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RESEARCH OF THE INDUCTION MOTOR ECCENTRICITY PHENOMENON CRITERIA

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The paper is devoted to the first step in the sphere of experimental investigations of the induction motors' (IM) eccentricity problem by the use of uniform displacement of the rotor centerline in the stator bore under the no-load and breaking conditions. The changes in the stator voltage and rotor current, the voltage drop along rotor shaft and the EMF induced in the search coil by the leakage magnetic flux at the free butt of motor shaft have been analyzed. Two performance criteria demonstrated can be proposed for practical application.

The problem of the IM eccentricity is a subject of much current interest because there are no proven ways for carrying out the periodical air gap measurements in the course of their operation. It is obvious that the model motor designed for operation at the various air gap positions should be redesigned. In case being considered the motor shields were reconstructed to ensure, within certain limits, the rotor position changes in the stator bore. The purpose to be achieved should be supplemented by possibility of measuring the rotor currents.

Requirements mentioned above were satisfied through choosing the induction motor MA36-41/8 type (40 kW, 380/660 V, 730 rpm) equipped with the phase rotor windings.

The first step of using the motor for theoretical consideration of the phenomenon of eccentricity in general terms was described in [1]. The problem of eccentricity discussed below may be thought as the second look based on the same experimental set-up.

New goals to be sought are devoted to searching the proficient methods for quantitative analysis of the rotor eccentricity.

The general view of the adjustable eccentric arrangement based on the spiral gear built into the motor shields of the IM is shown in Fig. 1. The tests were carried out at three given values of eccentricity in the range between 10 and 60 percent. The greater value of eccentricity, taking into account the length of the air gap equals 0.9 mm, appears to be a hazard to the motor and a threat to experimenters.

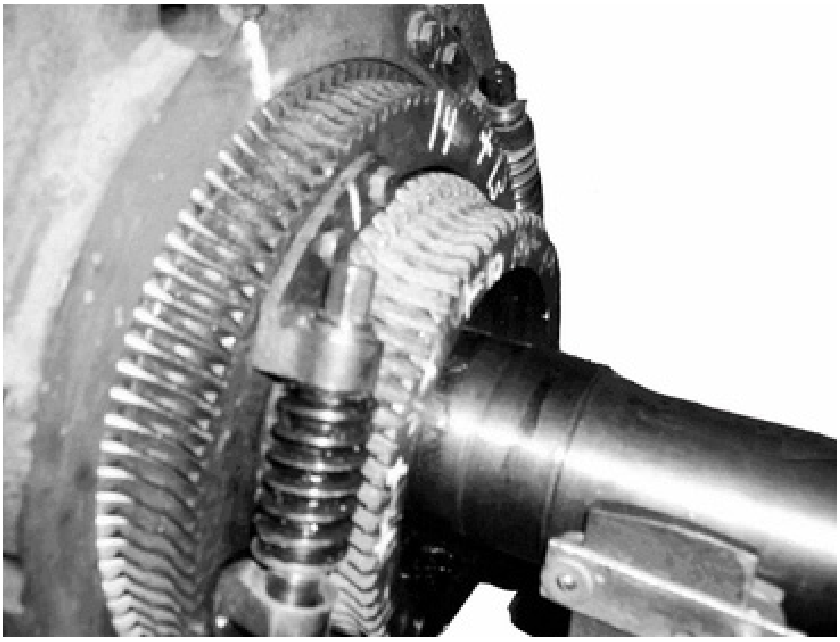

Figure 1 - General view of the adjustable eccentric arrangement used at the test

In the case under consideration the rotor plug-in type roller bearings were displaced uniformly to ensure the constant distance between the rotor and stator centerlines.

Structural arrangement of transducers used at the test measurements is shown in Fig. 2.

The test measurements in the search were carried out by the digital recording of the electromotive force induced in multiturn ferrite-core coil containing 30.000 turns. The mentioned coil is fairly small in size: inside and external diameters are equal to 1.0 cm and 3.6 cm, respectively, 6.0 cm in length. The coil axis was located coaxial with the rotor shaft. The air gap between the free butt of the shaft and core of the coil was taken equal to 0.5 cm.

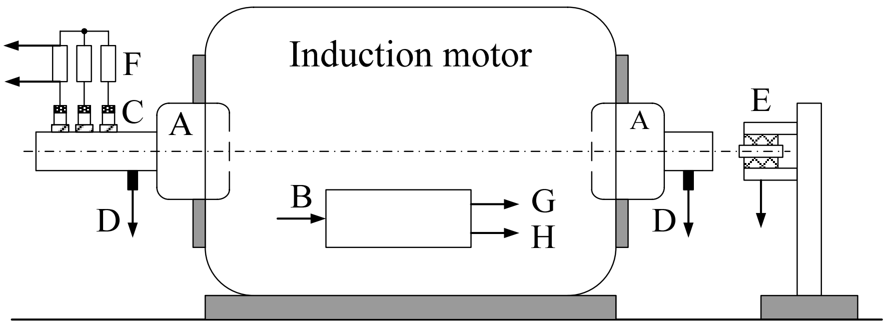

Figure 2 - Disposition of transducers at the motor test bench
A = Bearing and arrangement for changing the motor eccentricity; B = Lead-in of the power supply; C = Slip ring brushes; D = Single shaft brush; E = Induction coil and the wooden support; F = Noninductive shunts; G, H = Measurements of stator voltages and currents

Measuring device based on the 12-bit ADC provides the acceptable accuracy of measurements. All tests were made with the same initial temperature. For the base frequency the magnetic induction at the induction coil location can be calculated by the well known expression

$$B = E \cdot (w \cdot S \cdot \omega \cdot \sin(\omega \cdot t))^{-1}$$

where
E = EMF (V); w = quantity of the coil turns; S = area (m^2); ω = 314 s^{-1}.

Schematic diagrams of IM magnetic fluxes based on the physical notions about electromagnetic processes of the energy conversion at the test conditions are presented in Fig. 3.

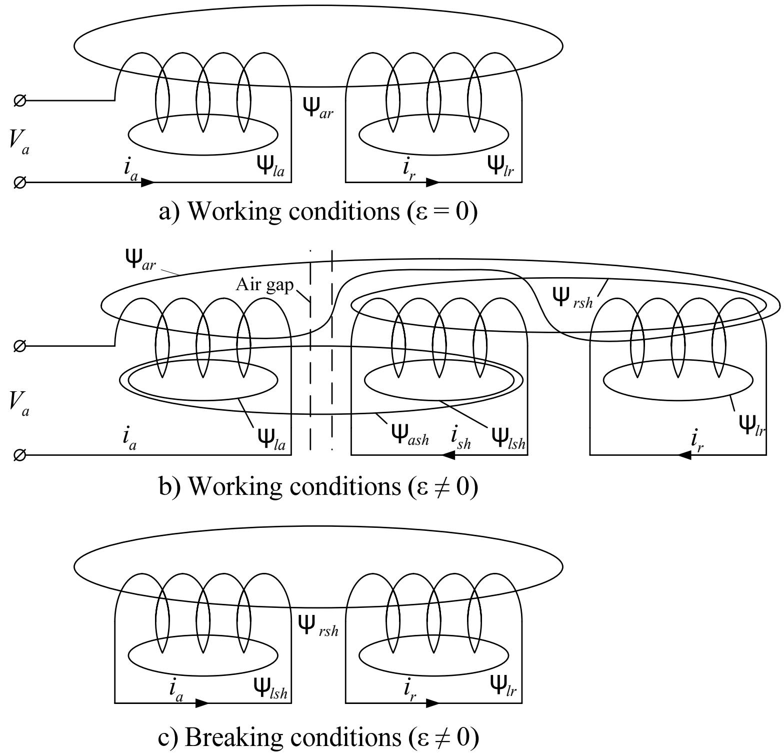

Figure 3 - Mutual flux linkages and leakage fluxes of an IM under various test conditions

Fig. 3(b) provides a possibility of mathematical description of an IM magnetic fluxes. In particular, magnetic fluxes at the rotor eccentricity the armature and rotor windings, and the damping effect of the massive iron shaft of a motor can be written, respectively, as

$$\psi_a = \psi_{la} + \psi_{ra} + \psi_{sh\ a} = i_a x_a + i_r x_{ra} + i_{sh} x_{sh\ a}$$

$$\psi_r = \psi_{lr} + \psi_{ar} + \psi_{sh\ r} = i_r x_r + i_a x_{ar} + i_{sh} x_{sh\ r}$$

$$\psi_{sh} = \psi_{lsh} + \psi_{ash} + \psi_{rsh} = i_{sh} x_{sh} + i_a x_{a\ sh} + i_r x_{r\ sh}$$

where

$$x_{ra} \neq x_{sha} \neq x_{shr}$$

$$(x_a - x_{la}) \neq (x_r - x_{lr}) \neq (x_{sh} - x_{lsh}).$$

It is well to bear in mind that the above mutual inductances are appreciably dependent on the degree of magnetic saturation and the air gap eccentricity.

From the above consideration it follows that there is a need to carry out a motor diagnostic tests at the same stator voltage level.

The simplest equivalent circuit shown in Fig. 4 provides but a rough idea of the rotor shaft adverse affect on the starting and breaking torques of the motor at the irregular air gap. Nonetheless the above mentioned hypothetical equivalent circuit gives an insight about the physical understanding of its structural determination.

It is well known that the ratio between the active and reactive components of the iron shaft essentially depends on the shaft current frequency and hence on the current penetration into the massive shaft.

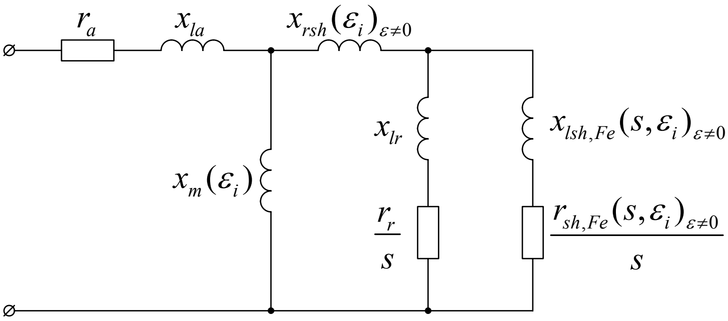

Figure 4 - The simplest equivalent circuit of an IM at the rotor eccentricity

Maintenance diagnostics of an IM exhibiting the most promise for detection of impermissible magnitude of the air gap eccentricity can be connected with record of the stator voltage when switching off the motor from the energy supply and leakage flux derivatives at the free butt of the rotor shaft.

Time constant of the stator voltage changes after switching off the no-load conditions is determined by the use of the generalized phasor of three instantaneous values of the linear voltages. For the purpose of excluding the influence of the saturation effect on the path of the main magnetic flux the time constant of the decaying stator voltage was determined at the voltage levels less than 0.65 V_N.

Changes of the average value of the stator winding time constant of the MA36-41/8 motor with rotor eccentricity are shown in Fig. 5. Deviations between the average values and measured ones do not exceed 5%.

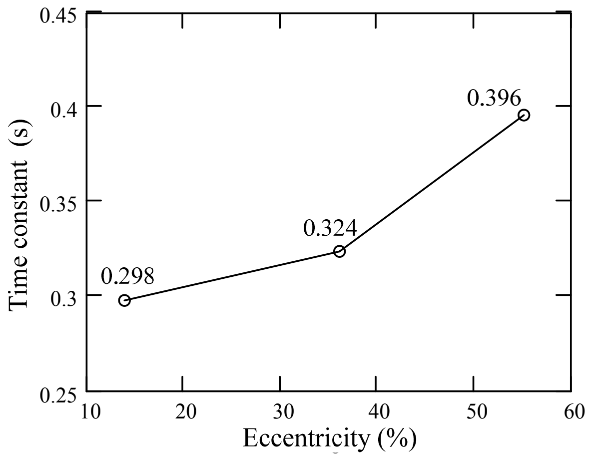

Figure 5 - Stator voltage time constants with rotor eccentricity of the IM MA36-41/8 type at the motor breaking conditions

Time constants of the stator voltage decay at the motor breaking conditions can't be virtually used for the high-voltage motors because switch board cells of the latter ones doesn't equipped with the voltage measuring transformers.

Changes in the time constants of the rotor current and induction coil effective EMF under uniform rotor displacement of the IM MA36-41/8 type at switching off the motor from the energy supply are shown in Fig. 6. The influence of the saturation effect was not taken into consideration.

The changes in spectral components of the induction motor EMF at the steady-state no-load conditions with the value of rotor eccentricity were obtained on processing the EMF measured at the terminals of the search coil. The assessment of harmonic with eccentricity was carried out by the use of coefficient of harmonic distortion

$$K_D = \frac{A_i}{A}$$

where

A_i = amplitude of the i -th harmonic; A = effective value of a signal.

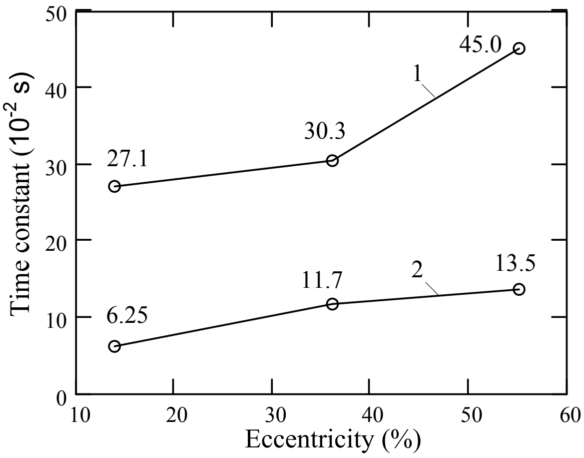

Figure 6 - Changes in time constant of the rotor current and induction coil EMF at switching off the motor from supply (1) – Rotor current; (2) – Induction coil EMF

The results of processing the search coil signals (for harmonics 12.5, 25, 37.5 and 50 Hz) are given in the Table 1.

Table 1 – Influence of the air gap eccentricity on coefficients of harmonic distortion of the IM MA36-41/8 type

Air gap eccentricity, %	Mean effective value of EMF, mV	Amplitude of harmonic component, mV				Coefficient of harmonic distortion			
		12.5	25.0	37.5	50.0	12.5	25.0	37.5	50.0
13.8	72.26	12.64	19.22	10.99	65.99	0.171	0.262	0.176	0.932
36.0	78.82	12.76	19.41	12.87	73.09	0.162	0.247	0.164	0.940
55.1	60.33	12.57	18.69	12.12	53.01	0.222	0.333	0.214	0.888

At exceeding the quantitative indices in the course of increasing the time constant of the induction coil EMF at switching off an IM or the coefficient of harmonic distortion at no-load conditions above the threshold value of the permissible rotor eccentricity the motor should be disconnected from the supply.

Physical modeling of the rotor eccentricity taking into account the normal air gap length of the motor under consideration equals 0.9 cm brings the threat for the motor test specimen. Taking into account that the development of the eccentricity is not precisely predictable the pointed value is to be set no more than 50 percent.

Records resulting from the tests carried out at the steady-state no-load conditions with the eccentricity equal to 13.8, 36.0 and 55.1 percent were analyzed. Visible distinctions between spectral components of the voltage drop along the motor shaft at the eccentricity equal to 13.8 and 55.1 percent are shown in Fig. 7.

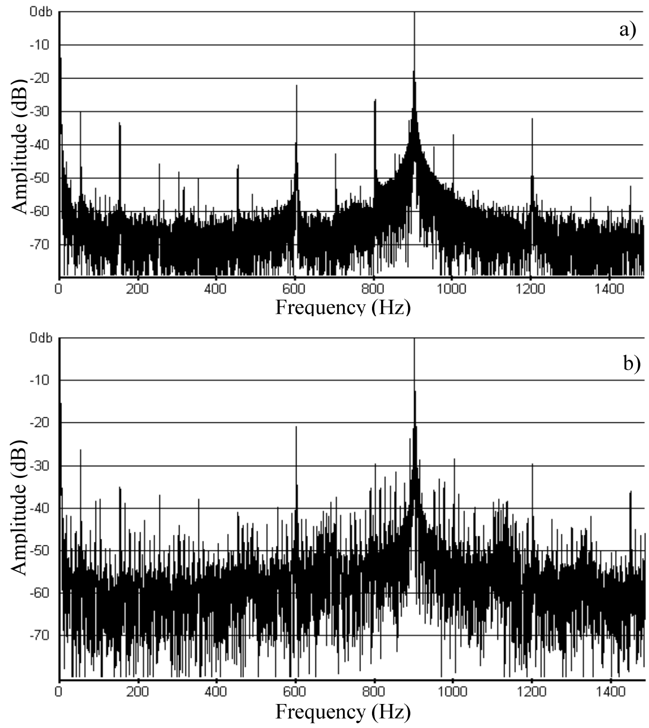

Figure 7 - Spectral components of the voltage drop along the rotor shaft of the motor MA36-41/8 type at eccentricity equal to 13.8 percent (a) and 55.1 percent (b)

Effective value of the signal was determined by expression

$$A = \sqrt{A_0^2 + \sum_{i=1}^{\infty} A_i^2}$$

where

A_0 = constant component; A_i = effective values of the basic harmonics.

The main information about the rotor eccentricity comes from analysis of the amplitude coefficient

$$C_a = \frac{A_{max}}{A}$$

where A_{max} = maximum value of the signal; A = effective value of the signal.

Under changes of eccentricity from 13.8 percent to 55.1 percent the mentioned above value of the signal was increased from 0.616 V to 0.822 V. At the eccentricity interval between 13.8 and 36.0 percent the amplitude coefficient is varied through a small range amounting up to 0.974 at the eccentricity equal to 55.1 percent, 36 percent more than at the rotor eccentricity equal to 36.0 percent.

Conclusions

The paper gives adequate analysis of the problem connected with the quantitative evaluation of the air gap eccentricity in induction motors under operating and no-load conditions.

The methods being considered are based on analyses of the following operating variables:

- voltage of the stator winding after switching off the IM from the energy supply;
- electromotive force induced across the terminals of the search coil located closely to the shaft butt of an IM after switching off from the energy supply;
- spectrum of the voltage drop along the IM rotor shaft at the no-load conditions.

It is believed that the results obtained regarding the voltage drop along the IM rotor shaft at the no-load conditions, or at the predetermined working conditions, are the promising variables on order to ensure the on-line diagnostics of the rotor eccentricity.

REFERENCES

1. G. G. Rogozin, “Impact of the air gap eccentricity on the leakage flux change outside the IM frame during run-out of the motor after disconnection from the supply”, SPEEDAM Symposium 2004, June 16-18, 2004, pp. 31-37.

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