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Two-Phase Asynchronous Motor - Simulation and Measurement

Abstract: The paper addresses modelling of a two-phase induction motor. Based on geometric dimensions, the model was created in the 2D and 3D ANSYS Maxwell program. Transient process at the motor start-up was calculated within the same program, too. Another model was made up based on the induction motor mathematical description in the MATLAB/Simulink program. Waveforms of the motor currents and torques are compared. Models created in MATLAB/Simulink and ANSYS are compared with measurements. For measurements was used a symmetrical two phase power supply.

1. Introduction

Three-phase induction machines are powered by three-phase symmetrical voltage. Windings of the motors are arranged within the stator and mutually shifted by 120 electrical degrees. These machines operate with circular magnetic fields.

Single-phase motors have two windings (phases) in their stators, which are mutually shifted by 90 electrical degrees. One of the windings is main and the other one is auxiliary. Both phases are powered by s single-phase network. Time shift of the voltage in the auxiliary winding is usually due to a capacitor connected in series with the auxiliary winding. This creates an elliptic magnetic field. The motor torque consists of a forward and a backward component.

If both main and auxiliary windings of a single-phase motor will be identical and powered by two-phase voltage, circular magnetic field will be developed within the machine.

The paper compares individual two-phase motor models, one developed within MATLAB/Simulink and the other in the ANSYS Maxwell program. The ANSYS Maxwell model works on geometric dimensions and takes into consideration non-linearity of the used magnetic material. The MATLAB/ Simulink model works with constant parameters that were attained by measurements performed on a real motor.

2. Mathematical model

To simulate two-phase motor in MATLAB/ Simulink program used was a model that takes into account asymmetrical windings [1]. Varying number of turns in phases reflects parameter "*a*". The system of fixed stator coordinates α-β is applied. In this specific case, asymmetry of the investigated motor parameters is due to the winding production. Number of turns in the main and auxiliary phases is identical.

Components of stator and rotor voltages of two-phase induction motor can by expressed as follows:

$$u_{s\alpha} = R_{s\alpha} i_{s\alpha} + \frac{d\psi_{s\alpha}}{dt} \quad (1)$$

$$u_{s\beta} = R_{s\beta} i_{s\beta} + \frac{d\psi_{s\beta}}{dt} \quad (2)$$

$$u_{r\alpha} = 0 = R_{r\alpha} i_{r\alpha} + \frac{d\psi_{r\alpha}}{dt} + a\omega_{r\alpha}\psi_{r\beta} \quad (3)$$

$$u_{r\beta} = 0 = R_{r\beta} i_{r\beta} + \frac{d\psi_{r\beta}}{dt} + a\omega_{r}\psi_{r\alpha} \quad (4)$$

where a - is the main per auxiliary winding turns ratio.

The components of stator and rotor flux linkages are:

$$\psi_{s\alpha} = L_{s\alpha} i_{s\alpha} + L_{m\alpha} i_{r\alpha}, \quad \psi_{s\beta} = L_{s\beta} i_{s\beta} + L_{m\beta} i_{r\beta}$$
$$\psi_{r\alpha} = L_{m\alpha} i_{s\alpha} + L_{r\alpha} i_{r\alpha}, \quad \psi_{r\beta} = L_{m\beta} i_{s\beta} + L_{r\beta} i_{r\beta} \quad (5)$$

The components of stator and rotor currents are:

$$i_{s\alpha} = \frac{L_{r\alpha}\psi_{s\alpha} - L_{m\alpha}\psi_{r\alpha}}{L_{s\alpha}L_{r\alpha} - L_{m\alpha}^2}, \quad i_{s\beta} = \frac{L_{r\beta}\psi_{s\beta} - L_{m\beta}\psi_{r\beta}}{L_{s\beta}L_{r\beta} - L_{m\beta}^2}$$
$$i_{r\alpha} = \frac{L_{s\alpha}\psi_{r\alpha} - L_{m\alpha}\psi_{s\alpha}}{L_{s\alpha}L_{r\alpha} - L_{m\alpha}^2}, \quad i_{r\beta} = \frac{L_{s\beta}\psi_{r\beta} - L_{m\beta}\psi_{s\beta}}{L_{s\beta}L_{r\beta} - L_{m\beta}^2} \quad (6)$$

Electromagnetic torque produced by the machine is given by the equation (7).

$$m_i = p(L_{m\beta} i_{s\beta} i_{r\alpha} - L_{m\alpha} i_{s\alpha} i_{r\beta}) \quad (7)$$

$$m_i - m_z = J\frac{d\omega}{dt} \qquad (8)$$

where:

$\psi_{s\alpha}$, $\psi_{s\beta}$, $\psi_{r\alpha}$, $\psi_{r\beta}$ are the stator and rotor flux linkages,

$i_{s\alpha}$, $i_{s\beta}$, $i_{r\alpha}$, $i_{r\beta}$ are the stator and rotor currents,

L_s, L_r, L_m are the stators, rotor, magnetizing inductances,

R_s, R_r are the stator and rotor resistances,

ω is the electrical rotor angular speed,

J is the rotor moment of inertia,

m_i is the electromagnetic torque of motor.

3. Model of the motor in ANSYS/Maxwell

The same motor was simulated in the ANSYS/ Maxwell program. When directly connected to the voltage the start-up of the motor was calculated. The motor magnetic field was calculated by the finite elements method in 2D and 3D space.

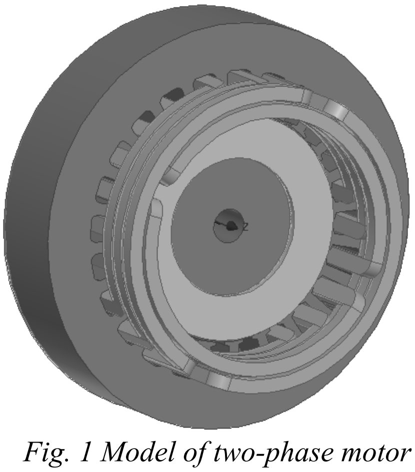
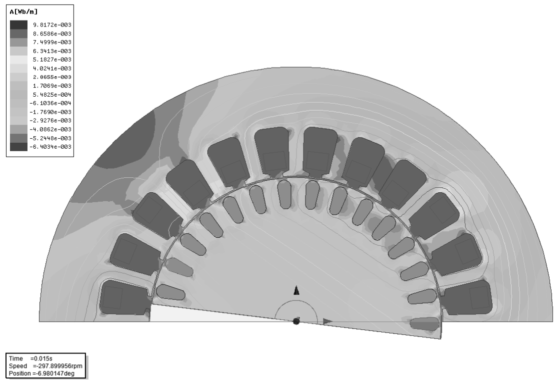


Fig. 1 Model of two-phase motor

Taken into account at calculating were nonlinear properties of the magnetic circuitry material. In space illustrated used motor model is shown in Fig. 1. Waveforms of the magnetic field calculated in Maxwell 2D are shown in Fig. 2 for time t=0,015 s (Fig. 2a) and time t=0,025 s (Fig. 2b). Distribution of the B-vectors calculated in Maxwell 3D for time t=0,01 s is shown in Fig. 3.

The motor is supplied by two-phase symmetrical voltage. Calculated waveforms of currents for individual phases, the inner torque and speed are demonstrated in Fig. 4 for 2D simulation and in Fig. 5 for 3D simulation.



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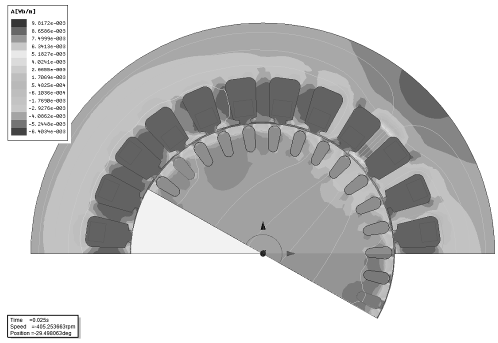


b)

Fig. 2 Magnetic field of motor (Maxwell 2D)

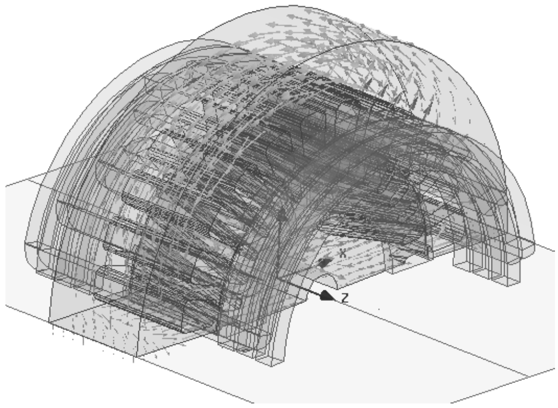
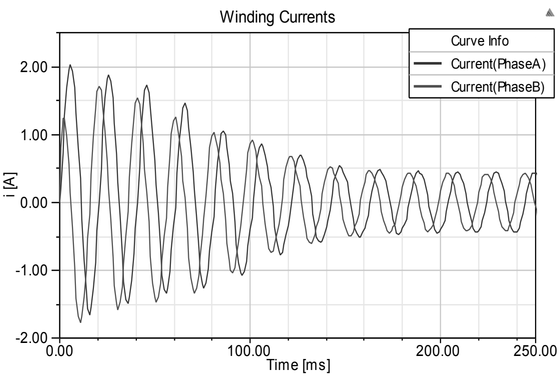
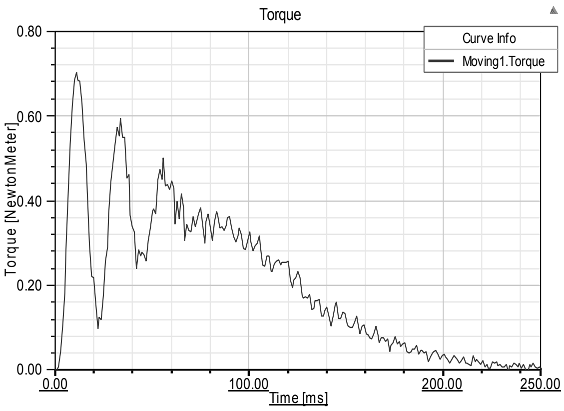


Fig.3 B-vectors calculaded by Maxwell 3D



a)



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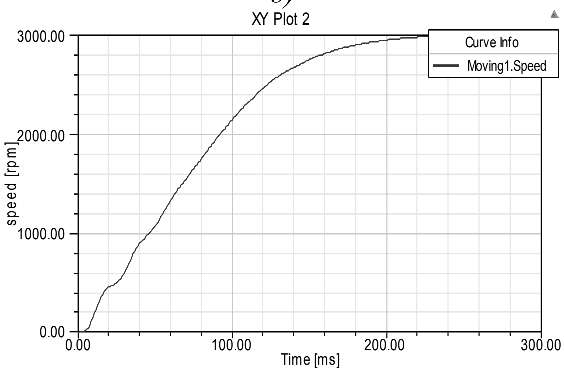
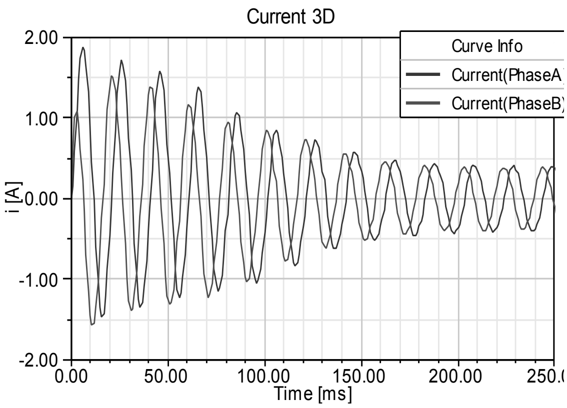


c)

Fig. 4 Calculated waveforms of two-phase motor- 2D solution: (a)-currents, b)-torque, c)-speed)



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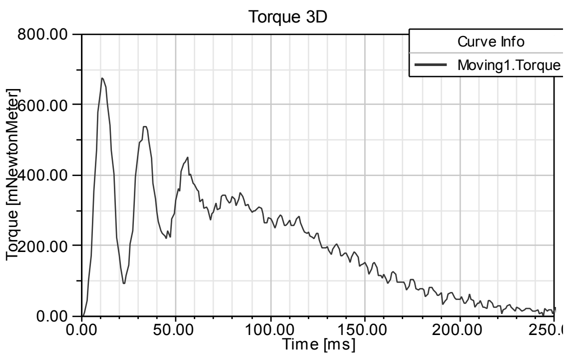

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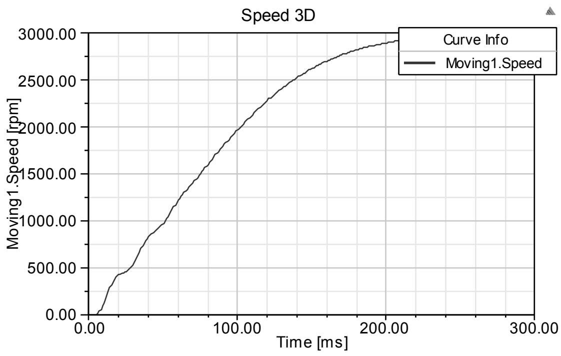


c)

Fig. 5 Calculated waveforms of two-phase motor- 3D solution: (a)-currents, b)-torque, c)-speed)

There are small differences between the solutions in the transient state. They are caused mainly by different number of elements and by influence of the end windings. 3D solution worked with 114293 mesh elements (the calculation took approximately 15 hours) and 2D solution worked with 4298 mesh elements (calculation took several minutes).

4. Computer simulation and experimenttal results

Based on equations 1-8, model of the two-phase asynchronous motor in the MATLAB/Simulink program was created. For calculations used motor parameters (resistances, inductances, and the moment of inertia) had been attained by measurements performed on a specific motor. Supplied values are shown in table 1.

Table 1: Parameters of the motor

$R_{s\alpha}$=	30,9 Ω	$R_{r\alpha}$=	51Ω
$R_{s\beta}$=	31,1Ω	$R_{r\beta}$=	51,35Ω
$L_{m\alpha}$=	1,187 H	$L_{r\alpha}$=	1,277 H
$L_{m\beta}$=	1,305 H	$L_{r\beta}$=	1,402 H
$L_{s\alpha}$=	1,277 H	J=	0,00016 kg.m^2
$L_{s\beta}$=	1,402 H	f=	50 Hz

Start-up of the motor through direct connecting to the supply without loading was simulated. The calculated waveform was compared with results of measurement performed on a real two-phase motor. For the sake of precision, fed to the model input was voltage as sensed read-off during measurements (Fig. 6). From the picture it is obvious that the supply voltage was not perfectly sinusoidal and that the supply was relatively soft.

Calculated angular speed waveform is shown in Fig. 9, and calculated motor torque waveform in Fig. 10.

Waveforms of currents attained by modelling were comparable with the measurement results. Fig. 7 illustrates the calculated waveform of the first phase current, and also measured current waveform. Shown in Fig. 8 are both calculated and measured waveforms of the second phase current.

The waveforms demonstrate relatively high degree of congruence.

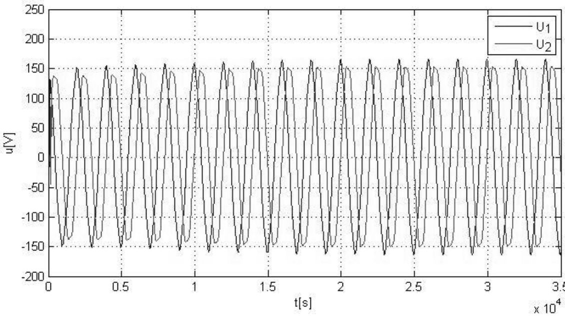


Fig. 6 The supply voltage of the two-phase induction motor (the first and second phase)

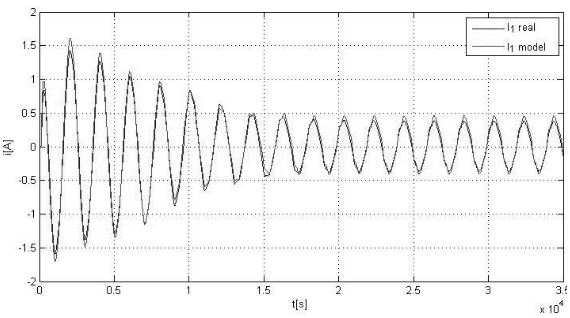


Fig. 7 Comparison of the current in first phase in simulation and measurement of the two-phase induction motor

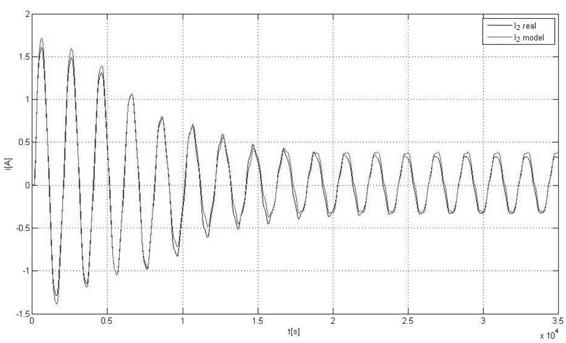


Fig. 8 Comparison of the current in second phase in simulation and measurement of the two-phase induction motor

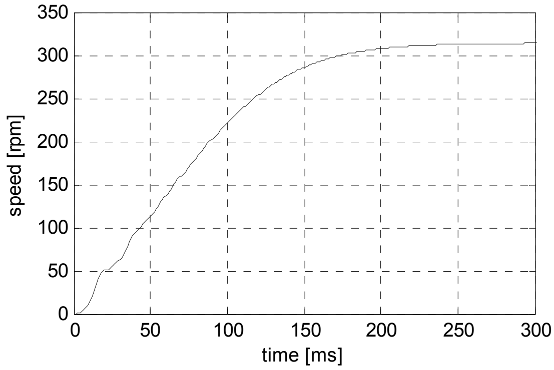


Fig. 9 The rotation speed of the two-phase induction motor

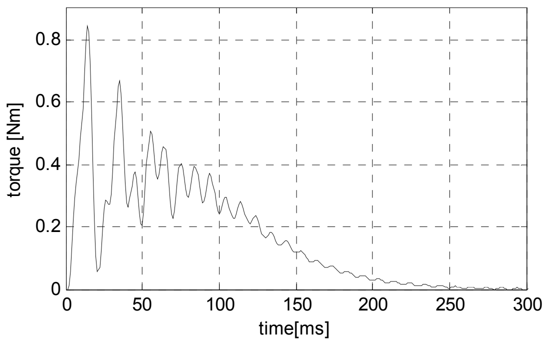
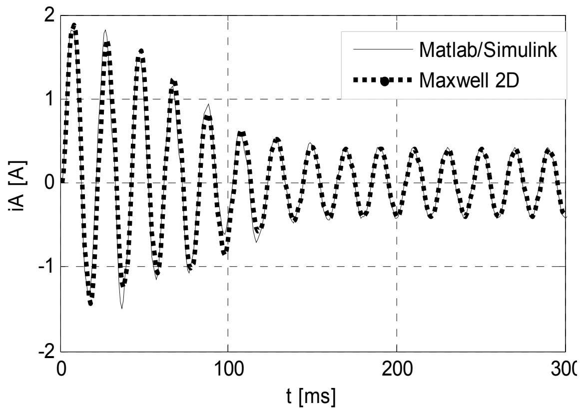


Fig. 10 The electromagnetic torque of the two-phase induction motor at no-load start

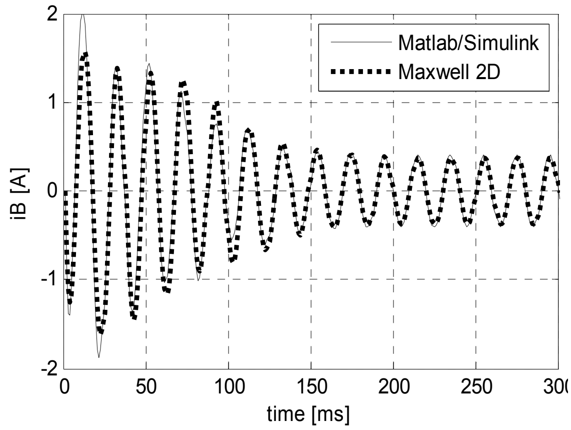
Figures 11 and 12 compare calculated waveforms of the torque and currents obtained from MATLAB/Simulink and ANSYS Maxwell 2D. At the input of both models there was simultaneously two-phase symmetrical 115 V, 50 Hz sine voltage. Start-up by direct connecting and without loading was simulated in both cases.

In Figs. 11a) and 11 b) there are compared the waveforms of currents of individual phases. The torque waveforms are compared in Fig. 12. Good agreement of current waveforms can be seen in the steady state. The program ANSYS Maxwell takes into account the magnetic circuit non-linear properties, which led to differences between the current waveforms in the transient process.

Oscillations in the torque waveforms are due to not entirely perfect symmetry of windings. Taken into account in the Maxwell waveform is non-linearity of the motor parameters, as well as the impact of winding slots.



a)



b)

Fig. 11 Comparison of calculated waveforms of the current in programs MATLAB/Simulink and ANSYS Maxwell 2D

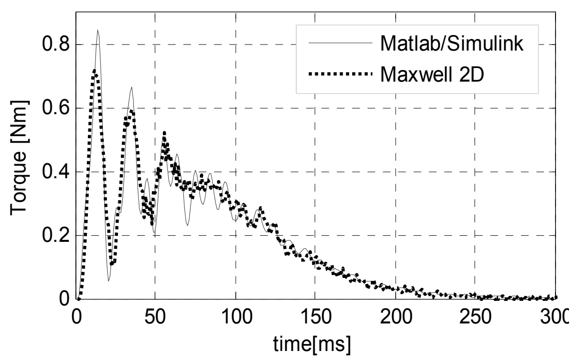
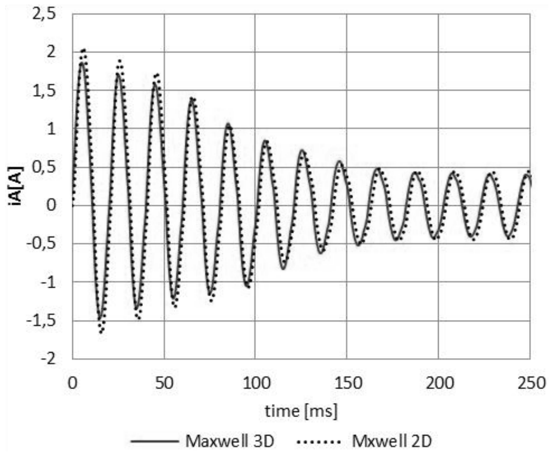
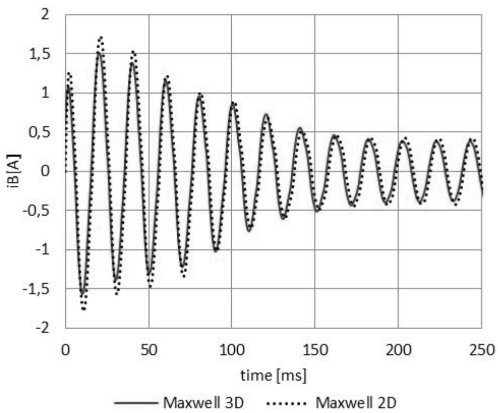


Fig. 12 Comparison of calculated of the torque waveforms in programs MATLAB/Simulink and ANSYS Maxwell 2D

Waveforms of currents and torque obtained from ANSYS Maxwell 2D and 3D are compared in Fig. 13 and Fig. 14.



a)



b)

Fig. 13 Comparison of calculated waveforms of the current in programs ANSYS Maxwell 2D and ANSYS Maxwell 3D

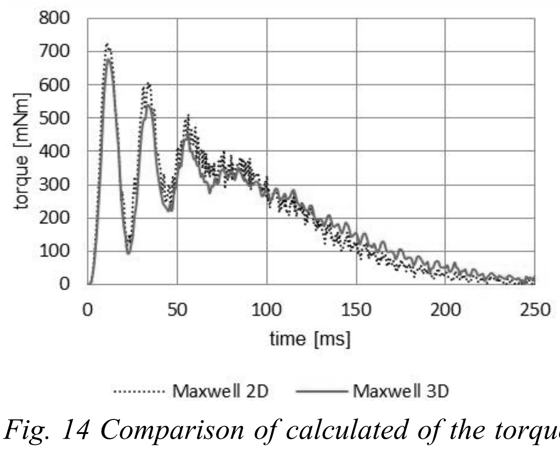


Fig. 14 Comparison of calculated of the torque waveforms in programs ANSYS Maxwell 2D and ANSYS Maxwell 3D

Conclusion

The paper presents three two-phase motor models. The first model of the same motor was developed in MATLAB/Simulink programs, the second one in ANSYS Maxwell 2D and the third model in ANSYS Maxwell 3D. We have compared results of waveforms from models. The results are not identical: the Simulink model works with constant parameters, whilst the ANSYS Maxwell 2D and 3D programmes calculate the magnetic field using the final elements method. The ANSYS Maxwell takes into account nonlinearity of the magnetic material, losses in the iron, as well as the influence of winding slots. Whereas in question is a 2D calculation, influence of the end winding is considered only through additional inductance and resistance.

Only the MATLAB/Simulink model has been compared with measurement results. The waveforms show appropriate similarity. The higher current waveforms are caused mainly by higher harmonics of the supply voltage.

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