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Investigation of a Model of Multi-Engine Electric Drive Based on Electromagnetic Working Shaft

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ABSTRACT: The article is devoted to the development and research of a new system of coordinated rotation of motors of a multi-motor electric drive of mechanisms based on an electromagnetic working shaft.

Coordinated rotation of two or more motors, arbitrarily located in space, the mechanical connection between which is undesirable and generally impossible, is implemented in practice by synchronous rotation systems. Depending on the requirements for the accuracy of the coincidence of speeds or angular turns, various schemes of coordinated rotation systems are used for regulation in the synchronization mode and other indicators. One of the options for automating the synchronous operation of electric motors is the use of an electromagnetic working shaft, with the help of which soft start, synchronous operation and speed control of the electric motor of multi-motor mechanisms are carried out.

KEY WORDS: Electromagnetic working shaft, overhead crane, multi-motor electric drive, synchronous rotation, induction rheostat, ferromagnetic core, mutual induction.

I. INTRODUCTION

The dynamic modes of the system depend on many parameters of both engines and the system as a whole. The analysis of such a multi-element system requires the development of special methods for studying electromagnetic processes in the system [9, 15].

According to the importance and the number of works performed, transient processes are divided into the processes of starting, braking, reversing, re-enabling and changing the load. These processes can proceed with symmetric and asymmetric machines [10,17].

To study the dynamics of an electric drive means to find out how the parameters and changes in independent variables affect transient processes and to choose the conditions under which electric machines will operate, as well as to identify the optimal parameters and the nature of the change in independent variables. Transient processes in electric drives are so diverse and complex that it is completely impossible to study them [6,16].

Investigation of the dynamics of the electromagnetic working shaft (EMWSh) on a simplified mathematical model. The interconnection of EMWSh motors due to electromagnetic coupling between the rotor imposes its own specific features on the nature of the flow of transient processes during start-up, shutdown and sudden changes in loads during operation. Of greatest practical interest are changes in the values of mismatch angles and their changes during operation.

The EMWSh equations are non-linear, which complicates the analytical study of dynamic processes [4,5]. Linearization of the system of equations in the region of small deviations, at the point of static equilibrium, greatly simplifies the analysis of transient processes in the EMWSh system.

For $S = 0 - S_m$ each engine of the EMWSh system of an overhead crane separately, in the linear section of the mechanical characteristic, it is described by the equation in operator form:

$$\begin{aligned}(1+T_{e1}P)M_1 &= \beta_1(\omega_0-\omega_1);\\ (1+T_{e2}P)M_2 &= \beta_2(\omega_0-\omega_2);\end{aligned} \qquad (1)$$

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Vol. 9, Issue 11 , November 2022

where: $M_{1,2} = \frac{2M_{c1,2}}{\omega_0 S}$ - stiffness modules of linearized mechanical characteristics;

$M_{c1,2}$ – critical moments of engines;

$T_{e1,2} = \frac{1}{\omega_0 \cdot S_{m1,2}}$ – electromagnetic time constants of motors.

The given system of linearized EMWSh equations makes it possible to study the modes in those cases when $S_m > 1$, that is when introducing an inductive reactance into the rotor circuit, in our case induction rheostat (IR), the critical slip value is always greater than 1.

This model allows you to explore both transient and stationary modes of operation of EMWSh (the processes of starting, braking, increasing and decreasing the load, periodic and random load fluctuations at different speeds), that is when the engines operate on a linear characteristic in the interval $0 < S < S_m$.

Due to the elastic force connection of the rotors, the EMWSh engines are interconnected. At the same time, in order to simplify the equations describing the system, it is advisable to identify the power rotor connection through the increments of the angular positions of the rotors of each engine relative to each other:

$$\omega = K_{1,2} \frac{d(\varphi_1 \ \varphi_2)}{dt} \tag{2}$$

where: are the angular mismatch feedback gains.

Then the linearized equation of motion of the EMWSh can be written as:

$$\begin{aligned}
&\left(1+\frac{1}{\omega_0 \cdot S_{m1}} P\right) M_1 = \frac{2M_c}{\omega_0 S_{m1}} [\omega_0 - \omega_1 - \Delta\omega]; \\
&M_1 - M_{c1} = J_1 P \omega_1 ; \\
&\left(1+\frac{1}{\omega_0 \cdot S_{m1}} P\right) M_2 = \frac{2M_{c2}}{\omega_0 S_{m2}} [\omega_0 - \omega_2 - \Delta\omega]; \\
&M_2 - M_{c2} = J_2 P \omega_2 ;
\end{aligned} \tag{3}$$

where: M_1, M_2 - engine moments;

ω_1, ω_2 – engine speeds;

M_{s1}, M_{s2} – static moments of engines;

J_1, J_2 - the reduced moments of the engines.

The given system of linearized equations of the EMWSh allows one to compose its simple linear scheme for research on a computer.

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II. RESEARCH PROBLEM AND METHOD

The mathematical model, due to the assumptions made when it was obtained, does not allow reproducing the processes of acceleration and deceleration of engines.

Based on the analysis of vector equations that reflect the relationship between the voltages on the stator and rotor windings, the magnetic fluxes of these windings, the angular velocities of the stator and rotor fields, and the moment on the shaft of an induction motor, an equation is derived that relates the driving moment M_{D} and the slip S. This second-order nonlinear equation has view

$$T_{\mathrm{e}}^2 \xi \frac{d^2 M_{\mathrm{D}}}{dt^2} + T_{\mathrm{e}} \xi \left(2 - \frac{T_{\mathrm{e}}}{S} \cdot \frac{ds}{dt}\right) \frac{dM_{\mathrm{D}}}{dt} + \left(1 - \frac{T_{\mathrm{e}} \xi}{S} \cdot \frac{ds}{dt}\right) M_D = 2\xi M_c \frac{S}{S_c} \tag{4}$$

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Vol. 9, Issue 11 , November 2022

In order to build a model that describes these processes (in those cases when $S_c < 1$), the equation together with the equation is a mathematical model of an induction motor, adequate in all modes of this operation (to the best of the Kloss formula, which is also an approximate expression of the static characteristic of the motor)

However, to implement the equation, let us turn to the implicit operator form of this equation given in [4,7]:

$$\left(1+T_e\frac{ds}{dt}\right)\cdot\left[\frac{S}{S_c}\left(1+T_e\frac{ds}{dt}\right)M_D\right]+\frac{S}{S_c}M_D=2M_c \tag{5}$$

We introduce an auxiliary variable with the dimension of the moment

$$\varepsilon=\frac{S_c}{S}\left(M_D+T_e\frac{dM_D}{dt}\right) \tag{6}$$

Substituting (5) into (6), we obtain a differential equation with respect to the auxiliary variable;

$$T_e\frac{ds}{dt}+\varepsilon+\frac{S}{S_c}M_D=2M_c \tag{7}$$

We transform equation (6):

$$S_c\cdot T_e\frac{dM_D}{dt}+S_c\cdot M_D=S_c \tag{8}$$

Solving the equation (7) and (8) with respect to the derivative by the equation, we obtain the equation of the mathematical model of an induction motor:

$$\begin{gathered}\frac{dM_D}{dt}=(\omega_0-P\Omega)\varepsilon-\frac{1}{T_e}M_D\\ \frac{d}{dt}=\frac{2}{T_e}M_c-\frac{1}{T_e}\varepsilon(\omega_0-P\Omega)M_D\end{gathered} \tag{9}$$

The coefficients of equations (9) contain only passport and catalog data of the engine, that is minimal easily accessible information is needed to implement the model. In order for equations (9) to correctly reproduce the engine acceleration process, it is necessary to set the initial condition $\varepsilon(0)=2M_e$.

$$\begin{aligned}\frac{dM_1}{dt}&=(\omega_0-P\Omega_1)\varepsilon-\frac{1}{T_{e1}}M_1\\ \frac{d\varepsilon}{dt}&=\frac{2}{T_{e1}}M_{c1}-\frac{1}{T_{e1}}\varepsilon-(\omega_0-P\Omega_1)M_1\\ \frac{dM_2}{dt}&=(\omega_0-P\Omega_2)\varepsilon-\frac{1}{T_{e2}}M_2\\ \frac{d\varepsilon}{dt}&=\frac{2}{T_{e2}}M_{c2}-\frac{1}{T_{e2}}\varepsilon-(\omega_0-P\Omega_2)M_2\end{aligned} \tag{10}$$

III. RESULT AND DISCUSSION

Investigation of the dynamic modes of the EMWSh, taking into account the inertia of the object. The studied real two-motor electric drive with EMWSh contains elastic and non-linear mechanical connections between moving masses and is a complex multi-mass system. The elastic mechanical vibrations acting in the system of disturbances in the mechanical part of the electric drive negatively affect its operation (increased dynamic loads, the appearance of mechanical vibrations, etc.). At the same time, elastic mechanical bonds significantly affect the stability of the system and the quality of the transition process. With certain combinations of system parameters, they can have a damping effect on oscillations in the electric drive system [6]. The analysis of dynamic processes in such systems is much more difficult due to the lack of precise quantitative characteristics of all elements and connections of the system.

When studying the dynamics of mechanism drives, not real working bodies are considered, but only their reduced dynamic models. This is explained by the fact that, firstly, the mathematical model turns out to be very

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Vol. 9, Issue 11 , November 2022

cumbersome, which makes it difficult to obtain an adequate solution, and secondly, there is no need to take into account all the working bodies that have little effect on the nature of the system's motion. Taking into account the inertial masses of the rotors of asynchronous motors and the elements of the mechanism, we believe that each of them is driven by one equivalent of an asynchronous motor. Let us represent the calculated mechanical scheme in the form of a two-mass system [7,9]. Then the equations of the mechanical system, the parameters of which are reduced to the motor shafts. can be written as:

$$M_1 - M_{s1} - M_{v1} - M_{12} = J_1 P\omega_1 \; ; \qquad (11)$$
$$M_2 - M_{s2} - M_{v2} - M_{12} = J_2 P\omega_2 \; ;$$

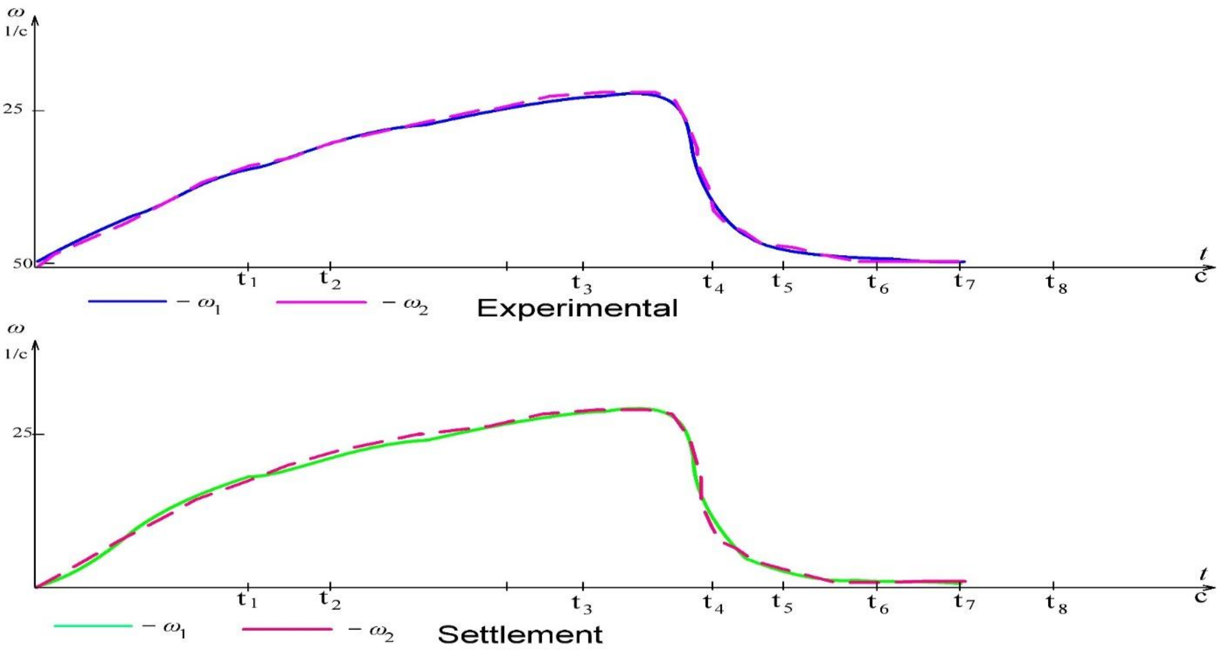
where: $\omega_1, \ \omega_2$ - angular speeds of engines;

$J_1, \ J_2$-are the moments of inertia of the first and second masses;

$J_1, \ J_2$ – static reactive moments;

M_{12}-are the moments of elastic interaction between the masses;

$M_{v1}, \ M_{v2}$-are moments of internal viscous friction.



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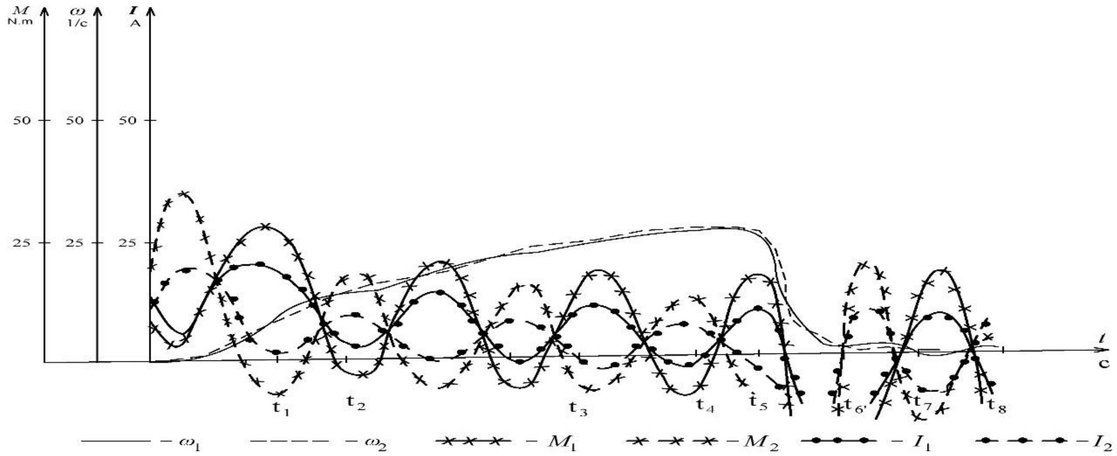

Fig.1. EMWSh transients.

In accordance with the above calculation method, the Euler method was used to simulate the dynamics of EMWSh with engines of the MTG-211 type. Fig.1.

During the starting process, the moments, angular velocities and currents of the motors oscillate about their average values. In this case, the oscillation frequency is determined by the oscillations of the moment of elastic interaction with the natural frequency of the mechanical system.

In the time interval from 0 to t_1 the moments of the motors increase with some average rates determined by the given intensity of the current rise in the circuit of the third winding of the IR. In the section from t_1 to t_2 the engine torques begin to decrease. A steady $t_2 - t_3$ state occurs in the section, where the moments, currents and speeds of the motors acquire steady-state average values of the parameters.

In general, a braking mode against turning on is observed $t_5 - t_8$ in the section. In this case, an increase in the moments and currents of the motors occurs in the section $t_5 - t_6$. In the section $t_6 - t_7$, the increase in the moments of the motor currents not only stops, but also begins to decrease. On the site $t_7 - t_8$, a decrease in parameters is observed and at the point t_8, the moments and currents of the motors are equal to zero.

IV. CONCLUSION

As the simulation results show, in the considered electric drive, under transient conditions, the rate of increase in speeds and the time of transient processes meet the requirements. By the nature of the transient processes, absolute synchronization of the speeds of the engines is observed.

The coordinated operation of EMWSh drive motors with sharply different loads on the motor shafts leads to a decrease in energy consumption and resource saving by electric drives in general. The considered characteristics make it possible to solve the inverse problem, that is given the parameters and values of the necessary moments of a particular electric drive system, it is possible to determine the parameters of the induction rheostat. The characteristics of the EMWSh indicate a wide range of coordinated operation of the EMWSh with sharply different loads on the motor shafts.

The use of electric drives with a synchronization system based on EMRV makes it possible to reduce dynamic loads not only in transient, but also in steady state.

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International Journal of Advanced Research in Science, Engineering and Technology

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