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Analysis of Characteristics of the Frequency-Controlled Asynchronous Feeder Drive in the Mining Industry Based with IR-Compensation

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Abstract. This article presents an analysis of the static and dynamic characteristics of a frequency-controlled asynchronous feeder drive in the mining industry, based on the scalar control method with IR-compensation. It provides essential information on the laws and methods of frequency control for the asynchronous feeder drive. Various operating modes and severe working conditions of the frequency-controlled feeder drive have been investigated, and its main electromechanical parameters have been determined. Furthermore, using frequency-controlled drives, the static and dynamic characteristics of the feeder drive under low-frequency operation with the application of the scalar IR-compensation method have been developed with the MATLAB Script program.

INTRODUCTION

In the world, the processes of extraction of mineral resources, rational use of fuel and energy resources, and further modernization of economic sectors are becoming increasingly important for the development of countries [1]. Also, due to the ongoing global financial crisis, the demand for fuel and energy resources in various sectors of the economy is increasing daily [2-3]. This leads to an increase in demand for the further development of the mining industry and the optimization of production processes, which plays an important role in the development of countries [4]. However, the mining industry is not only a source of raw materials, but also one of the most energy- and resource-intensive industries in the process of extracting mineral resources [5-6].It is known that the processes of extracting mineral resources, grinding raw materials, and transportation of raw materials all require high electricity consumption in this industry [7]. In particular, when processing or transporting raw materials from mines and quarries to reserve points, the role of load-carrying devices, including feeding devices, is considered high [8].Feeding devices in the mining industry play an important role in crushing extracted heavy raw materials, sorting mineral resources, or accurate delivery of cargo to conveyor systems continuously and at specified time intervals [9]. Since these devices are mainly powered by electric drives and require continuous operation, these devices consume high amounts of electrical energy [10]. Also, maintaining a constant rotational speed of the electric drives of the feeder devices practically leads to inefficient consumption of electricity [11].As a result of many years of scientific research, it has been established that by smoothly starting the electric drives of feeder devices in the mining industry, taking into account various technological processes, and fully controlling the dynamic processes of these devices, as well as automatically controlling the speed of electric drives depending on the amount of transported load, it is possible to significantly increase energy efficiency in this process [12]. However, in the process of applying frequency-controlled electric drives to feeder devices in the mining industry, excessive electricity losses are also observed in these devices.

The main reason for this is the sharp increase in mechanical loads on frequency-controlled electric drives, which leads to an increase in electric current and a sharp decrease in the voltage of electric drives. Taking into account these technological processes, the analysis of the static and dynamic characteristics of the frequency-controlled asynchronous electric drive of the feeder device in the mining industry based on the scalar IR-compensation method is the main goal and objective of this scientific article.

EXPERIMENTAL RESEARCH

In the mining and metallurgical industry of our country, asynchronous electric drives of various types of feeder devices are used, among which the most common is an asynchronous electric drive with an active power of $Pn = 55$ kW, the mains voltage of this asynchronous motor is $Un = 220\ V$, the power factor of the asynchronous motor is $cos\varphi = 0.85$, the rotational speed is $n = 1000\ (980)$ rpm, the efficiency is $\eta = 0.9$, the relative resistance of the stator coil is $Rs = 0.05$ Ohm, the maximum torque is $M_{max} = 1072\ [N \cdot m]$. However, the maximum torque of the asynchronous motor of the feeder device should not exceed $M_{max} = 1072\ [N \cdot m]$, and the installed network frequency fk=25-30 Hz should not be less than the established value. Otherwise, the asynchronous motor of the feeder device will quickly stop moving and fail. Based on the above data, we determine the nominal current of an asynchronous electric motor.

$$I_н = \frac{P_н}{\sqrt{3} \cdot U_н \cdot \cos\varphi \cdot \eta_1} = \frac{550000}{\sqrt{3} \cdot 220 \cdot 0{,}85 \cdot 0{,}9} = 189{,}4 \text{ А}; \quad (1)$$

We determine the IR-compensation voltage:

$$U_к = I_н \cdot R_s = 189{,}4 \cdot 0{,}05 = 9{,}47 \quad (2)$$

Let's determine the proportionality of the feeder device:

$$\gamma_1 = \frac{U_{н1}}{f_{н1}} = \frac{220}{50} = 4{,}4 \quad (3)$$

The relative (range) frequency of the network voltage is determined by the following formula:

$$\text{if } f_1\text{=50 Hz;} \qquad f_{д1} = \frac{f_1}{f_н} = \frac{50}{50} = 1; \quad (4)$$

$$\text{if } f_2\text{=25 Hz;} \qquad f_{д2} = \frac{f_2}{f_н} = \frac{25}{50} = 0{,}5; \quad (5)$$

$$\text{if } f_3\text{=10 Hz;} \qquad f_{д3} = \frac{f_3}{f_н} = \frac{10}{50} = 0{,}2; \quad (6)$$

$$\text{if } f_4\text{=5 Hz;} \qquad f_{д4} = \frac{f_4}{f_н} = \frac{5}{50} = 0{,}1; \quad (7)$$

where fd3 is the relative (range) frequency of the network voltage during the IR-compensation process of the frequency-regulated electric drive of the feeder device. The main reason for this is that the relative (range) frequency of the network voltage should be in the ratio of 1÷5, according to M.P. Kostenko, fd_3=0.2, as well as 15-20% of electricity losses in the IR-compensation process, taking into account various operating modes of the feeder device. The phase voltage in the stator coil of an asynchronous electric motor is expressed by the following formula:

$$U_{н1} = \gamma \cdot f_1 = 4{,}4 \cdot 50 = 220 \text{ V} \quad (8)$$

$$U_{н2} = \gamma \cdot f_2 = 4{,}4 \cdot 25 = 110 \text{ V} \quad (9)$$

$$U_{н3} = \gamma \cdot f_3 = 4{,}4 \cdot 10 = 44 \text{ V} \quad (10)$$

$$U_{н4} = \gamma \cdot f_4 = 4{,}4 \cdot 5 = 22 \text{ V} \quad (11)$$

where Un3 is the network voltage during the IR-compensation process of the frequency-regulated electric drive of the feeder device. Also, in the process of calculating the phase voltage in the stator coil of an asynchronous electric motor, it can be seen that a decrease in the network frequency leads to a proportional decrease in the voltage of the electric drive. Also, as a result of the determined values, it is possible to determine the angular velocity of an asynchronous motor in an ideal idle state. There are two options for technical solutions to stabilize the frequency of the output voltage. The first option is a direct mechanical effect on the rotation speed of the wind wheel, which is technically possible, for example, it is necessary to change the angle of the blades. The second option is to convert non-standard energy into standard electricity.

We determine the exponential coefficients of the frequency-controlled asynchronous electric drive of the feeder device:

$$\gamma_1 = \frac{U_{н1}}{\sqrt{f_{н1}}} = \frac{200}{\sqrt{50}} = 28{,}28 \quad (12)$$

$$\gamma_2 = \frac{U_{н2}}{\sqrt{f_{н2}}} = \frac{141{,}4}{\sqrt{25}} = 28{,}28 \quad (13)$$

$$\gamma_3 = \frac{U_{н3}}{\sqrt{f_{н3}}} = \frac{89{,}44}{\sqrt{10}} = 28{,}28 \quad (14)$$

$$\gamma_4 = \frac{U_{н4}}{\sqrt{f_{н4}}} = \frac{63{,}24}{\sqrt{5}} = 28{,}28 \quad (15)$$

where U_{n1}=200 V, U_{n2}=141.4 V, U_{n3}=89.44 V, U_{n4}=63.24 V - network voltage according to the exponential law of frequency-controlled asynchronous electric drive of the feeder device. Network frequency in the exponential law of frequency-controlled asynchronous electric drive of the feeder device

$$f_{n1} = 50\,Hz \quad f_{n2} = 25\,Hz \quad f_{n3} = 10\,Hz \quad f_{n4} = 5\,Hz$$

It is known that the electric drives of feeder devices in the mining industry are mainly controlled based on a linear law γ=Un/fn, the main reason for which is the interaction of kinetic (tractive electromechanical forces) and potential forces (descending electromechanical forces) in the feeder devices [10-12]. Accordingly, taking into account the selected network frequency of 10 Hz during the IR-compensation process of the frequency-controlled electric drive γ=4.4ga, we determine the base and compensation voltages of the feeder device:

Basic voltage in the IR-compensation process of the frequency-controlled electric drive of the feeder device:

$$U_б = \gamma \cdot f_1 = 4{,}4 \cdot 10 = 44\text{ V} \quad (16)$$

Compensating voltage in the IR-compensation process of the frequency-controlled electric drive of the feeder device:

$$U_k = U_b + U_k = 44 + 9{,}47 = 53{,}47 \quad (17)$$

In the process of IR-compensation of the frequency-controlled asynchronous electric drive of the feeder device, it was determined that the scalar control of this electric drive by the γ=Un/fn method, the regulation of the ratio of network voltages to frequencies based on the law of proportionality, as well as in the process of IR-compensation of this asynchronous electric drive, as a result of increasing the network frequency by 10 Hz, the compensating voltage in this drive will increase by 53.47 V. Also, based on the determined electromechanical values, we achieve complete control of various operating modes, mainly dynamic operating processes, of the frequency-controlled asynchronous electric drive of the feeder device [13-15].

RESEARCH RESULTS

Based on the above calculated data, we use the modern "Matlab" program to reduce electricity losses in dynamic operating modes of the frequency-controlled asynchronous electric drive of the feeder device and reduce them by changing voltage and frequency [16-19]. Also, using the "Matlab" program, we construct the electromechanical characteristics of the frequency-controlled asynchronous electric drive of the feeder device, presented in Table 1, based on the electromechanical parameters necessary for the scalar-controlled IR-compensation process. The data presented in Table 1 are data obtained from scientific research and various reliable sources [16-19]. Figure 1 below shows the mechanical characteristics of the AIR250M6 series asynchronous electric motor according to the control law U1/f1=const.

TABLE 1. Necessary electromechanical parameters for the scalor-controlled IR-compensation process of a frequency-controlled asynchronous electric drive of a feeder device

$f_н$ (Hz)	k_f	n_f (rpm)	ω (rad/s)	M (N·m)	$U_н$ (V)	$I_н$ (A)	ω (rad/s c)
50	1	1000	104.72	525	220	170	104.72
45	0.9	900	94.25	583	198	189	94.25
40	0.8	800	83.78	656	176	213	83.78
35	0.7	700	73.30	750	154	242	73.30
30	0.6	600	62.83	875	132	284	62.83
25	0.5	500	52.36	1051	110	340	52.36
20	0.4	400	41.89	1312	88	425	41.89
15	0.3	300	31.42	1750	66	567	31.42
10	0.2	200	20.94	2625	44	850	20.94
5	0.1	100	10.47	5250	22	1700	10.47

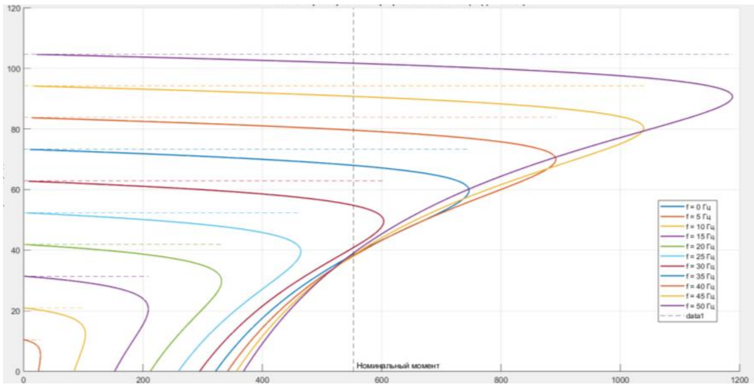


FIGURE 1. Mechanical characteristics of the AIR250M6 series asynchronous electric motor according to the control law U1/f1=const

Fig. 1 shows the mechanical characteristics of the AIR250M6 series asynchronous electric motor with speed regulation by varying frequencies according to the control law U1/f1=const [20-23]. As can be seen from this mechanical characteristic, an increase in the frequency supplied to the electric drive leads to a proportional increase in the voltage of this drive.

The following Figure 2 shows the mechanical characteristics of the AIR250M6 series asynchronous electric motor according to the control law U1/√ (f_1) =const.

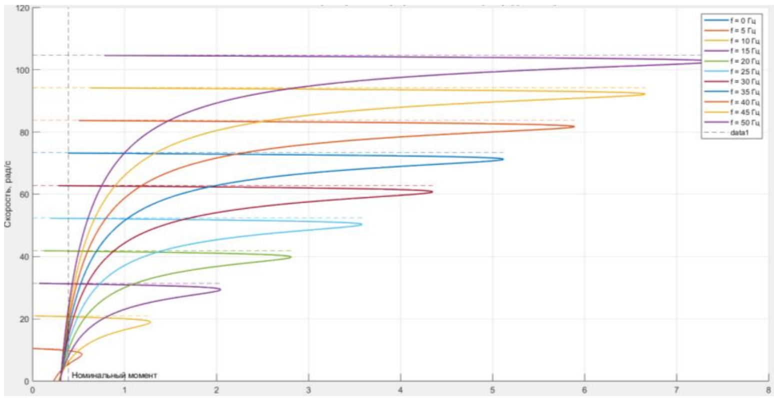


FIGURE 2. Mechanical characteristics of the AIR250M6 series asynchronous electric motor according to the control law U1/√ (f_1) =const

Fig. 3.a.b.c below shows the scalar IR-compensation graphs based on the electromechanical parameters of the frequency-controlled asynchronous electric drive of the feeder device according to the control law U1/f1=const.

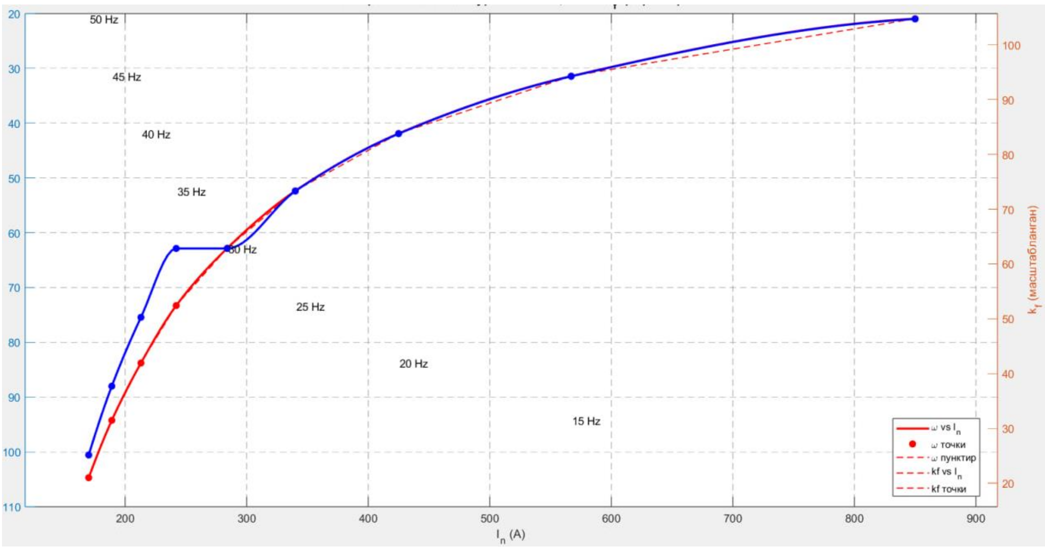
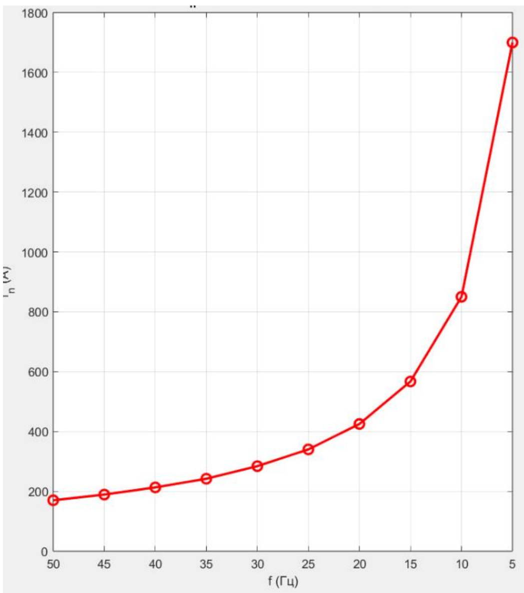


FIGURE 3.a. Scalar IR-compensation graph based on the electromechanical parameters of the frequency-controlled asynchronous electric drive of the feeder device according to the control law U1/f1=const



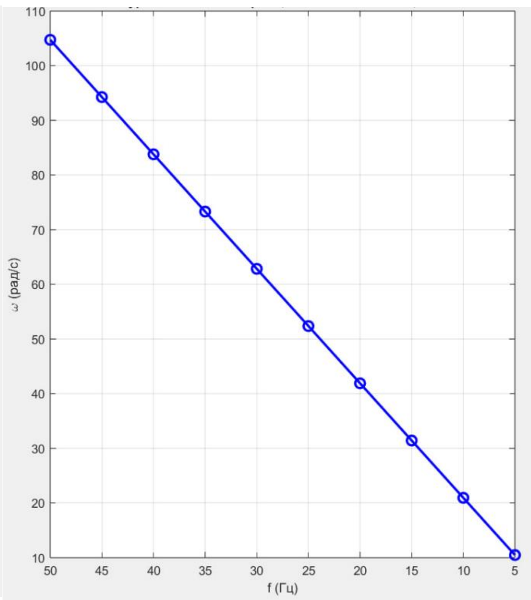


FIGURE 3.b. Graph of the dependence of electric currents on frequencies of the frequency-controlled asynchronous electric drive of the feeder device according to the control law U1/f1=const

FIGURE 3.c. Graph of the dependence of the angular velocities of the frequency-controlled asynchronous electric drive of the feeder device on the network frequencies according to the control law U1/f1=const

Figure 3.a shows a scalar IR-compensation graph based on the electromechanical parameters of the frequency-controlled (AIR250M6 series) asynchronous electric drive of the feeder device according to the control law $U1/f1 = const$. In this electromechanical characteristic, a graph of the dependence of the angular velocities of the asynchronous electric drive, nominal electric currents, and IR-compensation currents based on the compensation coefficient of the electric drive - kf - on network frequencies was constructed based on the Matlab program [24-25]. As can be seen from Fig. 3.a, when operating on a frequency-controlled asynchronous electric drive based on the law $U/f = const$, at low frequencies, the magnetic flux and velocity decrease due to losses $I \cdot Rs$ in the stator. Figure 3.b. The graph of the dependence of the electric currents of the frequency-controlled asynchronous electric drive of the feeder device according to the control law $U_1/f_1 = const$ is presented, and this graph shows how the network current In of the asynchronous electric drive changes with a decrease in frequency. The graph presented in Fig. 3.c shows the dependence of the angular velocity ω of an asynchronous electric drive on the network frequency f, and the graph clearly shows that there is an almost linear, i.e., proportional relationship between the angular velocity and frequency f of the electric drive. Also, in this graph, the angular velocity of the electric drive is $104.72\ rad/s$, and the frequency of the drive is 50 Hz. However, if the drive frequency decreases by 5 Hz, the angular velocity of the drive decreases to $10\ rad/s$, which fully depends on the network frequency and clearly indicates whether it operates at low or high frequencies.

CONCLUSIONS

1. Scientific research shows that when starting a frequency-controlled asynchronous electric drive of a feeder device, it reduces the starting current of the drive by increasing the voltage by a specified amount and further improves the dynamic operating modes of the electric drive, which ensures long-term operation of the device under heavy loads and various operating conditions in the mining industry.
2. Also, the scalar IR-compensation method of a frequency-controlled asynchronous electric drive of a feeder device in the mining industry allows controlling the drive at low rotational speeds, taking into account various operating modes and mechanical loads, and based on this process, increasing the stability and energy efficiency of the asynchronous drive. The scalar IR-compensation method of a frequency-controlled asynchronous electric drive of a feeder device in the mining industry is a convenient method both scientifically and practically, and is an important basis for the development of automated and frequency-controlled electric drives in the mining industry.

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