U_3/U_{3n}$ and $k=K/K_n$ - relative set voltage and transmission coefficient of the system closed by speed; $\lambda_н$ - nominal overload coefficient of AM in an open system, determined from the catalogue; D_n - is determined from (5) at F=1 and $\beta=S_n$.

Thus, according to (10), the value of "k" is determined, which provides the constancy of the AM overload coefficient over the entire range of controlled frequency in a closed frequency control system with a speed feedback.

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