Enhanced High-Speed Asynchronous Motor Model in Matlab/Simulink Environment

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***Abstract*—This article presents the construction of an advanced model of an asynchronous motor with a cage rotor at a high speed of rotation. Changes in motor parameters are examined when rotating at high speed. These are the resistances R_s,R_r=f(t,f_s), the inductances L_s,L_r,L_m=f(I_m,f_s) and the torque of their own mechanical losses M_m=f(f_{mec}). These features have been taken into account when creating the model. Simulation and experimental results are presented.**

Keywords—asynchronous motor model; MATLAB motor model; high-speed asynchronous motor.

I. Introduction

To make a successful simulation of a MATLAB/ SIMULINK environment containing high-speed drive (up to 1000Hz) and an asynchronous motor, a suitable motor model is required. The current model of an asynchronous motor in MATLAB can provide a credible simulation of up to about 5000rpm because the member representing the friction forces in the mechanical equation is linearly proportional to the mechanical shaft speed. At very high speed shaft stops and even begins to rotate backwards. That does not really happen. Therefore, it is necessary to build a new programming model that reflects the real processes in the asynchronous motor.

When identifying a high-speed asynchronous motor (ATF 80 E4 IM B3 of Elprom Harmanly JSCo) with 4 poles, data on the inductances, resistances and slip of the rotor are obtained. Experimental data are obtained at different frequencies of stator voltage f_s from 0 to 1000Hz and at different magnetic current I_m. It has been found that the mutual inductance L_m, stator inductance L_s and rotor inductance L_r change up to 80 times. The active resistance of stator and rotor windings R_s and R_r is changed up to 3 times. Unlike the currently existing model in MATLAB/SIMULINK, which has constant parameters, a model with variable parameters depending on the magnetic current and the stator voltage frequency L_s,L_r,L_m=f(I_m,f_s) must be created.

II. Creating the Model

Experimental study of processes in the motor [4] shows that the inductance and the torque are dependent on the frequency of the magnetic field and the speed of the shaft. We have to take into consideration this fact when building the model, as shown in [1].

The program model is based on a mathematical model of the motor, represented by a system with state variables of the rotor and stator magnetic flux in a rotating dq coordinate system with an angular velocity equal to the velocity of the stator magnetic field ω_s. If a description of the model, in which the variables are currents, is chosen, a search for their derivatives will be required. Inductances, that are not constants, will also have to differentiate. Therefore, the magnetic fluxes are chosen for variables so that differentiation of the inductances is not required. This will not complicate the calculations because these parameters are functions L_s,L_r,L_m=f(I_m(t),f_s(t)).

$$\frac{d}{dt}\begin{bmatrix}\psi_{sd}\\ \psi_{sq}\\ \psi_{rd}\\ \psi_{rq}\end{bmatrix}=\begin{bmatrix}-\frac{R_s}{L_s'} & \omega_s & k_r\frac{R_s}{L_s'} & 0\\ -\omega_s & -\frac{R_s}{L_s'} & 0 & k_r\frac{R_s}{L_s'}\\ k_s\frac{R_r}{L_r'} & 0 & -\frac{R_r}{L_r'} & \omega_s-\omega\\ 0 & k_s\frac{R_r}{L_r'} & -(\omega_s-\omega) & -\frac{R_r}{L_r'}\end{bmatrix}\begin{bmatrix}\psi_{sd}\\ \psi_{sq}\\ \psi_{rd}\\ \psi_{rq}\end{bmatrix}+\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}\begin{bmatrix}u_{sd}\\ u_{sq}\\ u_{rd}\\ u_{rq}\end{bmatrix} \quad (1)$$

and

$$\begin{bmatrix}i_{sd}\\ i_{sq}\\ i_{rd}\\ i_{rq}\end{bmatrix}=\begin{bmatrix}1/L_s' & 0 & -k_r/L_s' & 0\\ 0 & 1/L_s' & 0 & -k_r/L_s'\\ 1/L_r' & 0 & -k_s/L_r' & 0\\ 0 & 1/L_r' & 0 & -k_s/L_r'\end{bmatrix}\begin{bmatrix}\psi_{sd}\\ \psi_{sq}\\ \psi_{rd}\\ \psi_{rq}\end{bmatrix}, \quad (2)$$

where

$\sigma = 1-\frac{L_m^2}{L_sL_r}$ is leakage factor;

$L_s' = \sigma L_s = L_s\left(1-\frac{L_m^2}{L_sL_r}\right) = L_s-\frac{L_m^2}{L_r}$ is referred stator inductance;

$L_r' = \sigma L_r = L_r\left(1-\frac{L_m^2}{L_sL_r}\right) = L_r-\frac{L_m^2}{L_s}$ is referred rotor inductance;

$k_s = \frac{L_m}{L_s}$ is coefficient of magnetic coupling of the stator;

$k_r = \frac{L_m}{L_r}$ is coefficient of magnetic coupling of the rotor;

$\omega = p.\omega_{rmec}$ is the electric angular velocity of the rotor.

The shaft speed is calculated using the mechanical equation

$$J\frac{d\omega_{rmec}}{dt} = M_e - M_m - M_t\,, \qquad (3)$$

where J is the inertia moment of the rotor given by the motor manufacturer, ω_{rmec} is the mechanical speed of the rotor, M_m is the torque of its own mechanical loss, and M_t is the load torque.

The electromagnetic motor torque is

$$M_e = \frac{3}{2}p\left(\psi_{sd} i_{sq} - \psi_{sq} i_{sd}\right), \qquad (4)$$

where p is the number of pole pairs.

The input variables of the model are the components of the stator voltage u_{sd} and u_{sq}. They have to be calculate with the united transformation of Park and Clark. In the induction motor with squirrel cage rotor, the rotor voltage is zero. Also input variable is the electrical angular speed ω_s of the stator magnetic field.

The stator and rotor currents i_{sd}, i_{sq}, i_{rd} and i_{rq} are output variables. To transform them into phase variables, we need to use the opposite united transformation of Park and Clark.

The model consists of several basic blocks (A,B,C) for calculating the state variables - the fluxes, the output variables - the currents and the rotor speed ω_{rmec}. Other blocks calculate the variable coefficients in the main blocks. This is necessary because the inductances depend on the magnetizing current and frequency of the stator magnetic field, the resistances depend on the temperature and the torque of its own mechanical loss depends on the speed of the shaft. The general appearance of the software model of an asynchronous motor with cage rotor in a MATLAB/SIMULINK environment is shown in Fig.4.

Stator and rotor voltage equations (1) are modeled in block A. For the simplification and acceleration of the calculations, the values of block B are used. In block B the motor currents are obtained from equations (2).

The model parameters are variable. Inductions depend on the frequency of the stator magnetic field f_s and the magnetizing current I_m. The module of the space vector of the magnetizing current is calculated by the formula (5) in block E.

$$|I_m| = \sqrt{(i_{sd} + i_{rd})^2 + (i_{sq} + i_{rq})^2} \qquad (5)$$

Inductions are selected from tabular functions. These are obtained by identifying the asynchronous motor at different magnetic current and frequency of the stator magnetic field. The 3-D graphs of the tabular functions are given in Fig.1, Fig.2 and Fig.3.

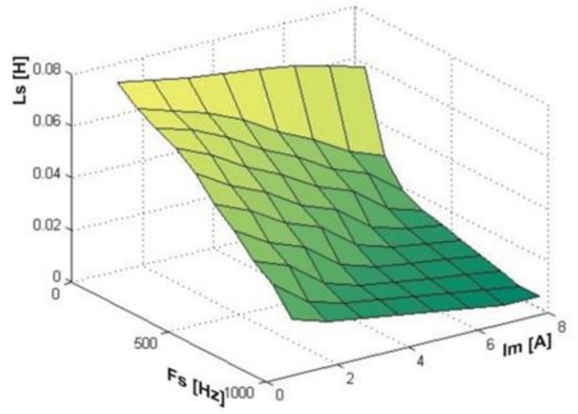

Fig. 1. Tabular function of the stator inductance.

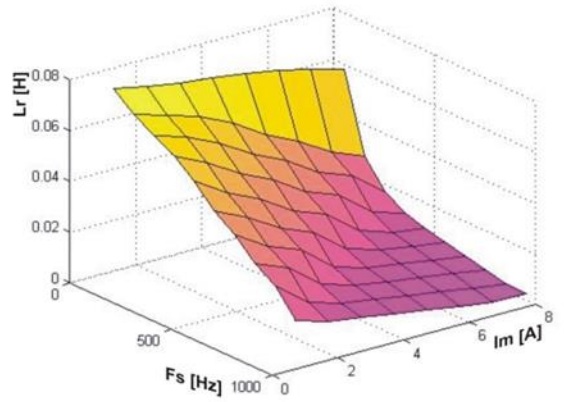

Fig. 2. Tabular function of the rotor inductance.

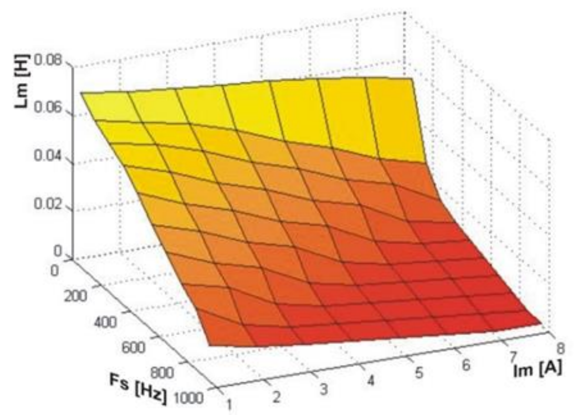

Fig. 3. Tabular function of the mutual inductance.

After selecting the corresponding inductance value, the auxiliary variables L_r', L_s', k_s and k_r are calculated in block D.

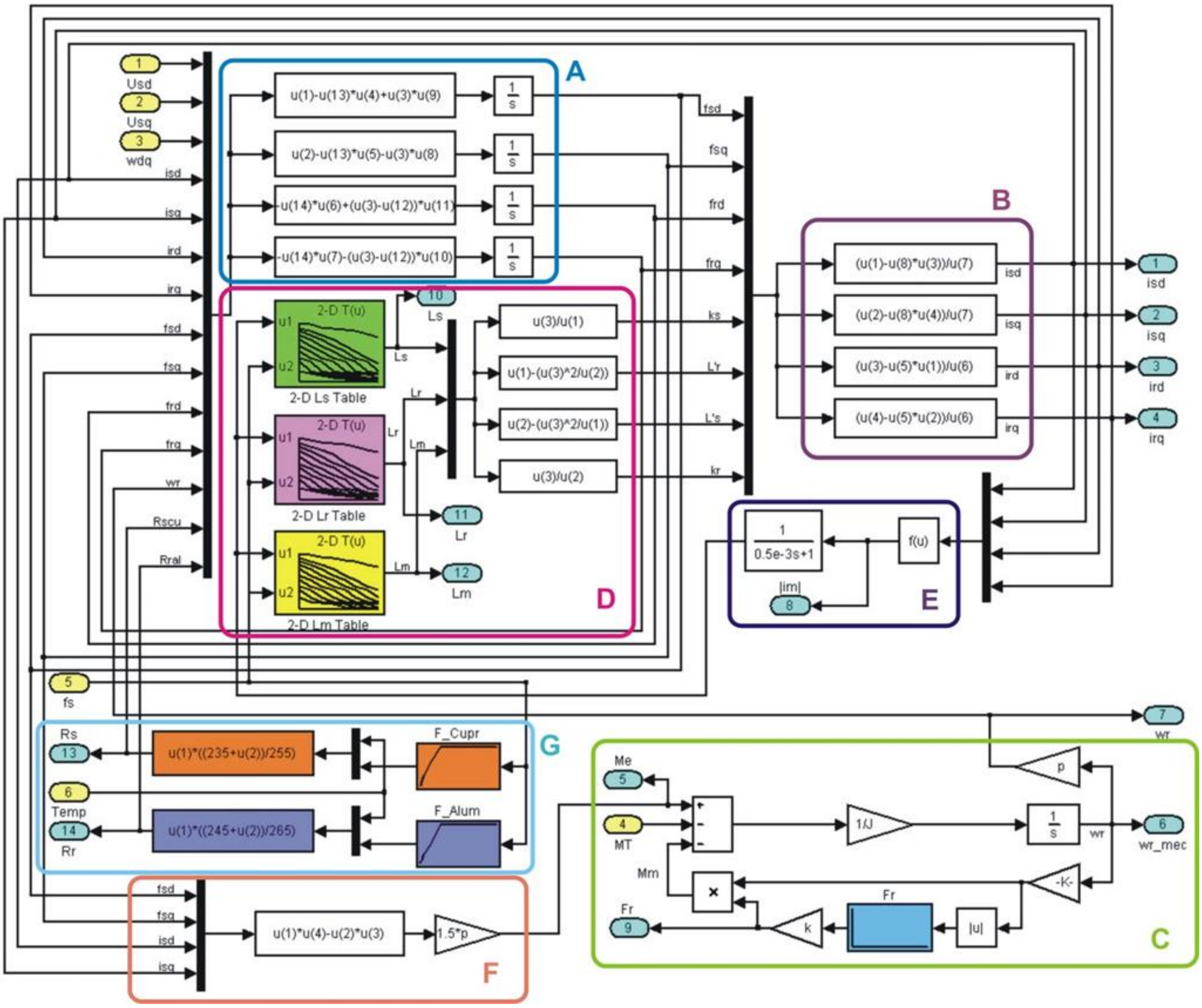

Fig. 4. Programming model of an asynchronous motor with cage rotor in the MATLAB/SIMULINK environment for high speed.

Block G calculates the values of resistances R_s and R_r. They depend on the frequency of the stator field and the temperature. When the motor is identified, it is found that the resistances increase linearly to 300Hz and then remain constant. This requires setting the resistances with a tabular function, dependent on the stator magnetic field frequency. The temperature dependence is expressed by the formula:

$$R = R_O \cdot \frac{K-\theta}{K-\theta_O} , \qquad (6)$$

where R_0 is the resistance at θ_0=20^{0}C, θ is the operating temperature, and K is a constant dependent on the specific resistance of the metal. For Copper K=235, and for Aluminum K=245.

Through all these parameters coefficients in system (1) and (2) in blocks A and B are calculated.

The mechanical equation (3) is calculated in block C. The load torque M_t is set at the input of the motor model. The moment of its own mechanical losses M_m includes the friction losses in the bearings and the ventilation losses of the rotor in the air gap [2],[3]. It is equal to the electromagnetic moment when no-load running in steady-state regime. The electromagnetic moment is calculated at different speeds and with use of the measured voltage, current and slip, as described in [4]. A function based on shaft speed is obtained. In order to preserve the traditional recording of the motor's own mechanical losses, the function $F_r = M_m / \omega_{rmec}$ presented in tabular form is used.

The electromagnetic motor torque is calculated in block F in equation (4).

III. SIMULATION STUDY OF THE MODEL

Fig.5 shows the transient processes obtained from the established model in simulation of a smooth start and the subsequent loading of a high-speed asynchronous motor ATF 80 E4 IM B3 with cage rotor with 4 poles at f_s=666,67Hz or n_s=20000rpm.

The first graphics shows the speed of the shaft n_2, as the assignment for speed is from 0 to 20000rpm. Realized idle speed with MATLAB model is 19813rpm

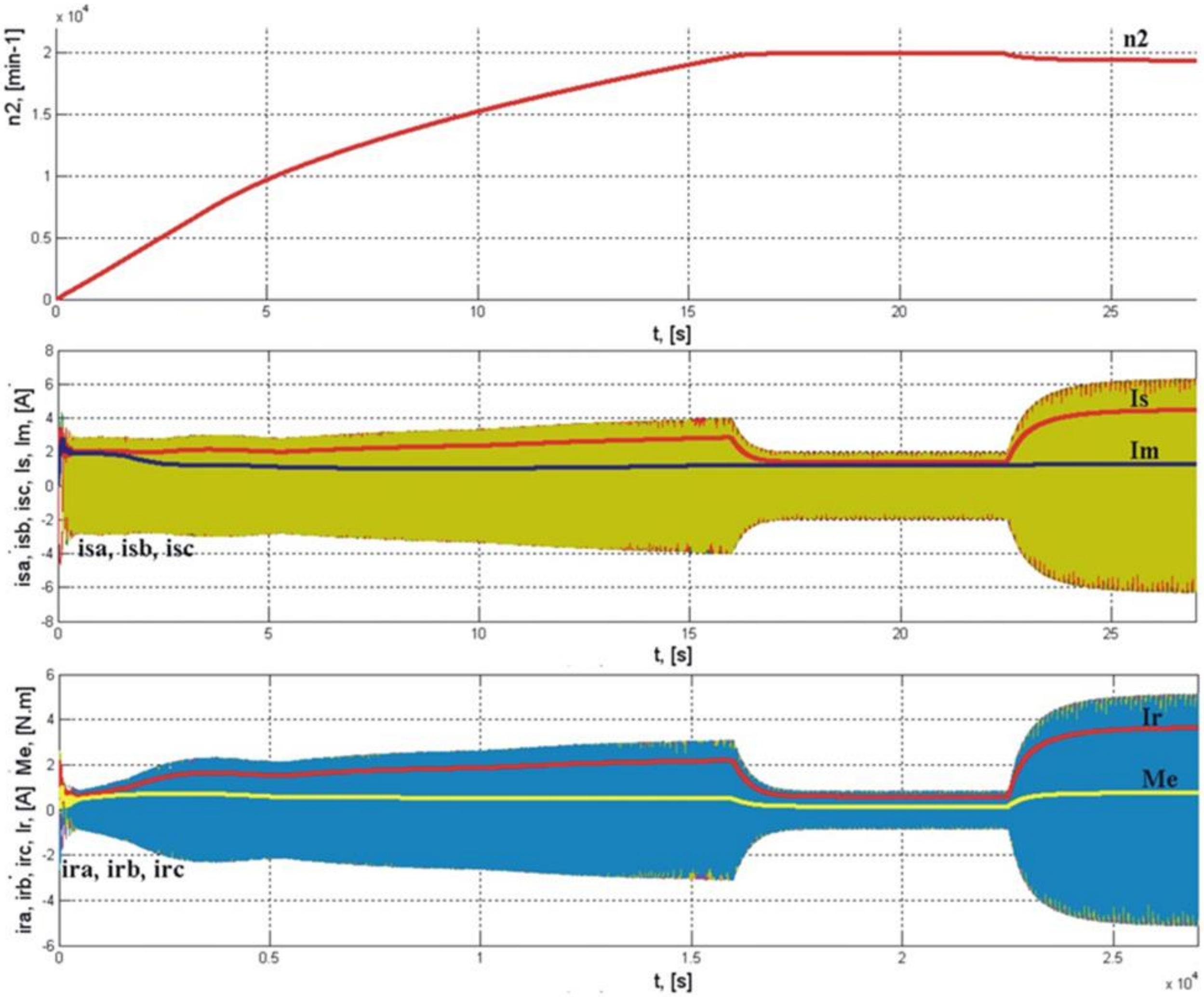

Fig. 5. Transitional processes in smooth start simulation and load of high-speed asynchronous motor ATF 80 E4 IM B3 with cage rotor and 4-pole at fs=666,67Hz, ns=20000rpm.

and which is close to the experimentally obtained - 19796rpm. After loading at 0.6Nm, the graphics speed decreases to 19351rpm.

On the second graphics are presented instantaneous values of the stator currents i_{sa}, i_{sb}, i_{sc}, the effective value of the stator current I_s and magnetizing current I_m. In idle after acceleration, the values of the two currents I_s and I_m become close, but with load, I_s increases according to the mechanical losses and the load and I_m changes slightly.

On the third graphics are shown the instantaneous values of the rotor currents i_{ra}, i_{rb}, i_{rc}, the effective value of the rotor current I_r and the electromagnetic torque M_e. The electromagnetic torque increases when loading at the value sets in the MATLAB model - 0.6Nm.

IV. CONCLUSION

The developed MATLAB model in dq reference frame of an asynchronous motor with cage rotor in high-speed motion shows a good match with the real object. The model has variable parameters L_s,L_r,L_m=f(I_m,f_s), R_s,R_r=f(θ,f_s) and mechanical losses F=f(f_s) at high speed.

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