BULETINUL Universităţii Petrol – Gaze din Ploieşti	Vol. LVIII No. 2 bis / 2006	163-168	Seria Tehnică

About Starting of Low Power Permanent Magnet Synchronous Motors

Corneliu Nică, Monica Adela Enache

University of Craiova
e-mail : cnica@em.ucv.ro

Abstract

The asynchronous starting process of the low power permanent magnet synchronous motors is analyzed in this paper. The influence of the excitation degree and of the electrical parameters value is emphasized. Thus, several curves (graphics) families showing this influence are presented.

Keywords: *permanent magnets, synchronous motors, asynchronous starting*.

Introduction

The increase of the electrical energy price has determined preoccupations for increasing the electromechanical converters efficiency. One of the solutions is the extended utilization of the permanent magnet synchronous motors with direct mains supply, in general use applications. The arguments in this sense are determined by their energy losses, lower with (25 – 30%) in comparison with the asynchronous motors rated the same and by the higher power factor. Thus, the greater acquisition cost of the permanent magnet synchronous motors (PMSM) is liquidated in a few years of utilization owing to the lower losses [1, 2, 3].

The designers of the PMSM with direct mains supply materialize their efforts in finding as simple as possible constructive solutions for the rotor and in ensuring good technical performances both at starting and in load operation. The latter requirement can be fulfilled hard, special difficulties occurring in regard to starting, especially at low powers. The motor parameters values and the excitation degree have contradictory influences on the starting and synchronous operation performances.

The paper is focused on the analysis of some aspects of the asynchronous starting for the permanent magnet synchronous motors with direct mains supply. The behaviour of a permanent magnet synchronous motor is studied during the staring (till the slip of 0,02 – 0,05), without tackling the proper synchronization; the analysis is focused on the components of the electromagnetic torque average value.

In order to establish the motor parameters the analytical computation is used, with the utilization both of relations and of some curves for certain coefficients, from the speciality literature [4, 5] and the material features of the used permanent magnets.

Asynchronous starting of the permanent magnet synchronous motors

In the great majority of cases the synchronous motors with direct mains supply are started in asynchronous. In this purpose, the rotor is fitted out with a short-circuited winding, like the squirrel-cage asynchronous motors. When supplying the armature winding, the motor starts owing to the asynchronous torque and when the speed reaches a value close to the synchronism value ($n \cong (0{,}95 \div 0{,}98)n_1$) the rotor is entrained in synchronism owing to the interaction between the induced magnetic field and the inductor magnetic field [2, 3, 5].

The asynchronous starting of the permanent magnet synchronous motors is complicated in an important extent because of the permanent magnets inductor field during the starting. In this time interval the inductor field induces in the stator winding electromotive force (e. m. f) U_{e0p}, with the frequency

$$f_{1p} = f_1(1-s) \tag{1}$$

and with the root-mean-square value

$$U_{e0p} = \pi\sqrt{2} f_1 (1-s) w k_w \Phi_0 = (1-s) U_{e0}, \tag{2}$$

where Φ_0 is the PM useful flux per pole and the other quantities have the known meaning [1, 2, 3].

Since the frequency f_{1p} is different from the supply voltage frequency, f_1, the e. m. f. U_{e0p} determines the current i_{0p} through every phase of the stator; this current passes through the circuit formed by the stator winding and the supply mains. In the cases of the low power motors, the supply mains impedance is practically negligible relatively to the stator winding impedance, Z_p, so that

$$I_{0p} \cong \frac{U_{e0p}}{Z_p}. \tag{3}$$

In the case of the synchronous motors having symmetrical rotor from magnetic view point, in synchronous regime the relation $X_d = X_q = X_s$ can be written and

$$Z_p = \sqrt{R^2 + (1-s)^2 X_s^2} \tag{4}$$

and

$$\cos\Psi_r = \frac{R}{\sqrt{R^2 + (1-s)^2 X_s^2}} \tag{5}$$

are the stator impedance and power factor, respectively during the starting.

As a consequence of the interaction between the PM magnetic field and the current I_{0p}, a breaking torque occurs in the machine, having the expression

$$M_f = -\frac{m U_{e0p} I_{0p} \cos\Psi_p}{\Omega_1 (1-s)} = -\frac{m}{\Omega_1} \cdot \frac{(1-s) R U_{e0}^2}{R_1^2 + (1-s)^2 X_s^2} \tag{6}$$

By noting with

$$k_e = \frac{U_{e0}}{U_N} \tag{7}$$

the motor excitation degree and with

$$k_r = \frac{R}{X_s}, \tag{8}$$

the following relation is obtained

$$M_f = -\frac{1}{\Omega_1} \cdot \frac{mU_N^2}{X_s} \cdot \frac{k_e^2 k_r (1-s)}{k_r^2 + (1-s)^2} . \tag{9}$$

In the case of the synchronous motors having asymmetrical rotor ($X_d \neq X_q$), the starting breaking torque has the expression [3]

$$M_f = -\frac{1}{\Omega_1} \cdot \frac{mU_N^2}{X_d} \cdot \frac{k_e^2 k_r (1-s)}{k_r^2 + k_x (1-s)^2} \tag{10}$$

where

$$k_x = \frac{X_q}{X_d} \tag{11}$$

is the factor of magnetic asymmetry.

Taking into account the ones presented before, both the asynchronous torque, M_a [2 ,3] and the breaking torque, M_f, react on the synchronous motors rotor during the starting, so that the average value of the resultant torque is

$$M_r = M_a + M_f . \tag{12}$$

By differentiating (10) in respect to the slip and by equaling with zero, are obtained the slip expression

$$s_{kf} = 1 - \frac{k_r}{\sqrt{k_x}} \tag{13}$$

and the maximum breaking torque expression, in absolute values

$$M_{kf} = -\frac{1}{\Omega_1} \cdot \frac{mU_N^2}{X_d} \cdot \frac{k_e^2}{2\sqrt{k_x}} . \tag{14}$$

As concerns the previous relations, it is mentioned that the reactances X_s, X_d, X_q correspond to the frequency f_1 and U_{e0} is the root-mean-square value of the e. m. f. induced by the inductor field in one phase of the stator winding, when the rotor has the synchronism speed.

Computation results

The results obtained by computation, with the previous relations, for a three-phase synchronous motor having the following rated and constructive data [2] are presented further on:

$U_{Nf} = 220$ V, $I_{Nf} = 0{,}55$ A, $2p = 8$ poles, $f_1 = 50$ Hz, $X_d = 226\,\Omega$, $X_{\sigma 1} = 74\,\Omega$, $X_{\sigma 2}^{/} = 65\,\Omega$, $R_1 = 73\,\Omega$, $R_2^{/} = 38\,\Omega$.

The results are expressed in per unit (noted with the superior index *), the base quantities being chosen as follows:

$$\Omega_b = \Omega_1 = \frac{2\pi f_1}{p}; \;\; M_b = \frac{mU_{Nf} I_{Nf}}{\Omega_b}; \;\; Z_b = \frac{U_{Nf}}{I_{Nf}}. \tag{15}$$

The figure 1.a presents the mechanical characteristics at asynchronous starting, both for the resultant torque, M_r and for its components and the influence of the stator winding resistance value on the curve $M_r^* = f(s)$ is presented in the figure 1.b.

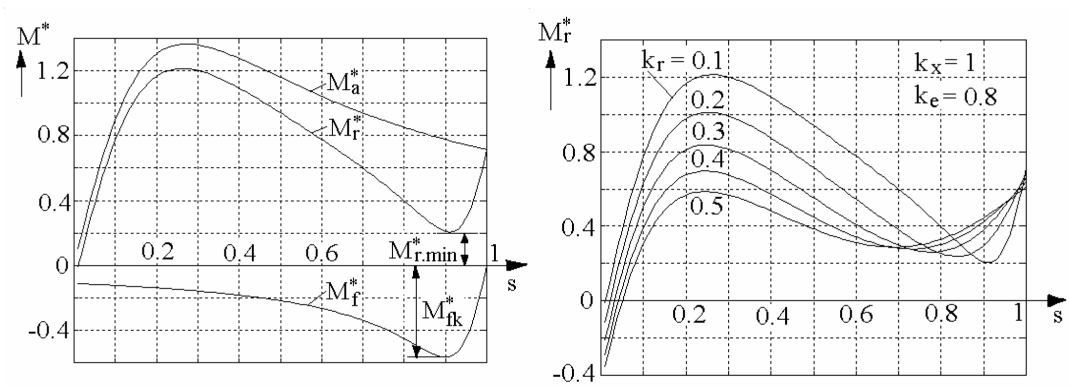

Fig. 1. Mechanical characteristics at asynchronous starting: a) – the torque components; b) – the influence of k_r.

The influence of the magnetic asymmetry factor (k_x) and of the equivalent rotor resistance is shown in the figure 2.

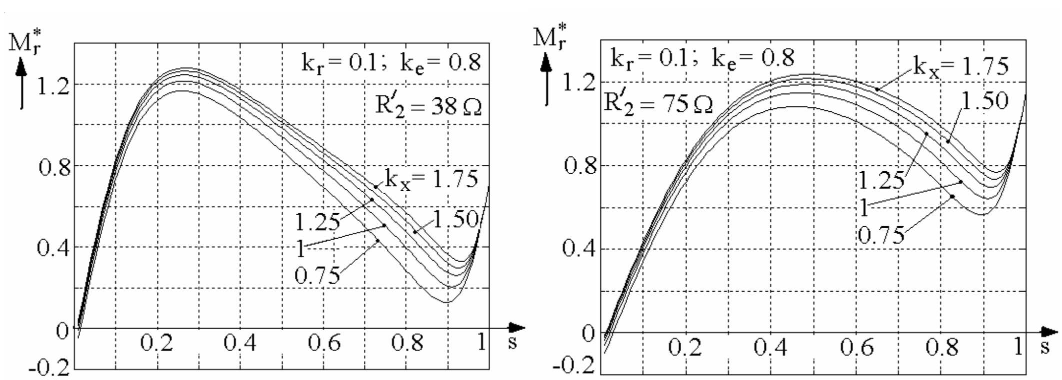

Fig. 2. Influence of the factor k_x on the resultant torque characteristic for: a) - $R_2^{/} = 38\,\Omega$; b) - $R_2^{/} = 75\,\Omega$.

The figure 3 emphasizes the influence of the synchronous motor excitation degree, at starting, for two values of the factor k_r.

As it can be noticed from the figures 1 – 3, the main difficulty at the asynchronous starting of the permanent magnet synchronous motors is that a "saddle" occurs in the curve $M_r^*(s)$, having the minimum value $M_{r\min}^*$, corresponding to the maximum breaking torque, M_{kf}^*. Because the asynchronous starting can occur only when the resistant torque is smaller than $M_{r\min}$ (fig. 1.a), the figure 4 presents the excitation degree influence (fig. 4.a) and the asymmetry factor influence (fig. 4.b) on the maximum breaking torque.

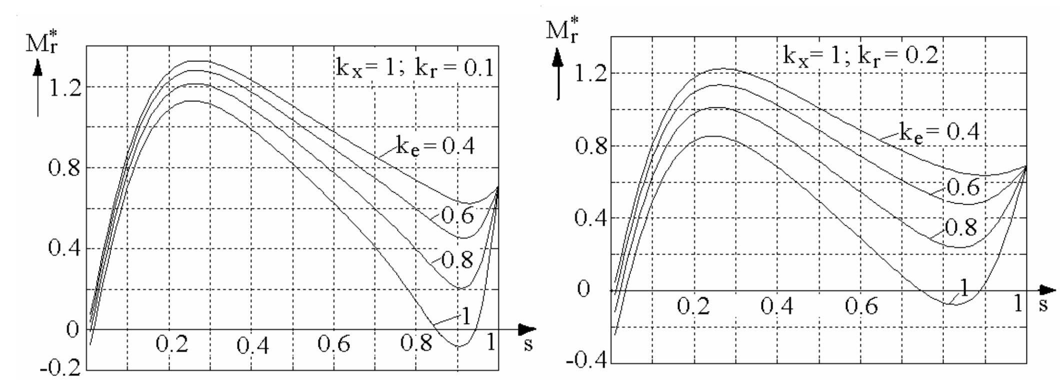

Fig. 3. Influence of the excitation degree, k_e, on the resultant torque characteristic for: a) $k_r = 0{,}1$; $k_r = 0{,}2$.

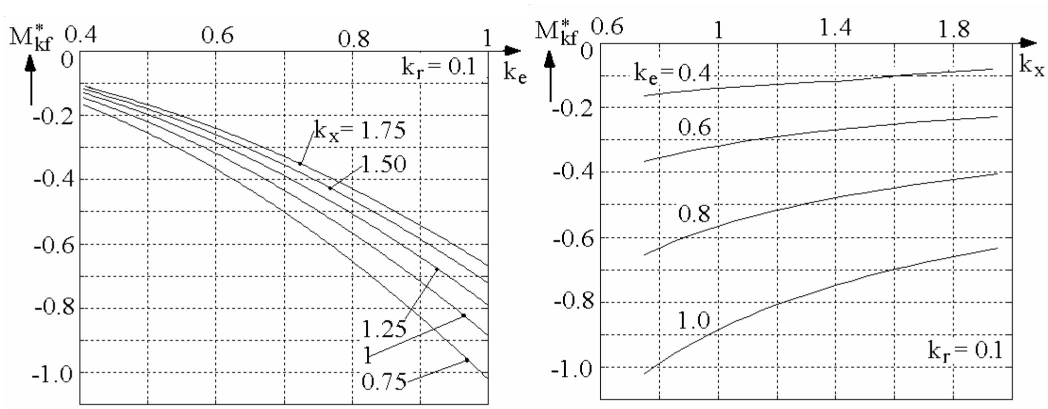

Fig. 4. Dependence of the maximum breaking torque on: a) – the excitation degree; b) – the magnetic asymmetry factor.

Conclusions

From the analysis of the characteristics presented in the previous chapter the following conclusions result:

- the presence of the PM inductor field has a negative influence on the starting process, materialized in: the decrease of the maximum resultant torque and a "saddle" in the resultant torque curve;
- for a certain value of the load torque there is a maximum value of the excitation degree, $k_{e\max}$, that must not be exceeded , in order to ensure the asynchronous starting. This restrictive

condition has negative effects on the operation parameters of the motor (the power factor and the maximum torque);
- the value of the rotor cage resistance has a contradictory influence on the starting process. Thus, an increase of it causes an increase of the starting torque and of the resultant torque;
- the maximum breaking torque depends on the value of the stator phases resistance.

It is mentioned that when the rotor cage is not symmetrical an inverse asynchronous torque also occurs, having a negative effect on the starting process.

References

1. But, A. D. - Beskontaktnîe electriceskie maşinî. *Vîsşaia Şcola*, Moskva, 1990
4. Nică, C. - Convertoare electromecanice de mică putere. *Editura Universitaria*, Craiova, 2005
5. Nicolaide, A. - Maşini electrice, Vol. II, *Editura Scrisul Românesc*, Craiova, 1975
2. Cioc, I., Nică, C. – Proiectarea maşinilor electrice. *Editura Didactică şi pedagogică*, Bucureşti, 1994
3. Minciună, T. L. – Contribuții la analiza regimurilor de funcționare ale motoarelor sincrone cu magneți permanenți. *Teză de doctorat*, U. P. Bucureşti, 1999

Asupra pornirii motoarelor sincrone de mică putere cu magneți permanenți

Rezumat

În lucrare este analizat procesul de pornire al motoarelor sincrone de mică putere, excitate cu magneți permanenți. Se evidențiază influența gradului de excitație şi a valorii parametrilor electrici. În acest sens sunt prezentate mai multe familii de curbe ce scot în evidență aceste influențe.