CONSIDERATIONS REGARDING ASYNCHRONOUS MOTOR ROTOR PARAMETERS DETERMINATION BY FEM

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Abstract*:* *The paper presents some considerations about asynchronous motor rotor parameters determination, using software based on finite elements method (FEM). For this, 2D magnetostatic and time harmonic analysis will be realized, at different frequencies, in case of a three phase asynchronous motor.*

1. INTRODUCTION

The asynchronous motor rotor parameters are determined experimentally by two tests: no load test and short circuit test. Magnetization resistance and the sum between stator leakage reactance and magnetization reactance are determined on the basis of measurements realized in no load test. Based on measurements of short circuit test are determined the short circuit resistance and reactance respectively. While the rotor resistance at start moment can be determined from the short circuit resistance (the stator resistance can be measured), the rotor leakage reactance can not be separated from the stator leakage reactance. In order to determine the stator leakage reactance separately, the "removed rotor method" [4] can be used.

2. PARAMETERS DETERMINATION BY FEM

Numerical methods development, especially FEM, makes possible the simulation of any permanent or transient regime, therefore the previously presented methods can also be simulated.

The ideal no load test assumes that the rotor speed is synchronous with the rotating magnetic field generated by the stator winding (s=0), then no current is induced in rotor bars. The rotor becomes exclusively a part of the nonlinear magnetic path for the stator magnetic flux.

No load test numerical simulation by FEM can be realized by a 2D magnetostatic field analysis, the goal being the magnetization reactance determination.

In case of an asynchronous motor with squirrel cage rotor (with high bars), double layered stator winding with shortened pitch to 5/6, six notches per pole and phase, two poles pair, the required numerical model for magnetostatic analysis is presented in figure 1.

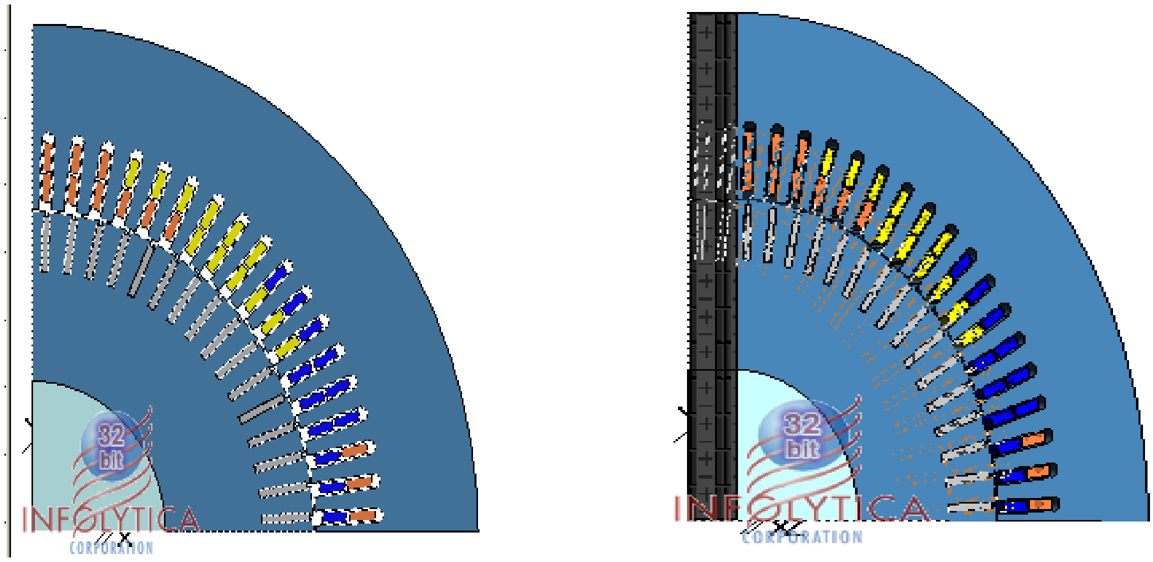


Fig. 1. The numerical model

Since the rotating electrical machines are symmetrical, the numerical model corresponds to a single pole, and the periodic boundary conditions are used.

The equivalent electrical circuit in case of no load regime is presented in *fig. 2a*. In order to realize the simulation, current sources are used.

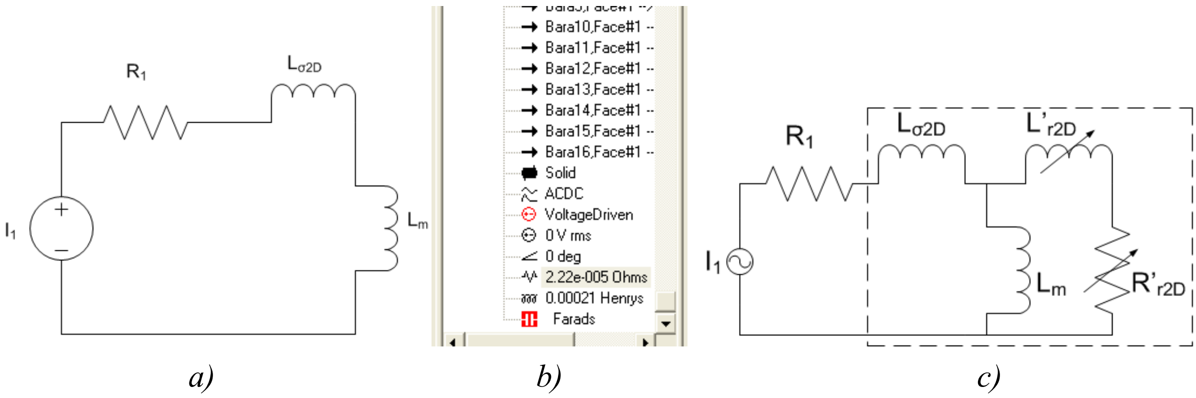


Fig. 2. The equivalent electrical circuits

The stator leakage inductance $L_{\sigma 2D}$ can be determined as is described in [2].

The magnetization inductance is determined in terms of the magnetic energy W_m stored in the analyzed model (in this case a quarter of the machine) and the maximum value of the phase current I_m, respectively:

$$L_m = 4\frac{4W_m}{3I_m^2} - L_{\sigma 2D} \tag{1}$$

Rotor leakage inductance determination, both at start at nominal current and at nominal speed, requires harmonic analysis at different frequencies, the numerical model being the same with the previous one, only that the rotor bars realize together a circuit that represents the squirrel cage winding (*fig. 2b.)*.

In *fig. 2c*. the equivalent electrical circuit is presented, and both the rotor resistance and rotor reactance are in terms of the slip.

As for the magnetization inductance, it is considered constant, its value corresponding to a low voltage supply regime, the magnetic circuit being no saturated.

The circuit parameters situated inside the dashed box in *fig. 2c*. can be replaced with an equivalent resistance and inductance obtained with [1]:

$$L_{eq} = 4\frac{2W_m}{3I_{ef}^2} \qquad R_{eq} = 4\frac{P_{jr}}{3I_{eq}^2} \tag{2}$$

P_{jr} represents the Joule losses in the rotor bars, these being known trough numerical analysis, and I_{ef} represents the RMS value of the stator phase current.

Since the stator leakage inductance and the magnetization inductance are known, both the rotor leakage inductance and the rotor resistance from the active portion can be determined.

The electrical resistance and inductance of the rotor ring had not been introduced in the equivalent electrical circuit, because the values of these parameters had been considered in the numerical model as external circuit elements, this being required for a high accuracy computation of the rotor bars induced currents.

For rotor parameters determination at start moment, the harmonic numerical analysis is realized at nominal frequency, while in case of nominal speed, the frequency is $f=s_n f_n$.

The magnetic field lines are presented comparatively for two limit cases, at start moment and ideal no load regime respectively (*fig. 3.*).

In *fig. 3*. can be noticed the influence of the currents induced in rotor bars over the stator magnetic field.

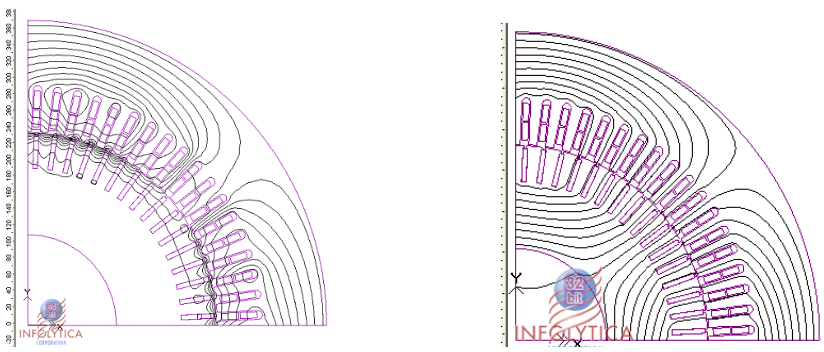


Fig. 3. Flux lines at start and at nominal speed

In case of asynchronous motors with high rotor bars or those with double squirrel cage, the rotor parameters have different values at start moment and at nominal speed, because of the non uniform current distribution in the rotor bars at high frequencies.

In *fig. 4.* the flux lines and current density in rotor bars are presented for two stator current frequencies: 50Hz (the start moment) – left, and 2.5Hz (nominal speed) – right, in case of an asynchronous motor with high bars.

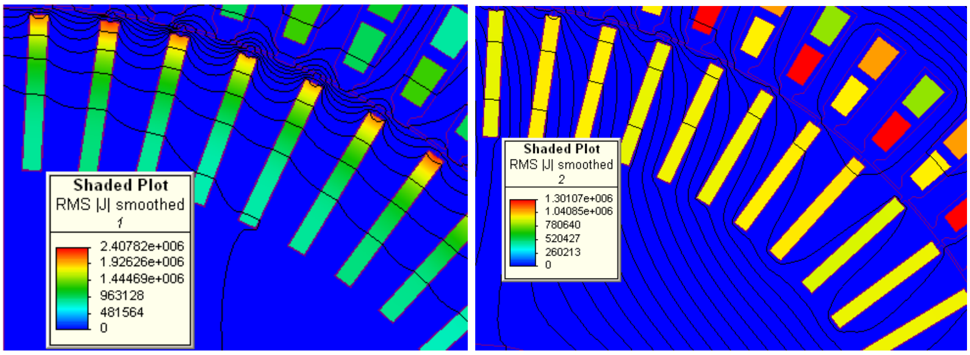


Fig. 4. The current distribution in high rotor bars at start and at nominal speed

The variation of rotor leakage inductance and the rotor resistance in terms of current frequency is presented in *fig 5.* in case of 55 kW asynchronous motor, with height of the rotor bars 25 mm, and the height/width bar ratio 8.3.

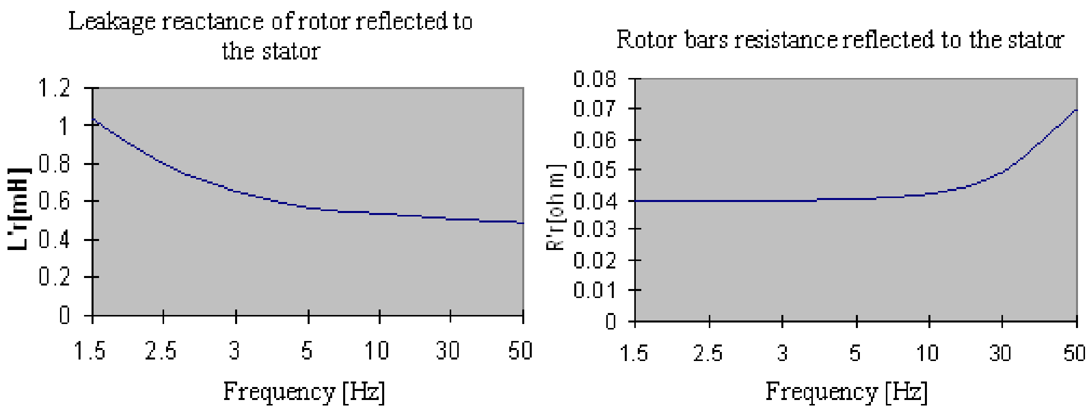


Fig. 5. The rotor leakage reactance and rotor resistance in terms of frequency

For this motor, the equivalent rotor resistance decreases from 0.07 Ω at start moment to 0.04 Ω at 3% slip, decreasing 1.75 times, while the rotor leakage inductance increases from 0.49 mH at start moment to 1.04 mH at 3% slip, increasing 2.1 times.

In order to study the rotor parameters change, have been realized models representing asynchronous motors with power in 5.5 – 1000 kW scale, and for each rotor the reduced height of the bar has been computed with relation:

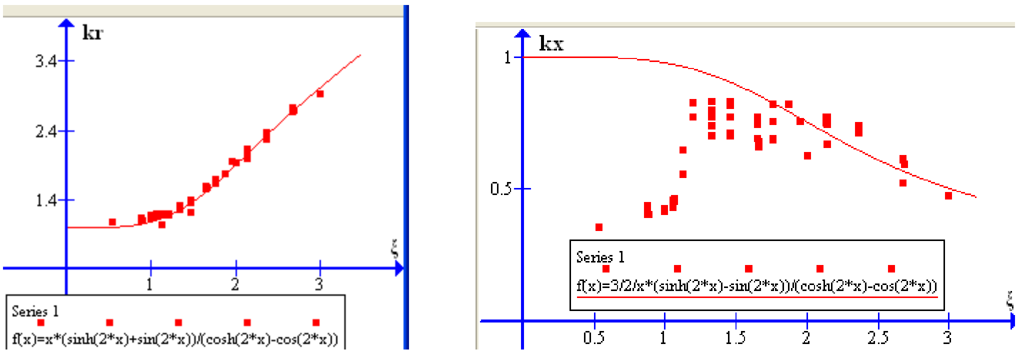
$$\xi = h\sqrt{\omega_r \mu_0 \frac{b}{2b_{cr}\rho}} \qquad (3)$$

Has been noted with h – high of the rotor bar, b – width of the rotor bar, b_{cr} – width of the notch, ρ – the electrical rotor bar resistivity, and $\omega_r=2\pi f_r$.

The nominal slip values have been chosen in 0.05 – 1.6 scale, in terms of the motor power, and the results regarding the value of the increasing resistance coefficient k_r in terms of the reduced height of the rotor bar ξ, for the analyzed models, are presented in *fig. 6a*.

The analytic curve that represents the variation of the increasing resistance coefficient k_r in terms of the reduced height of the rotor bar is presented comparatively.

A good concordance between analytically obtained and FEM results can be noticed.



a) b)

Fig. 6. The k_r and k_x coefficient in terms of reduced height of the rotor bar, ξ

The results obtained by presented method, regarding the variation of leakage inductance from active portion of the rotor in terms of the reduced height of the rotor bar ξ, are showed in *fig 6b.*

The comparison between the decreasing coefficient values, k_x, obtained by FEM and analytically, respectively, highlights the fact that, generally, for values of the reduced height of the rotor bar ξ up to 1.66, the discrepancies are important.

The explanation consist in the following: leakage inductance of the rotor in nominal regime determined according to the presented method is higher than the leakage inductance corresponding to the start. This high value is due to the higher value of the magnetic energy stored in the model analyzed at low frequency (at nominal regime) than the magnetic energy stored in the model analyzed at nominal frequency (at start regime). Considering that this increase of the magnetic energy is only due to the leakage inductance could explain the high value of leakage inductance at nominal regime.

The detailed analysis of the models regarding the magnetic energy stored in different parts of the machine however highlights that the most important increases are in the magnetic circuit and in the air-gap.

Thus, if at start moment the magnetic energy stored in the magnetic circuit is insignificant in comparison with the total energy, at nominal regime, this energy increases 20-30 times, up to 10%. At start moment, the magnetic energy stored in the air-gap represents about 30% from the total magnetic energy, and at nominal speed this energy comes up to 50%.

Based on these observations, for rotor slots leakage inductance determination, only the magnetic energy stored in the rotor slots has been taken into consideration, the relation of dependence being presented in (2).

In order to established the k_x coefficient, it has been taken into consideration that only leakage inductance corresponding to the rotor bar portion is affected by nonuniform distribution of the current.

In figure 7., k_x coefficient values obtained by FEM, based on magnetic energy stored in rotor slots, are presented in terms of the reduced height of the rotor bar ξ.

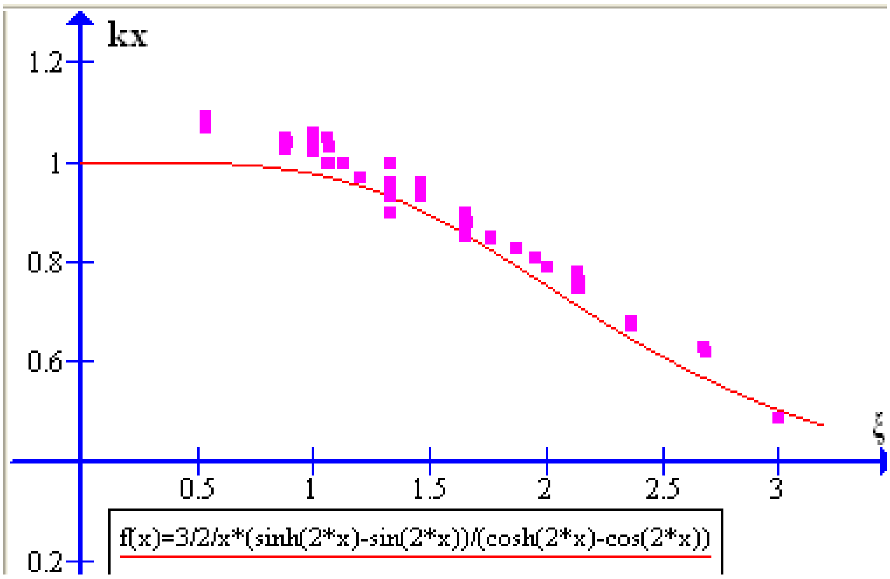
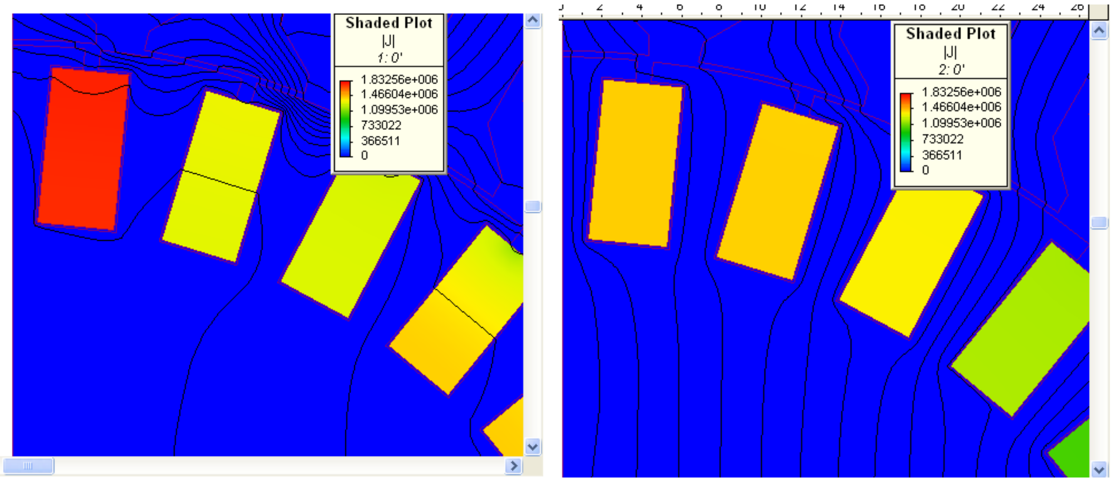


Fig.7. The k_x coefficient in terms of reduced height of the rotor bar, ξ, obtained by magnetic energy stored in rotor slots

This time, a good concordance between analytically and FEM obtained results can be noticed.

The values higher than one (up to 1.06), are due to the fact that in case of squirrel cage rotor without high bars, at start moment the current distribution is uniform like at nominal speed, *fig. 8*.



50 Hz 2.5 Hz

Fig. 8. The rotor bars current distribution in case of rotor without high bars

On the other hand, if at start moment the current distribution is uniform, more field lines close by rotor slots (*fig. 8.*), and thus the value of the magnetic energy stored in rotor slots is higher than that at nominal speed, although not all these lines represent the leakage field.

3. CONCLUZIONS

The computation of the rotor slots leakage inductance based on the first presented method, leads to satisfactory results only in case of the machines with the reduced height of the rotor bar generally higher than 1.66, in this case the rotor bars current distribution being nonuniform.

The computation of the rotor leakage inductance and of k_x coefficient based on the magnetic energy stored in the rotor slots highlights a good concordance between analytically and FEM results.

Thus can be noticed that the rotor leakage inductance determination from magnetic energy stored in rotor slots has a satisfactory accuracy, the method could be applied in general case, regardless of rotor bars shape.

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