AUTOMATION OF DRILLING RIG ROTOR ELECTRIC DRIVE

RESEARCH GROUP:
Biliuk Ivan
PhD, Associate Professor
Admiral Makarov National University of Shipbuilding, Ukraine

Savchenko Oleh
Lecturer
Admiral Makarov National University of Shipbuilding, Ukraine

Havrylov Serhii
PhD, Associate Professor
Admiral Makarov National University of Shipbuilding, Ukraine

Shareyko Dmitro
PhD, Associate Professor
Admiral Makarov National University of Shipbuilding, Ukraine

Maiboroda Oleksandr
PhD, Associate Professor
Admiral Makarov National University of Shipbuilding, Ukraine

Fomenko Andrii
Associate Professor
Admiral Makarov National University of Shipbuilding, Ukraine

Summary: This work is devoted to the automation of the electric drive of the drilling rig winch. The technical characteristics and features of the winch drilling rig are also considered. The synthesis of the automatic control system was made, the calculation of the parameters of the speed controller and the analysis of the dynamics of the electric drive were performed.

Key words: drilling rig, electric drive, automatic control system synthesis, control system.

Figure 1 shows a functional diagram of a drilling rig for deep rotary drilling with flushing the borehole with a drilling fluid. The winch is designed for lifting and lowering the drill string, produced periodically to replace the rock cutting bit. On installations of different classes, the winch drive power is 250...2500 kW [2, 3].

The type of drive and its properties must be selected taking into account the requirements and technological features of the winch in the lifting mode [2, 3].
Fig. 1. Functional diagram of a drilling rig

Depending on the class of the drilling rig, it is recommended to use for the winch drive: for deep and ultra-deep drilling rigs, a deeply adjustable gearbox or a gearless electric drive with an emergency mechanical transmission, depending on a number of additional requirements; for other drilling rigs - an adjustable electric drive with an adjustment range of up to 10:1.

The winch braking system must perceive the energy developed by the drill string during descent into the well, and provide adjustment of the descent speed within the specified limits. For this purpose, various types of electrical machines are used, primarily electromagnetic brakes of the induction or powder type specially created for this purpose. It is rational to use winch drive motors as brake machines. The power of the brake machine on installations of different classes ranges from 200 to 1500 kW. The current standards govern the running speed of a column of nominal weight and an unloaded traveling block, the remaining parameters are selected during design.

A simplified functional diagram of the winch drive motor control system is shown in Fig.2.

Fig. 2. Simplified functional diagram of the winch drive motor control system

The drilling rig operator controls the winch using the software installed on the top-level control system (drilling rig operator console) and from the control panel installed on the frequency converter cabinet. Using known data, the operator enters the rotation speed setting into the software, which, using a microprocessor control system in the frequency converter, generates an output control signal corresponding to a given rotation speed. The control signal in the form of pulses with a frequency corresponding to the specified rotation speed, with subsequent amplification, enters the thyristors of the inverter in the frequency converter, with
The help of which the frequency of the alternating current of the motor is changed. The direct and feedback control system with the electric drive is carried out using microprocessor equipment included with the frequency converter. The signal from the speed sensor, which is built into the motor, provides control systems with data on the speed, acceleration and deceleration of the motor at any time. Based on this signal, the engine rotation speed is adjusted to the values entered by the drilling rig operator.

The main specified parameters of the winch electric drive are the power and torque of the rotor. Based on these data, the nominal angular speed of the winch is determined. The drawworks always has a built-in bevel gear. Between the drive shaft of the winch and the engine, in general, there is a gearbox (single or multi-speed). The power, angular velocity and torque of the winch and engine are related by the following relationships (1, 2, 3).

\[
P_{IM} = \frac{P_w}{\eta_w \eta_{red}} \quad (1)
\]
\[
\omega_{IM} = \frac{\omega_w \eta_w \eta_{red}}{i_w} \quad (2)
\]
\[
M_{IM} = \frac{M_w}{i_w \eta_w} \eta_{red} \quad (3)
\]

where \(P_{IM}, P_w\) – respectively engine and winch power, kW; \(\eta_w, \eta_{red}\) – respectively the efficiency of the winch and gearbox; \(M_{IM}, M_w\) – torque on the motor and winch shaft, N m; \(\omega_{IM}, \omega_w\) – respectively, the angular speeds of the engine and winch, rad / s; \(i_w, i_{red}\) – respectively, the gear ratios of the winch and gearbox.

Based on the rated motor power of 630 kW, we select the "SIMOVERT MASTERDRIVES" drive type 6SE7141-1HJ62-3BA0 [2, 3].

The drilling rig drawworks electric drive control system (Fig. 3) ensures the rotation of the executive body at a given speed by controlling the rotation speed of the asynchronous motor (IM). The electric drive has a speed sensor (SS) of rotation of the IM, which is included in the negative feedback channel for speed in the FC – IM system with frequency-current control.

To build a block diagram of the electric drive shown in fig. 3, we determine the transfer functions of its individual links and the conditions under which the moment of the IM will uniquely depend on the absolute slip [4].

**Fig. 3. Block Diagram with Speed Feedback**
The transfer function between the given ideal idle speed IM $\omega_{03}$ and the frequency reference signal at the input of FC $U_{af}$ is determined by the relation (4)

$$W_f(p) = \frac{\Delta \omega_{03}}{U_{af}} = \frac{2\pi k_f}{p}$$

(4)

where $k_f$ - FC transfer coefficient equal to:

$$k_f = \frac{\Delta \omega_{03}}{\Delta U_{af}} = \frac{f_{\text{nom}}}{\Delta U_{\text{nom}}}$$

(5)

Accordingly

$$\Delta U_{af} = k_{\text{FSB}}(k_{SFS} \cdot \Delta U_{\text{SC}} + k_{MD} \cdot k_{FB} \cdot \Delta \omega)$$

(6)

where $k_{\text{FSB}}$, $k_{SFS}$, $k_{MD}$, $k_{FB}$ - transfer coefficients of FSB, SFS, SC devices and IM speed feedback circuits (7-10)

$$k_{\text{FCB}} = \frac{\Delta U_{af}}{\Delta U_{\text{ST}}}$$

(7)

$$k_{\text{SFS}} = \frac{\Delta U_{SFS}}{\Delta U_{\text{ST}}}$$

(8)

$$k_{\text{MD}} = \frac{\Delta U_{\text{MD}}}{\Delta U_{af}}$$

(9)

$$k_{\text{FB}} = \frac{\Delta U_{FB}}{\Delta \omega}$$

(10)

When the IM is powered from a current source, its transfer function is relative to changes in the electromagnetic torque and the difference in changes in the set speed of ideal idle and the current speed value.

$$\begin{align*}
W_M(p) &= \frac{\Delta M}{(\omega_{03} - \omega)} = \frac{\beta_c}{(T_{\text{EEC}} + 1)} \\
\beta_c &= \frac{2M_{CM}}{\omega_{\text{nom}} S_{CS}}
\end{align*}$$

(11)

where $M_{CM}$ i $S_{CS}$ - respectively, the critical moment and the critical slip of the induction motor when powered from a current source; $T_{\text{EEC}}$ - equivalent electromagnetic time constant given by the formula $T_{\text{EEC}} = 1 / \omega_{el, \text{nom}} \cdot S_{CS}$; Critical slip of an induction motor powered by a current source $S_{CS} = \frac{x_{\mu H}^2 + x_{2H}^2}{x_{\mu H}}$, where $x_{\mu H}$, $x_{2H}$ - respectively, the inductive resistance of the magnetization circuit, the inductive and active resistances of the rotor winding, reduced to the stator circuit of the IM at $\omega_{\text{nom}}$.

Then, when choosing the transfer coefficients of the functional devices of the electric drive, according to the condition $(\frac{2\pi k_f}{p \beta_c}) \cdot k_{MD} \cdot k_{FB} = 1$ we will get

$$(\Delta \omega_{03} - \Delta \omega) = k_M \cdot \Delta U_{\text{SC}}$$

(13)

where is the engine torque coefficient:

$$k_V = \frac{2\pi k_f}{p \beta_c} \cdot k_{\text{FSB}} \cdot k_{SFS}$$

(14)

Hence the transfer function of the AD between the change in the electromagnetic moment of the IM and the change in the signal at the output of the SC.

$$\begin{align*}
W_M(p) &= \frac{\Delta M}{\Delta U_{\text{SC}}} = \frac{k_M \beta_c}{(T_{\text{EEC}} + 1)} \\
\text{Transfer function of the speed controller} \\
W_{\text{STC}}(p) &= \frac{\Delta U_{\text{SC}}}{\Delta \omega} = \frac{k_M}{(T_{\text{EEC}} + 1) T_{\text{STC}}} \\
\text{The resulting transfer function of the control object containing the FC and IM} \\
W_{\text{c}}(p) &= \frac{\Delta \omega}{U_{\text{SC}}} = \frac{k_M}{[(T_{\text{EEC}} + 1) T_{\text{STC}}]} \\
\text{If we attribute the constant } T_{\text{EC}} \text{ to a small non-compensating time constant, that is, } E_{\mu} = E_{\text{EEC}}, \text{ then when adjusting the drive to the modular optimum, the transfer function SC} \\
W_{\text{SC}}(p) &= \frac{T_{\text{MTC}}}{(\omega_{\mu} T_{\mu} k_{FB} k_{M})} = k_{\text{SC}}
\end{align*}$$

(17)

(18)
With such a setting with a proportional SC for the drive, and also due to the fact that the electromechanical time constant IM when powered by a current source is less than when powered by a voltage source, the value of $k_{SC}$ is small. As a result, the resulting rigidity of the mechanical characteristic of the drive in a closed system is low. Higher accuracy can be realized by setting the drive to symmetrical optimum with speed PI-controller. In this case, the integration time constant and the transfer coefficient of the proportional part of the controller SC are determined as follows (19, 20): 

$$T_{SC} = \frac{2a_0 T_{m}}{k_{SC}}$$

(19) 

$$k_{SC} = \frac{T_{SC}}{(a_0 T_{m} k_{FB} k_{M})}$$

(20) 

Frequency control without affecting the frequency of the control function is used for single or multi-motor drives with SIEMOSYI motors and induction motors with high speed control accuracy.

These types of U/f control include the following functions: their compensation, current limiting, affecting both frequency and voltage.

The sinusoidal filter allows to provide almost sinusoidal output voltage and current. When using a sinusoidal filter, the higher harmonics in the output voltage with respect to the voltage frequency of 50 Hz are only 5%. The level of peak voltages applied to the motor is lower than required by DIN VDE 0530.

Using the MATLAB software environment, the Simulink module, we will build a model of the drilling rig rotor drive control system [5].

Let’s carry out modeling to evaluate the indicators of control quality based on the results of building mathematical models. Characteristics are constructed using Mathcad mathematical processing.

Knowing all the parameters of the mathematical model of the engine, as well as the control system, we will make its simulation to assess the system stability and control quality indicators.

Based on the results of the calculation, transient processes were obtained during start-up under load and without it, as well as a transient process with an abrupt change in the load torque with different load values. Graphs are shown in fig. 5 - 9.

Fig. 4. Drive speed transient at start without load
Fig. 5. Drive speed transient at load start

Fig. 6. Drive speed transient with load step change (15% load)

Fig. 7. Drive speed transient with load step change (30% load)
Also, in the process of modeling, transient processes of the electric drive current were obtained (Fig. 9 - fig. 11, corresponding to the transient processes shown in fig. 6 – 8).

Fig. 8. Drive speed transient with load step change (45% load)

Fig. 9. Drive current transient during load step change (15% load)

Fig. 10. Drive current transient during load step change (30% load)
Fig. 11. Drive current transient during load step change (45% load)

From these parameters it can be seen that the designed system is able to work out any changes during the operation of the electric drive and provide a constant rotation speed for the entire period of operation of the mechanism.

Conclusions:
In this work, a control system for the electric drive of the winch of a drilling rig has been developed. In the course of the work, the synthesis of a control system based on a frequency converter was performed. The use of a frequency converter as part of the drilling rig control system made it possible to simplify the structure of the winch electric drive control system and improve its characteristics.

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