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Aspects Regarding Reluctance Synchronous Motors Electromagnetic Torque

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Abstract

The armature winding parameters influence on the electromagnetic torque of the reluctance synchronous motors is analyzed in this paper. Thus, several curves families showing this influence are presented.

Key words: *reluctance synchronous motors, parameters, electromagnetic torque.*

Introduction

The efforts of the electrical motors designers and builders always aims to obtain as simple as possible constructive solutions, in order to reduce the cost price and to ensure at the same time as good as possible performances, both at starting and in operation.

The reluctance synchronous motors have many unchallenged advantages:

- they do not have sliding contacts (brushes and rings miss);
- they do not allow to occur sparks;
- their construction is very simple;
- they are silent;
- they have high reliability etc.
- they have not magnets, which is an advantage over the machines with permanent magnets in high temperatures applications, the demagnetization phenomenon does not occur and they are cheaper.

These advantages have made possible to use them in explosive or corroding medium, in mining industry, in petroleum industry or in chemistry.

In the case of the reluctance synchronous motors, the electromagnetic torque is produced owing to the tendency of its mobile part to move to the position in which the supplied winding inductance is maximum. The inductance variation is determined by the strong asymmetry of the magnetic circuit relatively to the coordinate to which the motion is made.

Because the torque that is developed by these motors in synchronous regime is proportional with the difference between the two-axes inductances, the rotor should have a strong magnetic asymmetry.

Electromagnetic Torque of the Reluctance Synchronous Motors

In accordance with the classical theory of the energy electromechanical conversion, the deduction of the reluctance synchronous motors electromagnetic torque is made by considering a series of simplifying hypotheses, acceptable for engineering computations. It is imposed to consider two important particularities:

- the necessity to consider the armature winding resistance, that cannot be neglected for low power;
- the strong magnetic asymmetry of the rotor by the two axes.

The electromagnetic torque expression is deduced on the basis of the armature voltage equation, of the phasors diagram and of the power balance.

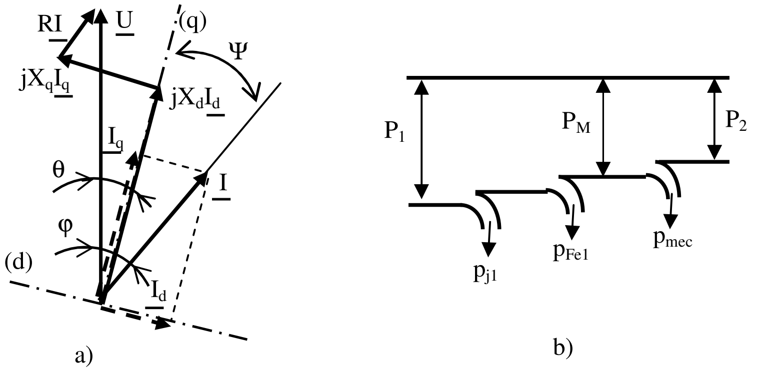
The voltage equation for one phase of the stator, in stationary regime, with quantities expressed in simplified complex, can be obtained from the synchronous motor voltage equation in stationary regime, with the condition $U_{e0} = 0$:

$$\underline{U} = jX_d \underline{I}_d + jX_q \underline{I}_q + R\underline{I} . \tag{1}$$

The phasors diagram from the figure 1 corresponds to this equation.

In accordance with the active powers balance (fig. 1.b), when neglecting the iron losses, the electromagnetic power can be expressed in the form:

$$P_M \cong P_1 - p_{j1} = mUI\cos\varphi - mRI^2 . \tag{2}$$



a)

b)

Fig. 1. Phasors diagram - a) the active powers balance
b) for the reluctance synchronous motor in stationary regime.

The following relations are obtained from the phasors diagram:

$$I\cos\psi = I_q ;$$

$$I\sin\psi = I_d ; \tag{3.a, b, c}$$

$$U\cos\varphi = X_d I_d \cos\psi - X_q I_q \sin\psi + RI .$$

These relations are introduced in (2) and lead to the expression:

$$P_M = mI_d I_q (X_d - X_q) . \tag{4}$$

The following equations system is also obtained from the phasors diagram:

$$U\cos\theta = X_d I_d + RI_q ;$$

$$U \sin\theta = X_q I_q - R I_d \, , \tag{5.a, b}$$

resulting

$$I_d = \frac{U(X_q \cos\theta - R\sin\theta)}{X_d X_q + R^2};$$

$$I_q = \frac{U(X_d \sin\theta + R\cos\theta)}{X_d X_q + R^2}. \tag{6.a, b}$$

By replacing (6) in (4), with $M = \frac{1}{\Omega_1} P_M$ and with the notations

$$k_x = \frac{X_q}{X_d}; \;\; k_r = \frac{R}{X_d}, \tag{7.a, b}$$

the *reactive electromagnetic torque (the reluctance torque)* is obtained

$$M_{dq} = \frac{mU^2}{2X_d\Omega_1} \cdot \frac{1-k_x}{(k_x + k_r^2)^2}[(k_x - k_r^2)\sin 2\theta + k_r(1+k_x)\cos 2\theta - k_r(1-k_x)]. \tag{8.a}$$

This torque can be expressed as a sum between two components:

$$M_{dq} = M_{dqa} + M_{dqf} \, , \tag{8}$$

where M_{dqa} is the *active reluctance torque*, depending on the internal angle and M_{dqf} is the *breaking torque,* determined by the magnetic asymmetry and by the stator winding resistance. The following expression can be written for M_{dqa}:

$$M_{dqa} = M_{dqa\max} \sin 2(\theta + \alpha_{dq}) + M_{dqf} \, , \tag{9}$$

with

$$M_{dqa\max} = \frac{mU^2}{2\Omega_1} \cdot \frac{1-k_x}{X_d(k_x + k_r^2)^2}\sqrt{(k_x - k_r^2)^2 + k_r^2(1+k_x)^2} \tag{10}$$

and

$$\alpha_{dq} = \frac{1}{2} arctg\left[\frac{k_r(1+k_x)}{k_x - k_r^2}\right]. \tag{11}$$

The following expression can be written for M_{dqf}:

$$M_{dqf} = -\frac{mU^2}{2\Omega_1} \cdot \frac{k_r(1-k_x)^2}{X_d(k_x + k_r^2)^2}. \tag{12}$$

The maximum value of the reactive synchronous torque is obtained for the internal angle $\theta_{kdq} = 45^0 - \alpha_{dq}$ and is computed with the relation

$$M_{kdq} = \frac{mU^2}{2\Omega_1} \cdot \frac{1-k_x}{X_d(k_x + k_r^2)^2}[\sqrt{(k_x - k_r^2)^2 + k_r^2(1+k_x)^2} - k_r(1-k_x)]. \tag{13}$$

In order to extend the possibilities for the comparison of the different motors performances per unit quantities are used,

$$M^* = \frac{M}{M_b}\text{, respectively } M_k^* = \frac{M_k}{M_b}, \tag{14}$$

where the basic torque is

$$M_b = p\frac{3U_N I_N}{2\pi f_1}. \tag{15}$$

Parameters Influence on the Torque

In order to emphasize the armature winding parameters influence, some MATLAB programs have been achieved and with their help there have been plotted the dependences of the maximum reluctance torque (fig. 2.) and of the internal angle for which this one is obtained (fig. 3) versus the factors k_x and k_r; the angular characteristics for a few particular cases have also been plotted (fig. 4 ÷ fig. 8).

The study has been made for a three-phase reluctance synchronous motor rated at: P_N=1,2 kW, U_{Nf} = 220 V; I_{Nf} = 3,8 A; m = 3; f_1 = 50 Hz, n_1=1500 r.p.m.

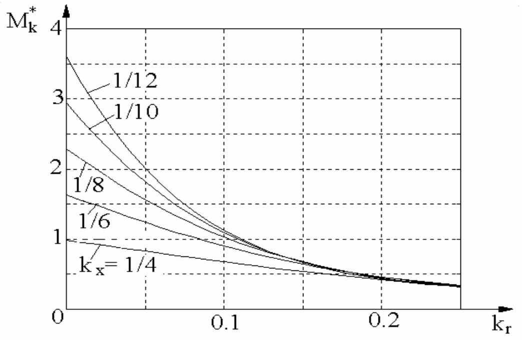


Fig. 2. Characteristics $M_k^* = f(k_r)$

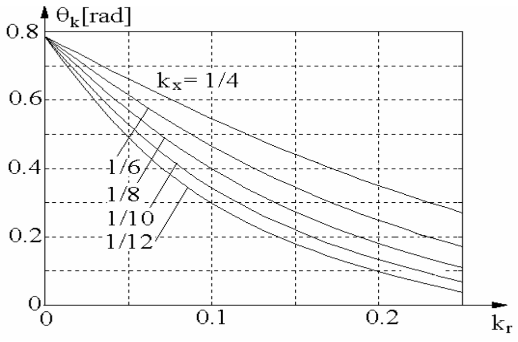


Fig. 3. Characteristics $\theta_k = f(k_r)$

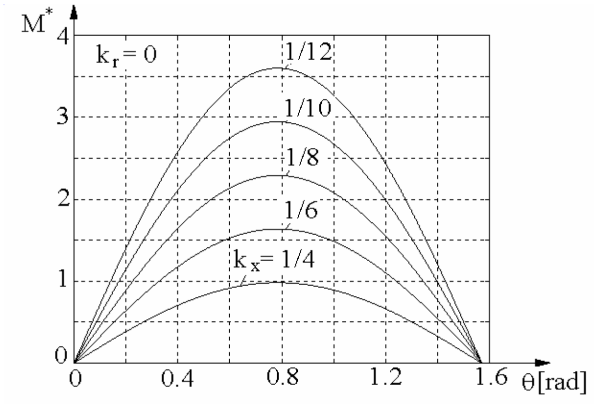


Fig. 4. Characteristics $M^* = f(\theta)$, for $k_r = 0$.

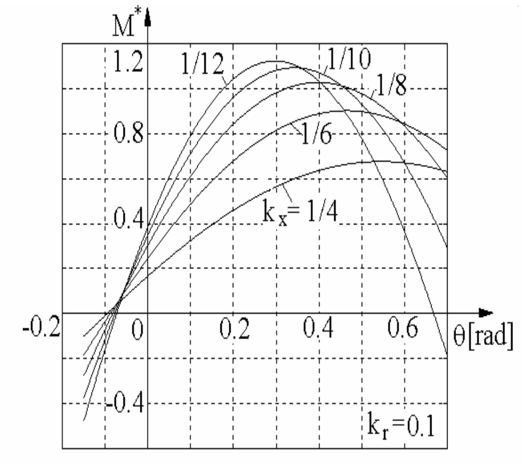


Fig. 5. Characteristics $M^* = f(\theta)$, for $k_r = 0.1$.

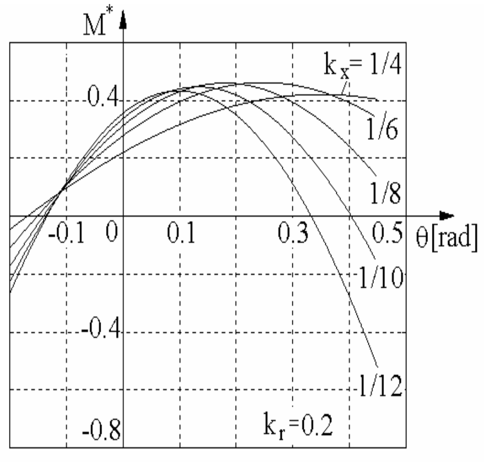
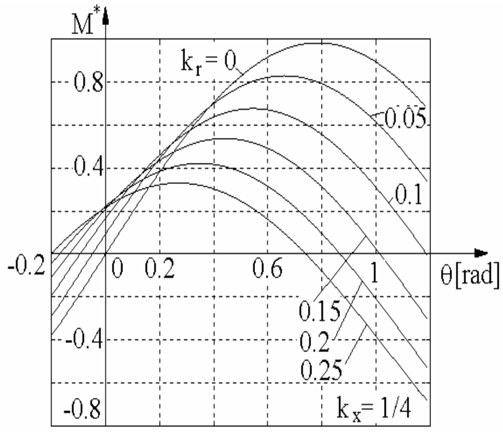


Fig. 6. Characteristics $M^* = f(\theta)$, for $k_r = 0.2$.



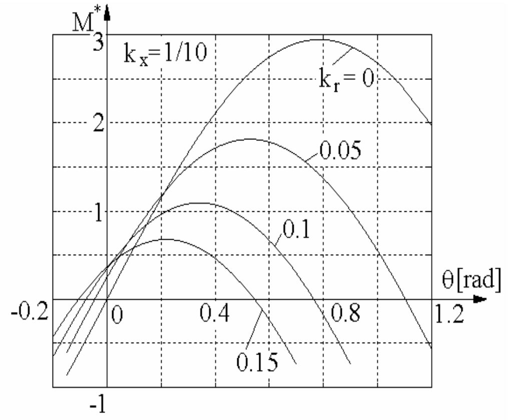


Fig. 7. Characteristics $M^* = f(\theta)$, for $k_x = 1/4$. **Fig. 8.** Characteristics $M^* = f(\theta)$, for $k_x = 1/10$.

Conclusions

The following conclusions, resulting from the ones presented before, can be emphasized:

- the greater the magnetic asymmetry degree is, the best the RSM technical performances (over-loading capacity and power factor) are (fig. 2, 4, 5). This thing justifies the preoccupation for the development of the rotor constructive solutions with distributed anisotropy;
- the armature winding resistance value cannot be neglected anymore and it must be taken into account in the case of the low power reluctance synchronous motors; it is noticed that this parameter has a negative influence, materialized in decreasing the zone of stable operation ($\theta_{kdq} < \pi/4$) and in decreasing the maximum torque (fig. 2, 3, 7, 8). It is mentioned that for relatively increased values of the winding resistance ($k_r > 0{,}15$ p. u.), the advantages obtained by increasing the magnetic asymmetry degree become unessential (fig. 2, 6);

- when designing the reluctance synchronous motors it is recommendable that, at the same time with the rated power decrease, the supply voltage to be also decreased; in this way the winding resistance value is kept under a certain limit. It is also aimed to obtain an as great as possible value for X_d, by adopting a small air-gap, the both solutions leading to the decrease of the ratio k_r.

References

1. Chiba, A., Nakamura, F., Fukao, T., Rahman, M. A. - *Inductances of Cageless Reluctance-Synchronous Machines having Nonsinusoidal Space Distribution*. IEEE Transaction on Industry Applications, vol. 27, no. 1, p. 44-51, 1991.
2. Enache, M. A. - *Influentele parametrilor infasurarii indusului asupra cuplului motoarelor sincrone cu reluctanta variabila*. Simpozionul „Zilele electrotehnicii romanesti”, Craiova, 2005.
3. Enache, M. A. - *Determinarea parametrilor masinii sincrone cu reluctanta variabila aferenti regimurilor stationar si dynamic*. Referat doctorat, Craiova, 2005.
4. Honsinger, V. B. - *Steady-State Performance of Reluctance Machines, IEEE Transaction on Power Apparatus and Systems*, vol. PAS-90, no. 1, p. 305-317, 1991.
5. Miller, T. J. E., Staton, D. A., Wood, S. E. - *Maximing the Saliency Ratio of the Synchronous Reluctance Motors.,* Internal Report, Speed Consortium, 1992.
6. Nica, C. - *Convertoare electromecanice de mică putere.* Editura Universitaria, Craiova, 2005.
7. Xu, L., Liao, F. - *Design of the Doubly-Fed Reluctance Motor for Adjustable Speed Drives.* IEEE-IAS Annual Meeting Proceedings, Denver, 1994.

Aspecte privind cuplul electromagnetic al motoarelor sincrone cu reluctanță variabilă

Rezumat

În lucrare este analizată influența parametrilor înfăşurării indusului asupra cuplului motoarelor sincrone cu reluctanță variabilă. În acest sens, sunt prezentate mai multe familii de curbe care evidențiază această influență.