STUDY ON THE ECCENTRIC ROTOR DYNAMICS IN A THREE-PHASE INDUCTION MOTOR WITH SQUIRREL CAGE ROTOR UNDER UNBALANCED MAGNETIC FIELD

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Electric machines are increasingly being used in a wide variety of industries due to a number of advantages, such as high efficiency and the ability to be directly connected to the drive's working body. One of the challenges in the design and operation of electric motors is the high level of vibration. Vibration is the main cause of bearing failure and a source of noise. The main cause of motor vibration is an unbalanced rotor [1].

The quality of rotor operation directly determines the performance of the motor. Rotor imbalance can occur both due to rotor mass eccentricity, when the center of inertia does not lie on the rotor axis of rotation, and due to unbalanced magnetic pull (UMP). Since in most cases the motor rotor can be considered rigid, the problem of rotor mass eccentricity is usually successfully solved by balancing. More difficult to solve is the problem of unbalance caused by magnetic forces, in particular UMP. Under ideal conditions, the air gap between the stator and rotor is uniform and symmetrical. Under this condition, the resulting radial magnetic attraction force around the rotor circumference is zero [2].

Despite the existence of studies on the subject of induction motor vibrations under the influence of UMP, the mechanism of UMP occurrence, the interaction of mass and magnetic unbalance forces, and possible solutions to the problem require additional research. For this purpose, this paper proposes a simulation model of a rotor with mass eccentricity, static magnetic eccentricity, and mixed magnetic eccentricity, which allows studying the phenomena of unbalance under the simultaneous action of forces of different nature.

In the proposed mathematical model of rotor vibrations [3], a rigid rotor of mass m of the motor has three degrees of freedom and, rotating with an angular velocity Ω, can make small translational movements in the direction of the x and z axes. In the model shown in Fig. 1, the following assumptions are made: the elastic characteristics of all supports are linear; the rotor is assumed to be rigid and its deformations are neglected; the position of the center of mass point S of the rotor is known; the stator is considered to be absolutely rigid and rigidly fixed to a rigid foundation.

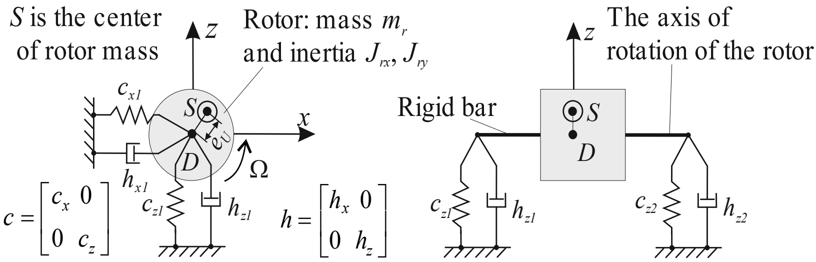

Fig. 1. Dynamic model of a rotor with mass eccentricity

In the diagram, the mass eccentricity is equal to $e_U = SD$, where point D is obtained as a result of the intersection of the rotor axis of rotation with a plane drawn through the center of mass point S perpendicular to the axis of rotation of the rotor. For generalized coordinates, we take the x, y coordinates of point D.

To analyze the effect of magnetic eccentricity, we use the approach described in [4, 5]. The expression for the unbalanced magnetic pull on the rotor surface for number of pole pairs p=1 is defined as

$$\begin{cases} F_{UMPx} = f_1 \cos\varphi + f_2 \cos(2\omega t - \varphi) + f_3 \cos(2\omega t - 3\varphi), \\ F_{UMPz} = f_1 \sin\varphi + f_2 \sin(2\omega t - \varphi) + f_3 \sin(2\omega t - 3\varphi), \end{cases} \quad (1)$$

where F_{UMPx} and F_{UMPz} are projections of the magnetic pull force on the x and z axes, respectively; ω is angular frequency of the motor stator winding power supply source; f_1, f_2, f_3, f_4 are the amplitudes of the components of the UMP [3].

The angular speed of rotation of the rotor taking into account the slip s of the induction motor is related to the angular speed of rotation of the magnetic field ω_m and the angular frequency of the electric current supplying the winding ω as follows $\Omega = (1-s)\omega_m = (1-s)\omega p^{-1}$. The system of differential equations to describe the rotor behavior

$$\begin{cases} m\ddot{x} + (h_{x1} + h_{x2})\dot{x} + (c_{x1} + c_{x2})x = \Omega^2 me \sin\Omega t + F_{UMPx}, \\ m\ddot{z} + (h_{z1} + h_{z2})\dot{z} + (c_{z1} + c_{z2})z = \Omega^2 me \cos\Omega t + F_{UMPz}. \end{cases} \quad (2)$$

We will use numerical methods to solve this system of equations with a nonlinear right-hand side. The simulation model was created in the

Simulink/Simscape multibody environment of the MATLAB mathematical package. The general view of the model is shown in Fig. 2. A three-phase squirrel-cage induction motor with a power of 11 kW and an operating speed of 3000 rpm was chosen for the simulation.

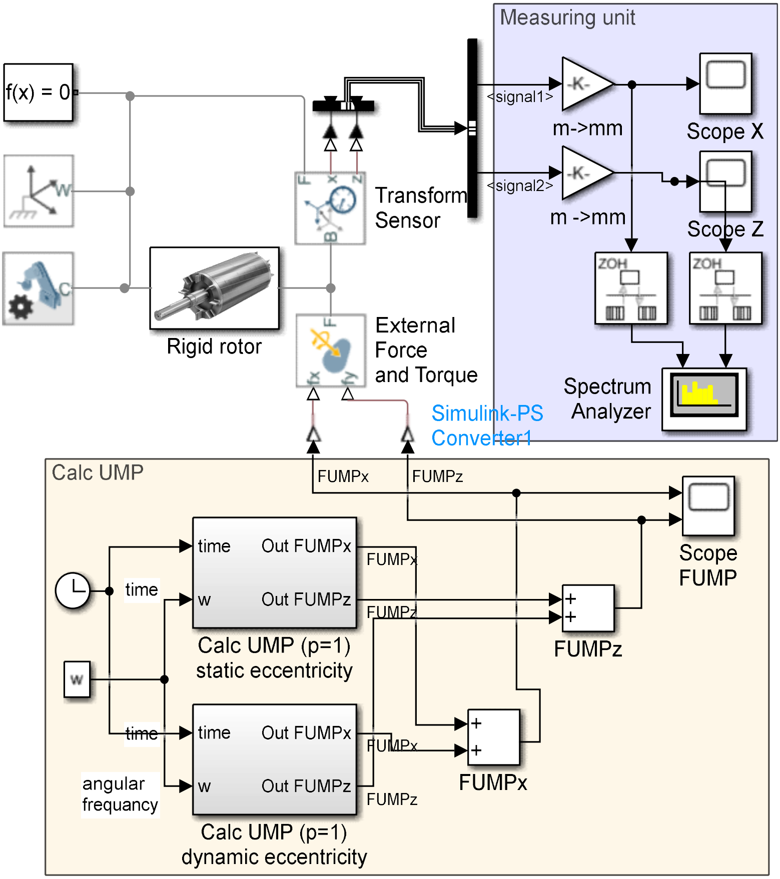

Fig. 2. Simulation model of rotor research

The simulation of the vibration process according to (12) was carried out at an operating rotor speed of n=2910 rpm, which corresponds to an angular rotation frequency of Ω=303.5 rad/s. The static magnetic eccentricity causes a vibration with a double frequency 2ω of the electric one. In the spectrogram, this harmonic is observed at a frequency of f=93.75

Hz. In addition, the static magnetic eccentricity causes the rotor to shift in the direction of the minimum air gap, which corresponds to the zero harmonic f=0. Under the influence of dynamic eccentricity, the entire spectrum is centered on the rotor speed f=48.8 Hz. The time vibration signal is modulated with the rotor precession frequency. Mixed magnetic eccentricity, which is most common in practice, is a source of a complex non-sinusoidal signal.

Vibrations caused by static magnetic eccentricity occur at twice the electrical frequency. This feature reduces the overall rigidity of the rotor and lowers the critical rotor frequencies, which must be significantly higher than the operating frequency. Vibrations caused by dynamic eccentricity take the form of a rotor speed signal modulated at a low frequency depending on the rotor precession.

The model can be used for vibration diagnostics of electric motor rotor eccentricity.

References

1. Popa, L. M., Jensen, B. B., Ritchie, E., et al. (2003). Condition monitoring of wind generators. 38th IAS Annual Meeting on Conf. Record of the Industry Applications Conf., Salt Lake City, Utah, USA, vol. 3, pp. 1839 - 1846
2. Salah, A. A., Dorrell, D. G., Guo, Y. (2019). A Review of the Monitoring and Damping Unbalanced Magnetic Pull in Induction Machines Due to Rotor Eccentricity. In IEEE Transactions on Industry Applications. 55(3). pp. 2569-2580
3. Goroshko A. V., Zembytska M. V., Paiuk V. P. (2024). Induction motor vibrations caused by mechanical and magnetic rotor eccentricity. Journal of Engineering Sciences (Ukraine), 11(1), pp. D66–D77.
4. Du, J., & Li, Y. (2023). Analysis on the variation laws of electromagnetic force wave and vibration response of squirrel-cage induction motor under rotor eccentricity. Electronics, 12(6), 1295.
5. Wang, Z., He, W., Du, S., Yuan, Zh. (2021). Study on the Unbalanced Fault Dynamic Characteristics of Eccentric Motorized Spindle considering the Effect of Magnetic Pull. Shock and Vibration, vol. 2021, pp. 1-12