ASPECTS REGARDING DETERMINATION OF THE INDUCTION MACHINES PARAMETERS

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Abstract **– This paper presents the classical methods used for finding the induction machines parameters; then an original method conceived by the authors is detailed.**
The method consists in the acquisition of the voltages and currents corresponding to the phases A and B and also of the speed, during the no-load starting transient process of an induction motor.
The mathematical model used in this situation is the one containing the voltages and fluxes equations, in the two-axes theory, with per unit quantities and in a reference frame solidary with the induction machine stator, to which the motion equation is added.
The used objective function is built for having minimum value when the mathematical model answer is closed to the data obtained experimentally. In other words, it must be minimum when the areas delimited by the graphics of the longitudinal and transversal components of the stator current phasor (determined experimentally and by computation), respectively between the ones of the speeds (determined experimentally and by computation) are minimum.
The advantages of the new method over the classical methods are emphasized with the help of a graphic comparison. The method proposed for the determination of the induction machine parameters, has the following advantages: it provides an estimation precision which is superior over the similar methods tackled in the literature; it may be successfully used both for the determination of the squirrel cage induction machine parameters and of the phase-wound rotor ones; it requires a very low energetic consumption.

Keywords: *induction machine, parameters, method, experimental determination*

1. INTRODUCTION

The problem of the induction machine parameters determination is very important for a correct study of its operation regimes. As a consequence, further on, the main classical ways used for obtaining their values are briefly presented.
As it is shown in [6], [7] etc., the resistances of the induction machines windings can be determined in cold or warm state, in direct current, by using one of the following methods (STAS 7246/2-74, 9904/3-75):
- the method of the simple or double bridge;
- the ammeter or voltmeter method;
- the comparison method.

The leakage inductivity of the stator winding can be determined by using many methods. The method of the removed rotor is the most used one.
In this case, the stator winding is supplied by a three phase system of voltages when the rotor is removed. In addition, a test winding placed in the stator winding slots is also used.
The determination of the rotor winding leakage inductivity is made with the help of the data obtained in the short circuit test of the induction machine. Thus, the stator winding is supplied by a three phase source of variable voltage, at rated frequency, by means of an autotransformer or a synchronous generator.
The short circuit test is performed when the machine rotor is locked. In the case of the wounded rotor, its winding is in short circuit at the rings.
The determination of the useful cyclical inductivity is made on the basis of the data obtained at the no-load test. The no-load test is performed when the machine operates as a motor, without load at its shaft and having a speed closed to the synchronism speed. Before this, the machine operates without load between 10 minutes (for machines rated at powers exceeding 1 kW) and 240 minutes (for machines rated at powers exceeding 1000 kW); this way the bearings can reach a stable thermal regime.
Experimental determination of the internal axial inertia moment can be made by using methods requiring or not the machine dismantling.
So, according to STAS 9904/9-76, a few methods can be used: the method of the torsion oscillations, the method of the oscillating pendulum and the releaser method. The releaser method, known as the method of the natural stopping or the self-breaking method does not require the machine dismantling.
Further on an original method is detailed. Thus, with its help, the induction machine parameters can be determined by means of a no-load starting.

2. MATHEMATICAL MODEL

The mathematical model used in this situation is the one containing the voltages and fluxes equations, in

the two-axes theory, with per unit quantities and in a reference frame solidary with the induction machine stator, to which the motion equation is added [1], [5].
These equations can be written in the matrix form, too:

$$\begin{vmatrix} L_s & 0 & L_{sh} & 0 & 0 \\ 0 & L_s & 0 & L_{sh} & 0 \\ L_{sh} & 0 & L_r^/ & 0 & 0 \\ 0 & L_{sh} & 0 & L_r^/ & 0 \\ 0 & 0 & 0 & 0 & \dfrac{J}{p} \end{vmatrix} \frac{d}{dt} \begin{vmatrix} i_{sd} \\ i_{sq} \\ i_{rd}^/ \\ i_{rq}^/ \\ \omega \end{vmatrix} =$$

$$= \begin{vmatrix} u_{sd} - R_s i_{sd} \\ u_{sq} - R_s i_{sq} \\ u_{rd}^/ - R_r^/ i_{rd}^/ - \omega(L_r^/ i_{rq}^/ + L_{sh} i_{sq}) \\ u_{rq}^/ - R_r^/ i_{rq}^/ + \omega(L_r^/ i_{rd}^/ + L_{sh} i_{sd}) \\ \dfrac{3}{2} p L_{sh}(i_{sq} i_{rd}^/ - i_{sd} i_{rq}^/) + m_r \end{vmatrix} \quad (1)$$

By noting the constant matrix with $|A|$, the matrix of the unknown quantities with $|X|$ and the matrix from the second member with $|Y|$, the brief form is obtained:

$$|A| \frac{d}{dt} |X| = |Y|, \quad (2)$$

or, equivalently:

$$\frac{d}{dt} |X| = |A|^{-1} |Y|. \quad (3)$$

In these equations, if the rotor is in short-circuit ($u_{dr}^/ = u_{qr}^/ = 0$), u_{ds} and u_{qs}, obtained for the particular case β_B, are:

$u_{ds} = u_{Ae}$;

$$u_{qs} = \frac{1}{\sqrt{3}} u_{Ae} + \frac{2}{\sqrt{3}} u_{Be}. \quad (4)$$

The computed values of the A and B phase currents are determined for the situation when there are not components of null succession and $\beta_B = 0$:

$$i_{Ac} = i_{ds}; \qquad i_{Bc} = -\frac{1}{2} i_{ds} + \frac{\sqrt{3}}{2} i_{qs}. \quad (5)$$

Moreover, the rotor angular speed is computed in the following manner:

$$\Omega_c = \frac{\omega}{p}. \quad (6)$$

The programming medium MATLAB has been used for the numerical simulation of the induction machine on the basis of these equations. An integration sub-routine for the differential equations has been carried out on the basis of the mathematical model presented before.

3. COMPUTATION METHOD

The method consists in the acquisition of the voltages and currents corresponding to the phases A and B and also of the speed, during the no-load starting transient process of an induction motor.
So, we possess the currents and the speed determined experimentally (noted with index e) and the currents and speed obtained by computation by integrating the induction machine mathematical model (noted with index c).
An objective function $f(\bar{x}) = f(R_s, R_r^/, L_s, L_r^/, L_{sh}, J)$ will be built with their help and it will be minimized with the help of the SIMPLEX algorithm.
The point $\bar{x}^* = (R_s, R_r^/, L_s, L_r^/, L_{sh}, J)$, corresponding to this minimum, obtains the searched values of the induction machine parameters.
The objective function that has been built is of the form:

$$f(\bar{x}) = \int_0^{t_{\max}} [(i_{sd_e} - i_{sd_c})^2 + (i_{sq_e} - i_{sq_c})^2 + p(\Omega_e - \Omega_c)^2] dt \quad (7)$$

where:
- $\bar{x} = (R_s, R_r^/, L_s, L_r^/, L_{sh}, J)$;
- p is a weight chosen in a convenient way by the programmer.

SIMPLEX algorithm in two stages [2]

Given the problem of linear programming at the standard form of maximum:

$$\begin{cases} (\max) f = c^T \cdot x \\ A \cdot x = b \\ x \geq 0 \end{cases} \quad (8)$$

where it has already been established that all the free terms to be positive $b \geq 0$.

Stage 1. The problem is built:

$$\begin{cases} (\min) g = y \\ A \cdot x + y = b \\ x, y \geq 0 \end{cases} \quad (9)$$

ant it is solved with SIMPLEX algorithm by starting its solving from the unit matrix basis, two situations being possible:

a) The minimum of g function is strict positive.

By applying the simplex algorithm in two stages the following succession of tables will be obtained in the first stage:

c_B	x_B	x_B	0	0	0	0	1
			x_1	x_2	x_3	x_4	x_5
0	x_3	10	3	1	1	0	0
1	x_5	2	1	4	0	-1	1
		2	1	4	0	-1	1
			1	4	0	-1	0

c_B	x_B	x_B	0	0	0	0	1
			x_1	x_2	x_3	x_4	x_5
0	x_3	$\frac{19}{2}$	$\frac{11}{4}$	0	1	$\frac{1}{4}$	$-\frac{1}{4}$
0	x_2	$\frac{1}{2}$	$\frac{1}{4}$	1	0	$-\frac{1}{4}$	$\frac{1}{4}$
		0	0	0	0	0	-1

The optimum equal to 0 has been obtained in the basic solution (x_3, x_2) which will be the initial solution for the simplex algorithm applied to the initial problem in the second stage.
We eliminate the column of x_5 in the table, we replace the values of the objective function coefficients and therefore its value, the Δ values and we obtain the table:

c_B	x_B	x_B	2	3	0	0
			x_1	x_2	x_3	x_4
0	x_3	$\frac{19}{2}$	$\frac{11}{4}$	0	1	$\frac{1}{4}$
3	x_2	$\frac{1}{2}$	$\frac{1}{4}$	1	0	$-\frac{1}{4}$
		$\frac{3}{2}$	$-\frac{5}{4}$	0	0	$-\frac{3}{4}$

c_B	x_B	x_B	2	3	0	0
			x_1	x_2	x_3	x_4
0	x_3	4	0	-11	1	3
2	x_1	2	1	4	0	-1
		4	0	5	0	-2

c_B	x_B	x_B	2	3	0	0
			x_1	x_2	x_3	x_4
0	x_4	$\frac{4}{3}$	0	$-\frac{11}{3}$	$\frac{1}{3}$	1
2	x_1	$\frac{10}{3}$	1	$\frac{1}{3}$	$\frac{1}{3}$	0
		$\frac{20}{3}$	0	$-\frac{7}{3}$	$\frac{2}{3}$	0

c_B	x_B	x_B	2	3	0	0
			x_1	x_2	x_3	x_4
0	x_4	38	11	0	4	1
3	x_2	10	3	1	1	0
		30	7	0	3	0

The optimum solution of the first problem is therefore $x_1 = 0$ and $x_2 = 10$ which gives a maximum of the function equal to 30. If we apply the **second method** we shall obtain successively the tables:

c_B	x_B	x_B	2	3	0	0	$-M$
			x_1	x_2	x_3	x_4	x_5
0	x_3	10	3	1	1	0	0
-M	x_5	2	1	4	0	-1	1
		-2M	-M	-4M	0	M	-M
			-M-2	–4M-3	0	M	0

c_B	x_B	x_B	2	3	0	0	
			x_1	x_2	x_3	x_4	
0	x_3	$\frac{19}{2}$	$\frac{11}{4}$	0	1	$\frac{1}{4}$	$-\frac{1}{4}$
3	x_2	$\frac{1}{2}$	$\frac{1}{4}$	1	0	$-\frac{1}{4}$	$\frac{1}{4}$
		$\frac{3}{2}$	$-\frac{5}{4}$	0	0	$-\frac{3}{4}$	$M+\frac{3}{4}$

c_B	x_B	x_B	2	3	0	0	$-M$
			x_1	x_2	x_3	x_4	x_5
0	x_3	4	0	-11	1	3	-3
2	x_1	2	1	4	0	-1	1
		4	0	5	0	-2	$2+M$

c_B	x_B	x_B	2	3	0	0	$-M$
			x_1	x_2	x_3	x_4	x_5
0	x_4	$\frac{4}{3}$	0	$-\frac{11}{3}$	$\frac{1}{3}$	1	-1
2	x_1	$\frac{10}{3}$	1	$\frac{1}{3}$	$\frac{1}{3}$	0	0
		$\frac{20}{3}$	0	$-\frac{7}{3}$	$\frac{2}{3}$	0	M

c_B	x_B	x_B	2	3	0	0	$-M$
			x_1	x_2	x_3	x_4	x_5
0	x_4	38	11	0	4	1	-1
3	x_2	10	3	1	1	0	0
		30	7	0	3	0	M

The final result is obviously the same one.

4. RESULTS

The results from the table 1 have been obtained with the help of the classical methods for the determination of the induction machine parameters, presented in the speciality literature [3].

Parameters	Value
R_s	8,35
R'_r	5,92
L_s	0,512
L'_r	0,512
L_{sh}	0,48
J	0,004

Table 1: Parameters obtained by classical methods.

By using these data, the dynamic regime of no-load starting by direct coupling to the supply mains has been then simulated, this one being compared to the results obtained experimentally (figures 1, 2, 3, 4, 5 and 6).

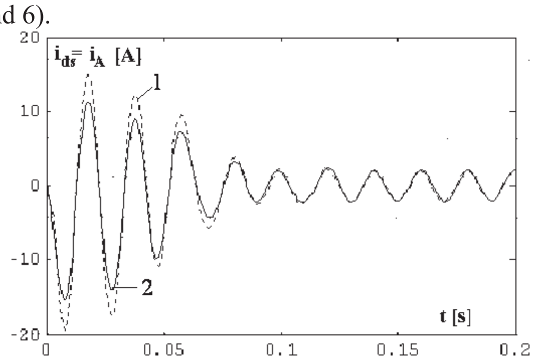

Figure 1: Components i_{ds} determined experimentally (1) and by simulation (2).

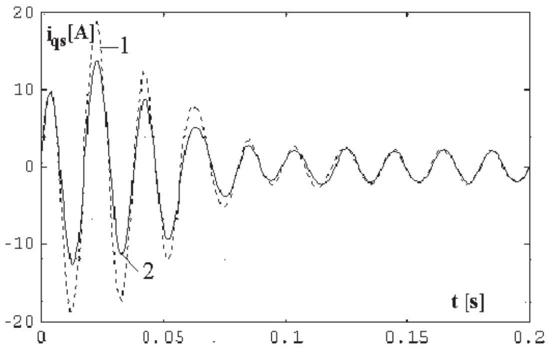

Figure 2: Components i_{qs} obtained experimentally and by simulation.

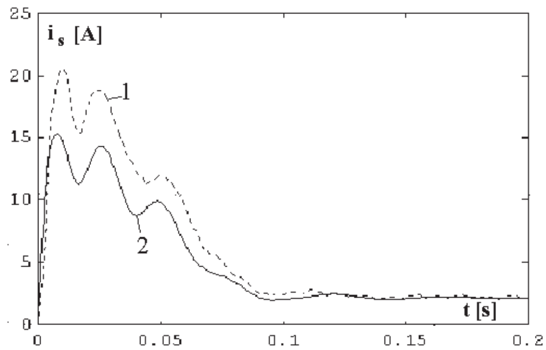

Figure 3: i_s computed with the help of the experimental values (1) and of the simulated ones (2).

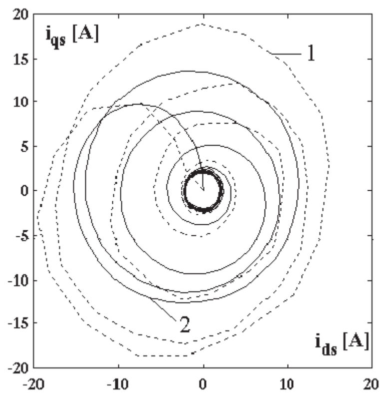

Figure 4: Dependences iqs=f(i_{ds}) corresponding to the two cases.

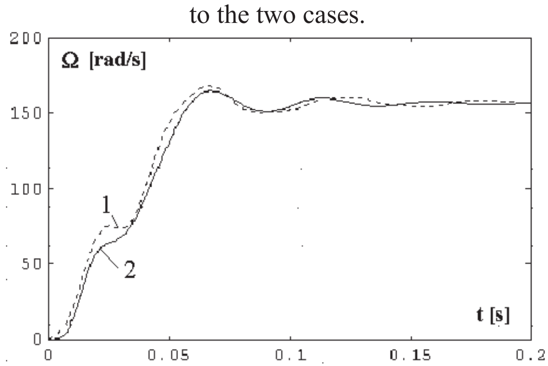

Figure 5: Angular speeds determined experimentally (1) and by simulation (2).

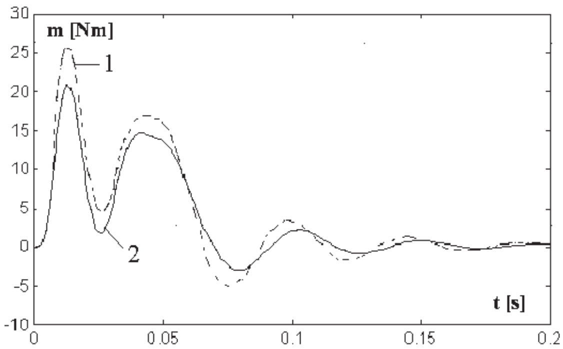

Figure 6: Dependences torque versus time, in the considered situations.

By running the program conceived with the help of the objective function minimization algorithm for the case of a motor rated at 1,1 kW, the following parameters have been obtained.

Parameters	Value
R_s	8,35
R'_r	5,5
L_s	0,548
L'_r	0,508
L_{sh}	0,498
J	0,004

Table 2: Parameters obtained by algorithm Simplex.

It has to be mentioned that these parameters must not be regard as being even the real parameters of the machine, but that set of values which, for the respective mathematical model, provides the answer which is the closest to the real one by simulating.
The answer of the induction machine mathematical model in the case of no-load starting has been simulated by using these parameters (figures 7 and 8).

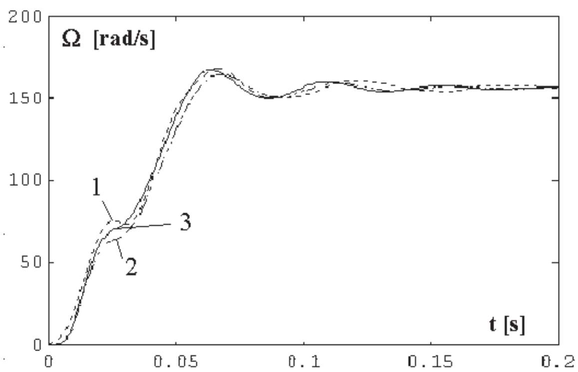

Figure 7: Angular speed determined experimentally (1), by simulating with parameters determined classically (2) and by simulation with parameters resulted by optimization (3).

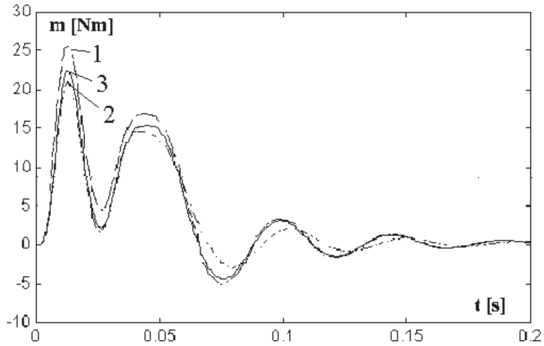

Figure 8: Dependence m(t) for three cases presented before.

4. CONCLUSIONS

The method proposed for the determination of the induction machine parameters, has the following advantages:
- it provides an estimation precision which is superior over the similar methods tackled in the literature;
- it may be successfully used both for the determination of the squirrel cage induction machine parameters and of the phase-wound rotor ones;
- it requires a very low energetic consumption.

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