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Influence of Stator Winding Resistance upon Maximum Torque of Reluctance Synchronous Motors

This paper starts from the conclusion that, in case of low power reluctance synchronous motors, it is imposed to consider the resistance of the armature winding because its value may not be neglected. In order to study the influence of this resistance upon the maximum torque, there are presented the computation relations of the reactive electromagnetic torque, of the active reluctance torque and of the breaking torque. With their help there have been plotted, in per unit, a few static angular characteristics, for different values of the stator resistance. The results of the simulations have been confronted with a few experimental data corresponding to a reluctance synchronous motor rated at 1,5 kW. The paper ends with conclusions afferent to this study.

Keywords: reluctance synchronous motor, stator resistance, maximum torque, angular characteristics, experimental tests

1. Introduction

The problem of reluctance synchronous motors is lately widely encountered in the papers published in the specialty literature [1], [5], [6], [8] etc. In this context, it is very important to know the maximum torque developed by such a motor and how different parameters influence this value.

In this paper there is studied the influence of the stator winding resistance upon the maximum torque. In this purpose, it is compulsory to know the link relations between the quantities analyzed, these relations being the starting point for carrying out the simulations.

It is also necessary to check experimentally the conclusions obtained by simulation, such a check being presented in the second part of the paper.

2. Computation relations

The expression of the reactive electromagnetic torque (reluctance torque) for a reluctance synchronous motor is, according to [7]:

$$M = \frac{mU^2}{2X_d\Omega_1} \cdot \frac{1-k_x}{(k_x + k_r^2)^2} [(k_x - k_r^2)\sin 2\text{¯} + k_r(1+k_x)\cos 2\text{¯} - k_r(1-k_x)] . \tag{1}$$

where:

$$k_x = \frac{X_q}{X_d} ; \quad k_r = \frac{R_s}{X_d} .$$

This torque may be expressed as a sum of two components:

$$M = M_a + M_f , \tag{2}$$

where:

- M_a is the active reluctance torque (dependent upon the internal angle);
- M_f is the breaking torque (determined by the magnetic asymmetry and by the stator winding resistance).

For M_a it is possible to write the expression [3]:

$$M_a = M_{a\max} \sin 2(\text{¯} + \sim_{dq}) , \tag{3}$$

with

$$M_{a\max} = \frac{mU^2}{2\Omega_1} \cdot \frac{1-k_x}{X_d(k_x + k_r^2)^2} \sqrt{(k_x - k_r^2)^2 + k_r^2(1+k_x)^2} \tag{4}$$

and

$$\sim_{dq} = \frac{1}{2}\text{arctg}\left[\frac{k_r(1+k_x)}{k_x - k_r^2}\right]. \tag{5}$$

In its turn, the breaking torque has the expression [7]:

$$M_f = -\frac{mU^2}{2\Omega_1} \cdot \frac{k_r(1-k_x)^2}{X_d(k_x + k_r^2)^2} . \tag{6}$$

The maximum value of the reactive synchronous torque is obtained for the internal angle $\text{¯}_k = 45^0 - \sim_{dq}$ and is computed with the help of the relation:

$$M_k = \frac{mU^2}{2\Omega_1} \cdot \frac{1-k_x}{X_d(k_x + k_r^2)^2} [\sqrt{(k_x - k_r^2)^2 + k_r^2(1+k_x)^2} - k_r(1-k_x)] . \tag{7}$$

To enlarge the possibilities for comparison of the performances for different types of motors there are used quantities in per unit and there are defined, beside the factors k_x and k_r, the per unit torque:

$$M^* = \frac{M}{M_b}, \text{ respectively } M_k^* = \frac{M_k}{M_b}, \tag{8}$$

where:

$$M_b = p\,\frac{3U_N I_N}{2\pi f_1}, \tag{9}$$

is the basic torque.

3. Simulations

To emphasize the influence of the stator winding resistance, there has been conceived a MATLAB program [4] and with its help there will be plotted the graphic dependences presented below.

To finalize the study proposed, there has been used a motor having the following data: U_{Nf} = 220V; I_{Nf} = 3,8 A; m = 3 phases; f_1 = 50Hz, n_1=1500 r.p.m.

In figures 1 and 2 there are presented two families of characteristics, for two values of the magnetic asymmetry ratio ($k_x = 1/4$, $k_x = 1/10$) and six values of k_r.

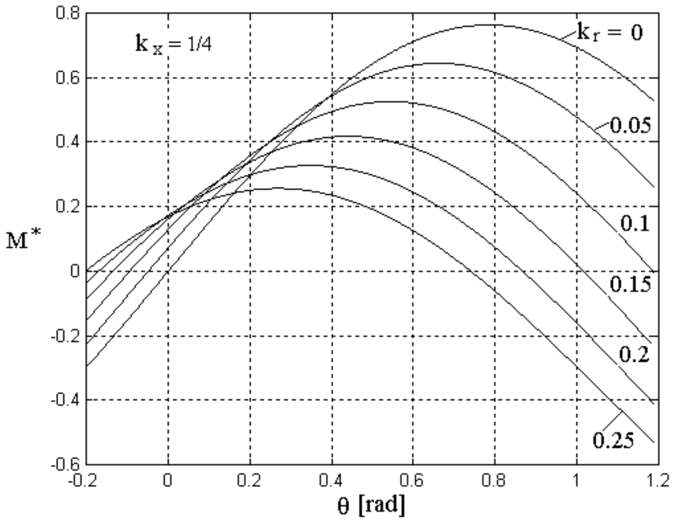

Figure 1. Static angular characteristics for k_x=1/4.

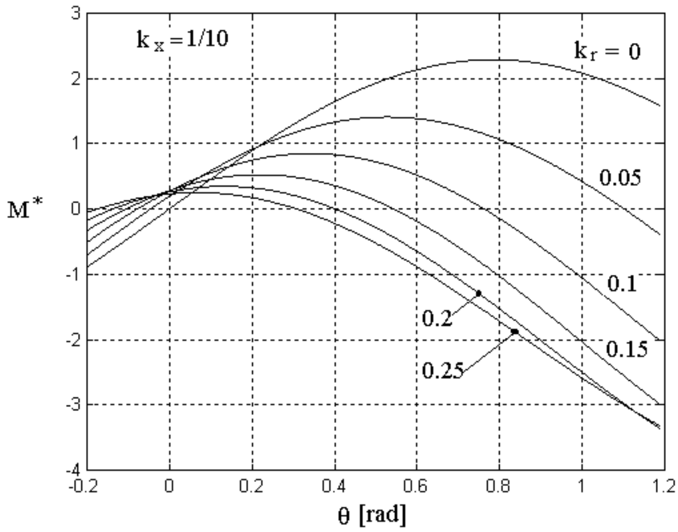

Figure 2. Static angular characteristics for k_x=1/10.

4. Experimental determinations

In order to catch experimentally the influence of the armature winding resistance upon the maximum torque developed by the motor, the scheme from the following figure has been used.

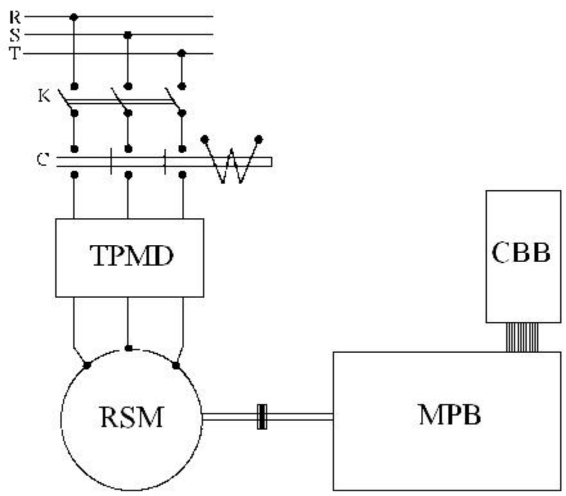

Figure 3. Scheme for establishing the maximum torque.

The notations used in the previous figure are:

RSM – reluctance synchronous motor;

TPMD – three-phase measurement device;

MPB – magnetic powder brake [9];

CBB – command block of the brake [10].

The maximum torque has been determined experimentally in three situations, the results obtained being filled in the table 1.

Table 1

Total resistance of the armature circuit [Ω]	I [A]	$M_{k\ measured}$ [Nm]	$M_{k\ simulated}$ [Nm]
5,2	7	10	9,7
6,7	6	8,75	9
10,2	5,6	7,5	8

The results obtained for the cases corresponding to the three situations mentioned before, are presented in the following figures.

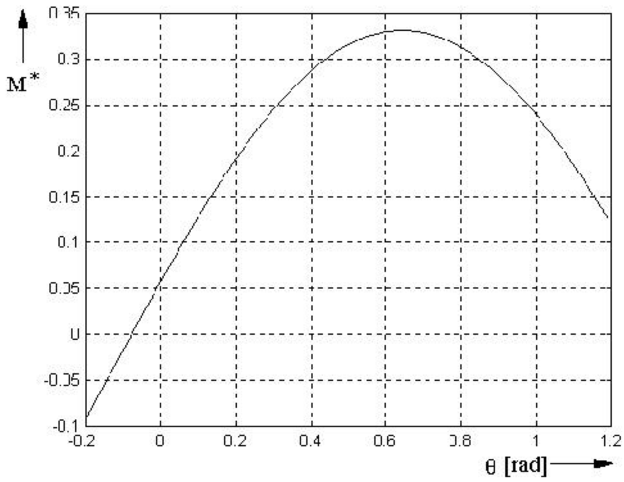

Figure 4. Static angular characteristic for the case 5,2 Ω.

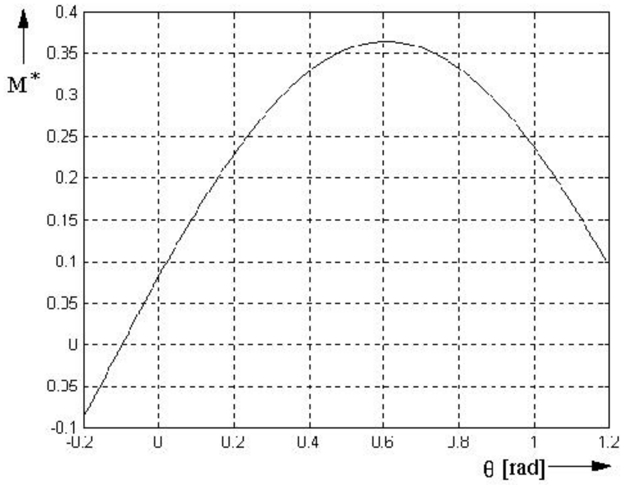

Figure 5. Static angular characteristic for 6,7 Ω.

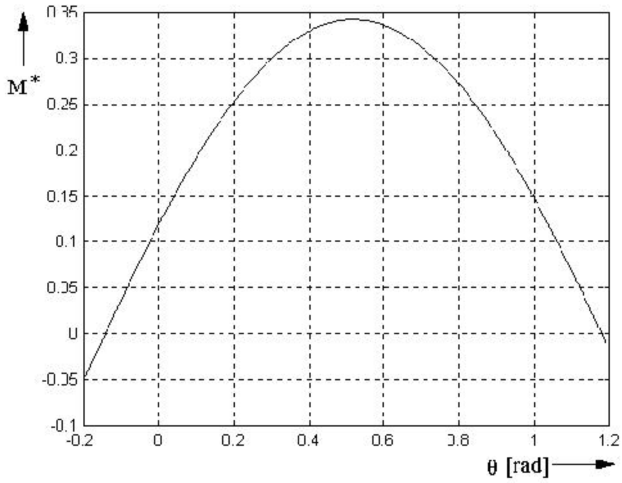

Figure 6. Static angular characteristic corresponding to the case 10,2 Ω.

In the first case the basic torque M_b , used for relating to it, is:

$$M_b = p\,\frac{3 \cdot U \cdot I}{2 \cdot \text{®} \cdot f} = 2\,\frac{3 \cdot 220 \cdot 7}{2 \cdot \text{®} \cdot 50} = 29{,}4 \;\text{ Nm.} \qquad (10)$$

As a consequence, the maximum torque obtained from the graphic, will be:

$$M_{k_{simulat}} = 0{,}3313 \cdot 29{,}4 = 9{,}7\,\text{Nm.} \qquad (11)$$

In the second case, doing as in the previous case, the torque M_b, used for relating to it, is:

$$M_b = 25{,}2 \text{ Nm}. \quad (12)$$

The maximum torque, obtained by graphic, has the value:

$$M_{k_{simulat}} = 0{,}3646 \cdot 25{,}2 = 9 \text{ Nm}. \quad (13)$$

In the third case, the torque M_b, used for relating to it, is:

$$M_b = 23{,}5 \text{ Nm}. \quad (14)$$

The maximum torque obtained by graphic, has the value:

$$M_{k_{simulat}} = 0{,}3418 \cdot 23{,}5 = 8 \text{ Nm}. \quad (15)$$

The values mentioned by (11), (13) and (15) can now be filled in the fourth column of the table 1. It is noticed that the results experimentally obtained confirm, qualitatively and quantitatively, the conclusion regarding the interdependence between the maximum torque and the total value of the armature circuit resistance.

5. Conclusions

The following conclusions emerge analyzing the previous graphics:

- in case of reluctance synchronous motors, the higher the asymmetry degree is, the higher the overloading ability is;
- in case of low power motors it is imposed to consider the armature winding resistance, because its value may not be neglected;
- it is noticed that this parameter has a negative influence, materialized in the decrease of the stabile operation zone (¯$_{kdq}$ < ® / 4) and the decrease of the maximum torque value; it is mentioned that for relatively high values of the winding resistance ($k_r > 0{,}15$), the benefits obtained by increasing the asymmetry degree become irrelevant.

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