Development And Research Of Method Of Reducing Losses In Asynchronous Motors Testing By Mutual Loads

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Abstract— an analysis of the process of testing electric machines by the method of mutual loading is given. The case in which an asynchronous machine is used as a loading machine is considered. Effect: increased energy efficiency due to regulation of voltage parameters applied to stator winding of load machine. The mathematical model of the system of two mechanically coupled three-phase asynchronous machines is refined by taking into account the dependence of the power of magnetic losses in the stator on the frequency and the effective voltage value. Mathematical modeling and experimental studies have shown the effectiveness of the proposed method of reducing losses. The results of mathematical modeling on machines of different capacities showed a significant decrease in efficiency of the proposed method for high-power machines. The obtained results are recommended for implementation at the enterprises engaged in the production and operation of electric machines.

Keywords— induction machine, frequency converter, energy efficiency, mutual load method, voltage regulation

I. INTRODUCTION

Modern developments in control of asynchronous electric drives have significantly increased their energy efficiency and expand the scope of application [1-7]. Frequency converters, developed on the basis of IGBT-transistors, can effectively apply various laws of frequency control of the supply voltage to reduce losses in the process of electromechanical conversion [8-10]. Production and operation of asynchronous motors at various stages of their life cycle requires testing them in accordance with current standards. The load testing is the most energy-intensive of all the mandatory test types. The method of mutual load previously offered with the purpose of saving electricity while testing by this method [11-12]. Schemes, allowing to carry out tests of asynchronous motors by the method of mutual loading, are presented in [13-17].

In load tests, the motor must be loaded with nominal mechanical power. In this case, the parameters of the supply voltage (the effective value and frequency of voltage) should be closest to the nominal values. The parameters of the generator operation mode are not specified in the guidance documents.

II. BASIC IDEA

The known schemes of mutual loading do not use the possibility of increasing the energy efficiency of the test scheme by regulating the voltage parameters supplied to the stator winding of the load machine [13-17].

The implementation of this idea requires a set of technical devices, shown in Fig. 1.

Fig. 1. Fragment of the scheme of testing induction motors by mutual load

The above block diagram (Fig. 1) includes common elements for known test schemes: test asynchronous motor 1, coupling 2, load asynchronous machine 3, inverter controlled 4. Also on the block diagram shows the elements necessary for regulation: control system 5, voltage frequency calculator 6, speed sensor (for example, an incremental encoder) 7. An alternating three-phase voltage is applied to the stator winding of the test asynchronous motor. A constant voltage is applied to the power input of the controlled inverter.

III. THE PRINCIPLE OF OPERATION OF THE CIRCUIT

The proposed method of increasing the energy efficiency of the asynchronous motors test scheme by the mutual load method (Fig. 1) assumes the following principle of its work.

Initially, both asynchronous machines run at idle. In this case, the stator winding of the test motor is supplied with the nominal voltage frequency and effective voltage value.

Further, the conclusion of the test asynchronous motor to the rated load mode is achieved by specifying the difference in the frequency of voltages applied to the stator windings of both machines. Thus, the mechanical characteristics of the test asynchronous motor and load asynchronous machine take the form shown in Fig. 2.
IV. MATHEMATICAL MODEL

Mathematical modeling of the test scheme is performed in order to assess the energy efficiency of the effective value and frequency of the voltage supplied to the stator winding of the load generator (Fig. 1). The mathematical model of a pair of asynchronous machines operating by the method of mutual loading is considered in [18]. This model consists of an equation of motion and equations composed by the second Kirchhoff law for each phase of the stator and rotor for both machines. However, this mathematical model does not take into account the dependence of magnetic losses in the stator on the current voltage value. This assumption is not applicable for the analysis of energy processes in the system under consideration (Fig. 1) when adjusting the voltage parameters at the output of the controlled inverter. We take into account in the equation of motion the torque of losses. This torque is represented as two components, one of which is due to mechanical losses, and the other is due to losses in the magnetic system of the stator:

\[
\frac{d\omega}{dt} = -\frac{p}{J}\{(L_{12}\{i_{1a}(i_{2b} - i_{2a}) + \ldots
+ i_{1b}(i_{2c} - i_{2a}) + \ldots
+ i_{1c}(i_{2a} - i_{2b})\} + \ldots
+ L_{21}\{i_{2a}(i_{2b} - i_{2c}) + \ldots
+ i_{2b}(i_{2c} - i_{2a}) + \ldots
+ i_{2c}(i_{2a} - i_{2b})\}) - \ldots
\}
\]

\[
\frac{M_{mech} + M_{mag}}{J}\text{sign}(\omega),
\]

where \(\omega\) – angular speed of rotation of the rotor;
\(t\) – time;
\(p\) – number of pole pairs;
\(J\) – moment of inertia;
\(L_{12}\) – the highest value of the mutual inductance of the three-phase winding of the test motor;
\(L_{21}\) – the highest value of the mutual inductance of the three-phase winding of the load machine;
\(i_{1a}, i_{1b}, i_{1c}\) – the currents of the stator winding of the test motor;
\(i_{1a}', i_{1b}', i_{1c}'\) – the currents of the rotor winding in the T-equivalent circuit of the test motor;
\(i_{2a}, i_{2b}, i_{2c}\) – the currents of the stator winding of the load machine;
\(i_{2a}', i_{2b}', i_{2c}'\) – the currents of the rotor winding in the T-equivalent circuit of the load machine;
\(M_{mech}\) – the braking torque due to mechanical losses in the system;
\(M_{mag}\) – the braking torque due to the magnetic losses in the stators of the machines.

The T-equivalent circuit parameters of induction machines and their components of losses is determined according to the method presented in [19]. This method allows to obtain approximate parameters of the
asynchronous machine, based on its catalog data and a number of assumptions.

The braking torque due to mechanical losses can be found as

$$M_{\text{mech}} = \frac{\Delta P_{1\text{mech}} + \Delta P_{2\text{mech}}}{\omega},$$  \hspace{1cm} (2)$$

where $\Delta P_{1\text{mech}}$ – mechanical power losses in the test asynchronous motor;

$\Delta P_{2\text{mech}}$ – mechanical power losses in the load asynchronous machine.

The dependence of the magnetic losses in the stators of both machines on the parameters of voltage supplied to the load machine can be approximated as follows:

$$M_{\text{mag}} = \frac{\Delta P_{1\text{mag}} + \Delta P_{2\text{mag}}}{\omega} \left( \frac{U_2}{U_{2n}} \right)^2 \left( \frac{f_2}{f_{2n}} \right)^{1.2},$$  \hspace{1cm} (3)$$

where $\Delta P_{1\text{mag}}, \Delta P_{2\text{mag}}$ – the magnetic power losses in the test motor and the load machine;

$U_{2n}, f_{2n}$ – the operating value and frequency of the rated voltage of the loading machine;

$U_2, f_2$ – the effective value and frequency of the voltage applied to the loading machine.

As a result of mathematical modeling, the dependences for two types of asynchronous machines are obtained. The first type is IMM71B4Y2 with a nominal power $P_n = 0.37$ kW and the second type is 5AMH315M4 with a nominal power $P_n = 250$ kW.

V. EXPERIMENTAL DEVICE

Experimental verification of the results of mathematical modeling was carried out on a test bench. The test bench equipped with a load asynchronous machine type IMM71B4Y2, operating in the generator mode. This type of asynchronous machine has the following nominal parameters: power $P_n = 0.37$ kW, current $I_n = 2.37/1.37$ A, voltage $U_n = 220/380$ V, power factor $\cos(\varphi_n) = 0.7$, speed $n_n = 1370$ min$^{-1}$. When performing an experiment constant values of torque and speed were provided on the shaft of the loading machine. The voltage controlling was implemented by the frequency converter with AC/DC/AC system. The passport parameters of frequency converter: rated output current – 1.2 A, output voltage – 0…400 B, the frequency of the output voltage – 0…60 Hz. The scheme of the test bench is shown in Fig. 4.

During the experiment, manual regulation of the voltage parameters (effective value and frequency) supplied to the stator winding of the asynchronous load machine was performed by using a frequency converter and a laboratory autotransformer. The rotational speed and torque on the shaft were set by the smooth regulation of the armature voltage of the DC drive motor with independent excitation.

The dependences obtained in the experiment are shown in Fig. 5, 6 (dashed line).

VI. ANALYSIS OF THE RESULTS OF MATHEMATICAL MODELING AND EXPERIMENTAL STUDIES

Analysis of graphs obtained as a result of mathematical modeling and experiment (Fig. 5, 6, 7, 8), shows their qualitative coincidence.

![Fig. 4. Scheme of the stand for experimental studies](image)

![Fig. 5. Graphs obtained as a result of mathematical modeling and experiments with asynchronous machines rated power of $P_n = 0.37$ kW](image)
Each curve has a point corresponding to the highest energy efficiency of the test circuit. This point in Fig. 5, 6 corresponds to the power of about five times more than can be achieved under the law of regulation $U/f = \text{const}$. Thus, the application of the proposed method of increasing energy efficiency can give a significant effect for engines of small nominal power, if the frequency converter uses the law of regulation $U/f = \text{const}$. However, for a high-power asynchronous motor (see Fig. 7, 8) the point of maximum energy efficiency is close enough to the point corresponding to the law of regulation $U/f = \text{const}$. Thus, the effect of the proposed method of increasing energy efficiency for testing high-power induction motors is insignificant.

VII. CONCLUSIONS AND RECOMMENDATIONS

The results of mathematical modeling and experimental studies show that regulating effective value and frequency of voltage applied to the asynchronous load machine may improve energy efficiency of the scheme of mutual load. The effect of this regulation is reduced by increasing the rated power of the tested machines.

The developed method of improving the energy efficiency of the test process of induction motors is recommended for implementation in enterprises engaged in the production and operation of electric machines.

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