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FIELD-CIRCUIT ANALYSIS OF AC MACHINE TAKING INTO ACCOUNT STATOR WINDING ASYMMETRY

The paper presents the influence of an asymmetry of a stator winding on an axial flux in AC machine. The objective research was performed for selected values of asymmetry. The axial flux was calculated as the sum of flux linkage with stator winding. In order to achieve a magnetic field distribution a dedicated 2D finite element model of AC machine was elaborated. The waveforms of axial flux and torque-time characteristic have been shown. It can be concluded that the asymmetry has significant impact on the axial flux and the pulsation of torque.

1. INTRODUCTION

Forecasting of faults in electrical machine is significant in their operation. Therefore, in the diagnostics of electrical machines we look for diagnostics methods that are able to supervise the machine and do not interfere with the operation of the machine. The most popular methods are based on the measurements of the phase currents, the pulsation of the torque, or the vibrations of the machine. The measured signals can be analyzed using the following methods: the Motor Current Signatures Analysis (MCSA), the Extended Park's Vector Approach (EPVA) and the Discrete Wavelet Transform [1, 2]. On the basis of these measurements and results of their analysis, it can be concluded about faults in the machine. The majority of diagnostics method can identify the condition of the machine after major faults had occurred. The difficulty in faults identifying is separation of the diagnostics symptoms from the measured signals. For faults identification the dedicated Artificial Neural Network (ANN) can be used [3, 4].

The slight faults in the machine, i.e. on the electric circuit of the windings (short-turns, broken bars) as well as on the magnetic circuit (rotor eccentricity) are very

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barely noticeable, but they cause asymmetry in the machine [5]. Also due to improper manufacturing or fault of stator winding, the value of turns number of phase winding could change. One of the asymmetry symptoms is an axial flux [6]. It arises when the sum of linkage fluxes is not equal to zero.

In this paper an influence of the asymmetry of the stator winding on magnitude of the axial flux is investigated. For that purpose a 2D finite element model of an AC machine was elaborated. Making use of the numerical model the calculations were performed for different cases of asymmetry of the stator winding.

2. CALCULATION OF THE AXIAL FLUX

The axial flux can be calculated as the sum of linkage flux, the formula can be written in the following form

$$\phi_0 = \sum_{i=1}^{N} \Psi_i = \Psi_A + \Psi_B + \Psi_C \tag{1}$$

where ϕ_0 is the axial flux, Ψ_i is the flux linkage with *i*-th winding, *N* is the number of windings, Ψ_A, Ψ_B and Ψ_C are the fluxes linkage with phase *A*, phase *B* and phase *C* winding, respectively (Fig.1).

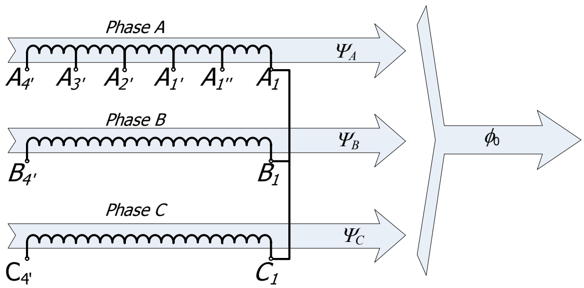

Fig. 1. The axial flux as the sum of phase fluxes

Because of voltage-excited supply a field-circuit analysis were used to obtain phase currents and fluxes linkage. The field-circuit model includes the field equations, the circuit equations and the motion equation. The magnetic field distribution was obtained by finite element method. The circuit equations can be expressed in the following matrix form

$$\mathbf{U} = \mathbf{Ri} + \frac{d\mathbf{\Psi}}{dt} \tag{2}$$

where **U** is the supply voltage matrix, **R** is the resistance matrix, **i** is the current matrix, $\mathbf{\Psi}$ is the flux linkage matrix.

When machine runs at no-load test the influence of the rotor winding flux can be neglected. Therefore, in case of asymmetry in stator winding the axial flux can be calculated as follows

3. SELECTED RESULTS OF THE CALCULATION OF THE AXIAL FLUX

The three phase squirrel cage induction machine has been chosen for the calculations. The rated values of machine are: supply voltage U_N = 380 V (star connected), power P_N = 2.2 kW, speed n_N = 1420 rpm, current I_N = 5.1 A.

In order to model the asymmetry of the stator winding the number of turns N_A in winding of phase A was varied. The values of N_A and share of each part in stator winding is presented in Table 1. Whereas, the number of turns in winding of phase B and phase C was equal to 55.

Table 1. The share of parts in stator winding

Part of phase A	N_A (number of turns)	Percentage share
$A_1 - A_{4'}$	55	100%
$A_1 - A_{3'}$	40	74%
$A_1 - A_{2'}$	27	49%
$A_1 - A_{1'}$	12	23%
$A_1 - A_{1''}$	6	11%

The calculations were performed for symmetrically three phase supply voltage, using FEM in software package Ansoft Maxwell. On the basis of obtained results the magnetic field distribution is presented in Fig. 2, at time t = 200 ms, U = 220 V and the number of turns N_A = 27. Two values of phase voltage, i.e. U = 220 V and U = 150 V were considered. The first value is equal to rated value, and the second is equal to value during an experiment measurements. It was assumed that the rotor run at no-loaded external torque with constant angular velocity equal to 1495 rpm. The calculations were carried out with the B-H curve assigned to material of the stator core, the rotor core and the shaft, i.e. the magnetic circuit was non-linear.

The influence of the number of turns on the axial flux has been investigated for different values of the voltage supply. The calculations were performed for the number of turns presented in Table 1 and two values of phase voltage, U = 150 V and U = 220 V. The results of calculation are presented in Fig. 3. It can be seen that decreasing the number of turns cause increasing the axial flux for each case of the voltage supply.

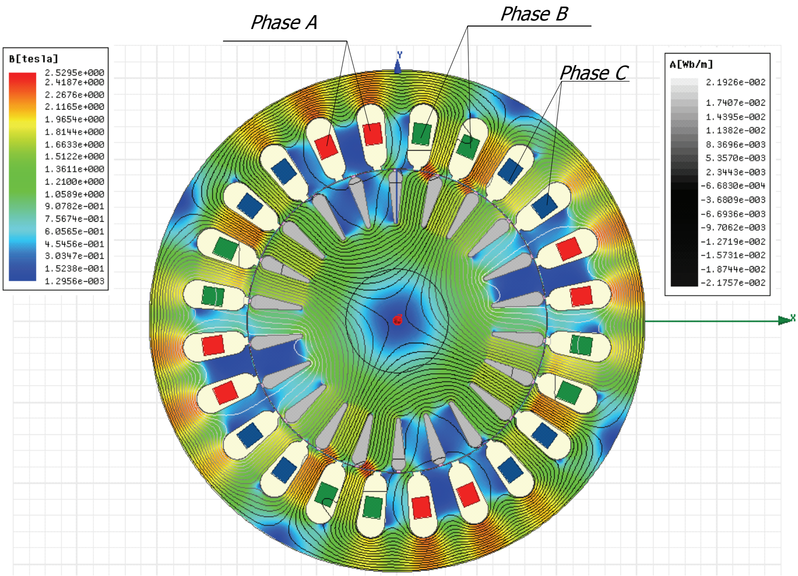

Fig. 2. Magnetic field distribution, at time t = 250 ms, U = 220 V and the number of turns N_A = 27

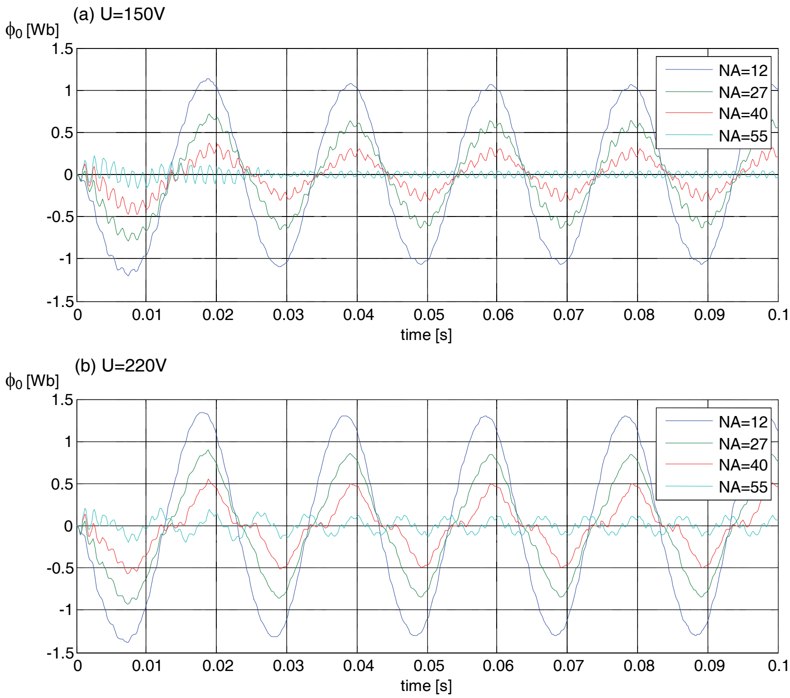

Fig. 3. The waveforms of axial flux for different values of phase voltage: a) U = 150 V, b) U = 220 V

4. VERIFICATION OF CALCULATIONS

The measurements of the axial flux have been describe in [7]. Figure 4 illustrates the comparison between the results obtained by the calculations and the measurements. The comparison was realized for the values of number of phase turns presented in Table 1. A discrepancy of calculations and measurements can be observed, due to two dimensional numerical model.

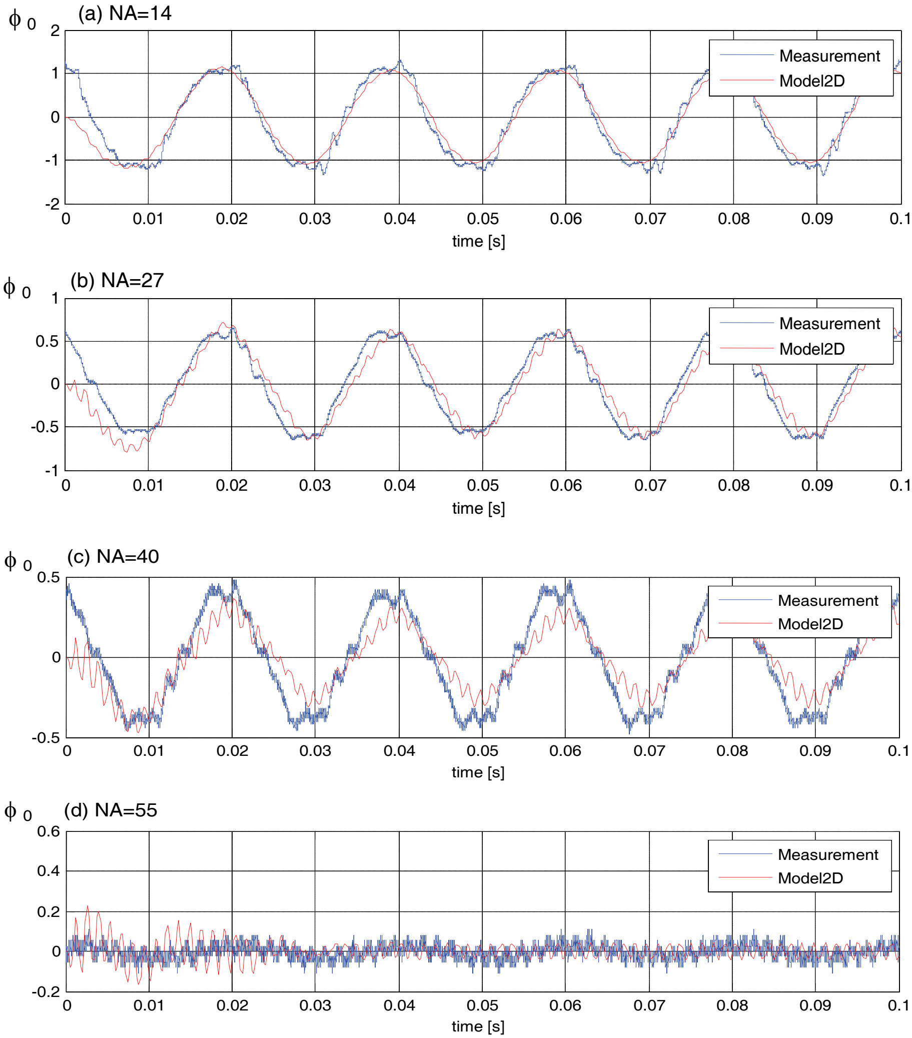

Fig. 4. The calculated and measured waveforms of axial flux for different values of the number of turns: a) N_A=12, b) N_A = 27, c) N_A = 40 and d) N_A = 55

5. TORQUE-TIME CHARACTERISTIC

The computer software makes possible calculations of a torque-time characteristic. In Figure 5 and Figure 6 the results of torque-time characteristic and harmonic analysis for varied number of turns in case of U = 150 V are shown, respectively.

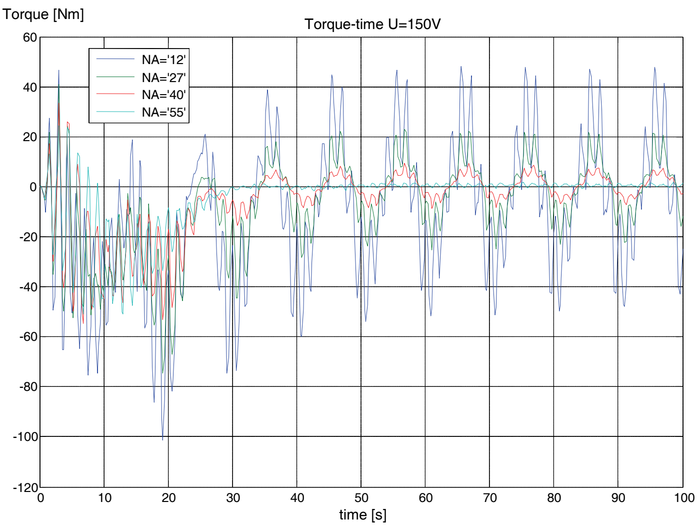

Fig. 5. Torque-time characteristic for N_A = 12, N_A = 27, N_A = 40 and N_A = 55 in case of voltage supply U = 150 V

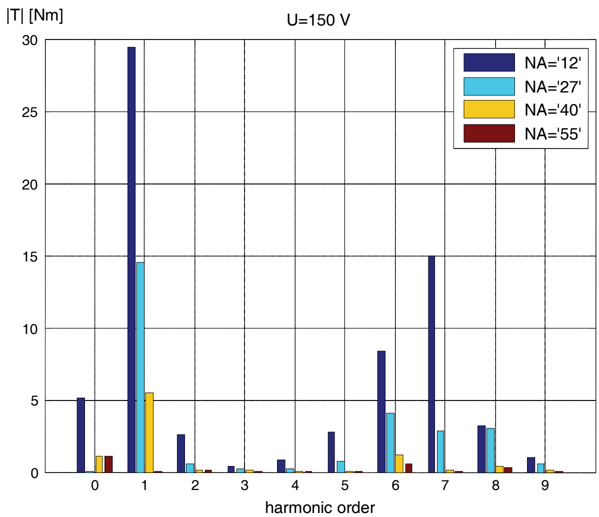

Fig. 6. Harmonic analysis of torque-time characteristic in case of voltage supply U = 150 V

6. SUMMARY

The field-circuit model of induction machine with variation of number of winding turns has been elaborated. The model includes the motion equation, the field equations and the circuit equations. The computer software allows to calculate the flux linkage and the axial flux as the sum of fluxes linkage. The obtained results of calculation were compared with results of measurements. The influence variation of number of winding turns on the axial flux and torque-time characteristic were investigated.

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