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DETERMINATION OF THE CHARGE ANGLE OF THE SYNCHRONOUS ENGINE WITH PERMANENT MAGNETS

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Abstract. *It was analyzed the dependence of the electromotive voltage and the voltage decline of the synchronous engine on the charge angle and the power factor. It has been proved that the electromotive voltage has a minimal value and corresponds to the optimal dimensions of the permanent magnets for the relation of the Θ charge angle and the φ angle of the power factor. There were obtained mathematical relations that can be used to determine the synchronous engine parameters with permanent magnets at the project phase.*
Keywords: *motor sincron, magneți permanenți, tensiune electromotoare, cădere de tensiune, unghi de sarcină, factor de putere.*

Introduction

The electrical machines have a dominant application in the modern electrotechnics as being a way of transforming the electromechanical energy into electric and on the contrary. Due to the high efficiency, comparing to other machines, the optimal distribution of the energy produced by the electrical generators, electrical energy transportation at big distances with not a big loss, parallel functioning that form great systems comfortable to be used, the electrical machines are actually considerably important.
But, the new technologies development of the ferromagnetic material production, current conductors, and isolative materials puts the problem of improving the electrical machines as well as constructively and optimizing the stationary and transitory processes.
Constructively, the synchronous machine can serve as an example of an electrical machine. This machine has application in both of the regimes and in most of cases the excitation system is electromagnetic.
The electromagnetic system of excitation reduces the reliability of the synchronous machine functioning to approximatively two times due to the slipping contact [1]. The wrap presence, usually on the rotor, increases the losses and respectively reduces the efficiency independently on the operating regime.
The permanent magnets that are actually massively produced with good parameters can replace the electromagnetic system of excitation and liquidates concomitantly the slipping contact, of course if taking into consideration the increased remanent induction and the great coercitive force.
The replacement of the electromagnetic system of excitation with permanent magnets considerably reduces the space occupied by the excitation wrap. But the excitation system with permanent magnets is not able to be regulated from the magnetic flux point of view [2, 3].
In order to ensure a normal functioning of a synchronous motor in an optimal mode of operation with variable load at the drive shaft, it is necessary to choose dimensions of permanent magnets properly.
It is important to determine the supercharge angle Θ at the synchronous engine regime of operation with permanent magnets that can be calculated taking into consideration the geometric dimensions of the permanent magnets, respectively the constructive parameters can be calculated basing on the nominal data for assuring the operation regime without exiting the synchronism in case of the charge variation.

Correlation between the Θ and φ angles

We admit by hypothesis that the synchronous engine with permanent magnets has a null stator wrap resistance and the permeability of the

permanent magnets is approached to a vide one by value. So the interfere of the engine is considered uniform [4].
The phase diagram for this case is simplified (Figure 1).

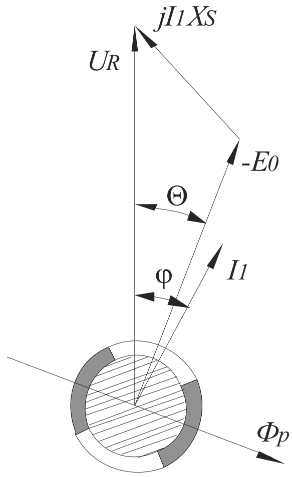

Figure 1. The simplified phase diagram of the synchronous engine with permanent magnets.

The balance equation of the stator wrap voltages in complex is

$$\underline{U_R} = -\underline{E_0} - j\underline{I_1}\underline{X_S} \tag{1}$$

where $\underline{U_R}$ – the phasor of the alimentation network's phase voltage;
$\underline{E_0}$ – the electromotive voltage phasor of the stator wrap;
$\underline{I_1}$ – the phasor of the current of the stator wrap;
$\underline{X_S} = X_a + X_{r1}$ – synchronous reactance of the stator wrap.
By adding the $\underline{E_0}$ and $j\underline{I_1}\underline{X_S}$ phasors projections on the $\underline{U_R}$ phasor direction we obtain the equation

$$\underline{U_R} = \underline{E_0}\cos\Theta + \underline{I_1}\underline{X_S}\sin\varphi \tag{2}$$

By adding the $\underline{E_0}$ and $j\underline{I_1}\underline{X_S}$ phasors projections on the $\underline{U_R}$ phasor perpendicular direction we obtain

$$I_1 X_S \cos\Theta - E_0 \sin\Theta = 0 \tag{3}$$

Signifying the voltage decline that corresponds to the synchronous reactance we obtain:

$$\Delta U = I_1 X_S \tag{4}$$

Using the relative units system we obtain

$$\left.\begin{aligned} &E^* \cos\Theta + \Delta U^* \sin\varphi = 1 \\ &\Delta U^* \cos\varphi - E^* \sin\Theta = 0 \\ &\Delta U^* = I^* X_S^* \end{aligned}\right\} \tag{5}$$

From the equations system follows

$$E^* \cos\Theta + E^* \frac{\sin\Theta}{\cos\varphi} \cdot \sin\varphi = 1$$

$$E^* \left(\cos\Theta + tg\varphi \sin\Theta\right) = 1$$

or

$$E^* = \frac{1}{\cos\Theta + tg\varphi \sin\Theta} \tag{6}$$

and

$$\Delta U^* = E^* \frac{\sin\Theta}{\sin\varphi} \tag{7}$$

The $E^* = f(\Theta)$ dependence for different values of the φ angle is presented in the Figure 2, but in the Figure 3 it is presented the dependence $\Delta U^* = f(\Theta)$, also for different values of the φ angle.

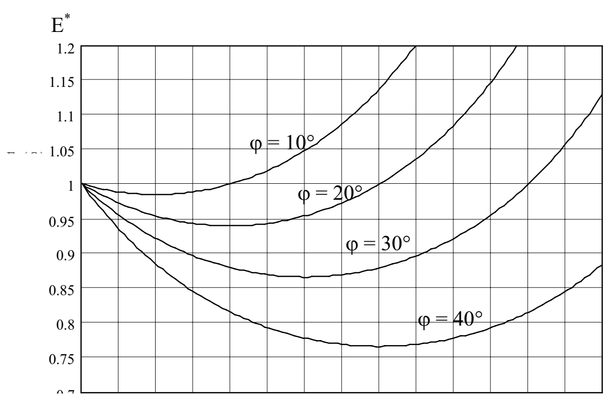

Figure 2. The $E^* = f(\Theta)$ dependence.

The graphic of the $E^* = f(\Theta)$ function is a curve which minimum can be determined by differencing the (6) expression. Differencing the (6) expression by the Θ angle we obtain

$$\sin\Theta = tg\varphi \cos\Theta$$

or $$tg\Theta = tg\varphi$$

It is evident that the minimum value of the $E^* = f(\Theta)$ function will correspond to the Θ=φ angle.
It is necessary to take into consideration this minimum at the project phase because the minimum value of magnetic induction from the interfere and respectively the minimum thickness of the polar permanent magnets will correspond to the minimum value of the electromotive voltage.

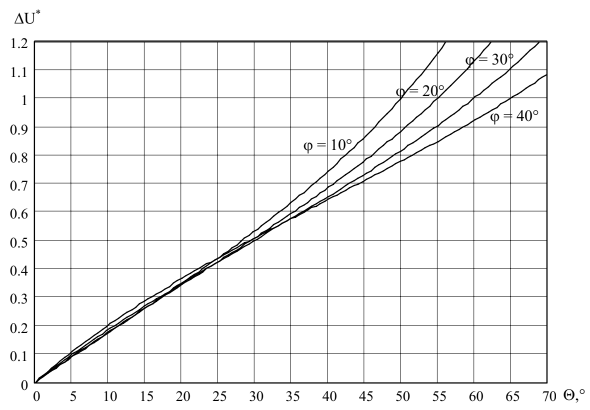

Figure 3. The $\Delta U^* = f(\Theta)$ dependence.

Solving the system (5) at the X_S ratio can be obtained the expression

$$X_S^* = \frac{E^*}{I^*} \cdot \frac{\sin\Theta}{\sin\varphi} \qquad (8)$$

So the electromagnetic power of the engine will have the following form in relative units

$$P_{em}^* = \frac{U^* E^*}{X_S^*} \sin\Theta = I^* \cos\varphi \qquad (9)$$

where $U^* = 1$, and $\frac{E^*}{X_S^*} = I^*$

For the nominal value of the current we have

$$P_{em}^* = \cos\varphi \qquad (10)$$

and $$\Delta U^* = X_S^*$$

The electromagnetic power value doesn't depend on the Θ angle, but is determined by the power factor (cosφ) at the project phase because $I_n^* = 1$ for corresponding values of the E^* and X_S magnitudes determined by the (6), (7) and (8) expressions.
The curves analysis in the Figure 2 and Figure 3 indicates that the rational limits of the φ angle variations and corresponding to the Θ angle are

φ = 25 ... 30°,

whom corresponds the power factor

cosφ = 0,906 ... 0,866

The minimum of the $E^* = f(\Theta)$ curve corresponds to the cosφ and to the relative value of the electromagnetic power of the synchronous engine and supposes a preventive selection of permanent magnets.

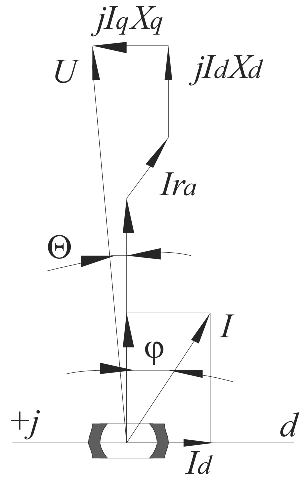

Figure 4. The phase diagram of the synchronous engine.

The $E^* = f(\Theta)$ dependence of the electromotive voltage can be deduced basing on the phase diagram (Figure 4) for the synchronous engine with apparent poles from permanent magnets, considering the stator wrap resistance.

In the phase diagram I_d, I_q, X_d, X_q – are the currents and the reactance by the d and q axes;

r – stator wrap resistance.

Conforming to the method used before the projections of the respective phasors by the real and imaginary axes allow writing the equations system in relative units as follows

$$\left.\begin{aligned} U^* \cos\Theta &= E^* + I_q^* r^* + I_d^* X_d^* \\ U^* \sin\Theta &= I_q^* X_q^* - X_d^* r^* \end{aligned}\right\} \tag{11}$$

Where

$$\left.\begin{aligned} I_d^* &= I \sin(\varphi - \Theta) \\ I_q^* &= I \cos(\varphi - \Theta) \end{aligned}\right\} \tag{12}$$

Dividing (11) to E^* and taking into a consideration (12) we obtain

$$\begin{aligned} E^* = I^* \Bigg[& \left(\frac{X_q^*}{tg\Theta} - r^* \right) \cos(\varphi - \Theta) - \\ & - \left(X_d^* + \frac{r^*}{tg\Theta} \right) \sin(\varphi - \Theta) \Bigg] \end{aligned} \tag{13}$$

The (13) equation can be used to determine $E^* = f(\Theta)$ and the variation of the engine parameters. The (13) equation can be simplified for the case when $\varphi = \Theta$ and for the nominal current, and can be written as follows

$$E^* = \cos\varphi - r^*$$

Conclusions

The electrical contact and the absence of the losses that are presented in the machines with electromagnetic excitation assure an increased reliability and a high efficiency in the limits of 95-97% at synchronous machines with the excitation system with permanent magnets.

The optimal geometric dimensions of the permanent magnets can be determined at the variations of the applied charge to the arbor when projecting the synchronous engines with permanent magnets and connecting them directly to the network in asynchronous regime.

It was proved that the optimal dimensions of the polar permanent magnets correspond to the minimum value of the electromotive voltage induced into the stator wrap by the magnetic flux produced by the permanent magnets.

The minim value of the electromotive voltage corresponds to the equation of the Θ charge angle and φ angle of the power factor that varies in limits of 25 – 30°.

Beside this the Θ and φ angles equality assures the exclusion of the induced transversal reaction that deforms and negatively influences the magnetic flux produced by the permanent magnets.

References

[1] But A.D. (1990) *Bescontactnîe ălectriceschie maşinî*, Editura Vîsşaia Şcola, Moskva.

[2] Câmpeanu A., Nică C. (2001) *Maşini electrice sincrone – regimuri particulare*, Editura SITECH, Craiova.

[3] Nică C. (2005) *Convertoare electromecanice de mică putere*, Editura Universitaria, Craiova.

[4] Ambros T., Burduniuc M., Lisnic I. (2005) *Les aimants permanents dans la construction des machines electrique*, 5th International Conference on Electromecanica land Power Systems, SIELMEN 2005, October 6-8.