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Alternative Design Relationship of Inner Diameter for Fault Approach of Salient Poles Synchronous Machine

In this paper an alternative relationship of inner diameter for design computing on salient poles synchronous machine that take into account fault approach, has been developed. This approach is based on the finding of a dependence of inner diameter by relative reactive drop voltage. Numerical simulations for a concrete case study of salient poles synchronous machine prove the work developed.

Keywords: fault approach, salient poles synchronous machine, inner diameter, design

1. Introduction

Electrical machines play a major role in a variety of applications: industrial drive with adjustable speed for motion control, power plant, conversion system of renewable energy, special applications etc. In all these kind of applications, the electrical machine –by its particularities- leads to different specific benefits. UN undoubted general opinion about synchronous machine is the supremacy of its using in power plant [15]-[16]. This one is the ever largest electrical machines built by human. The actual maximal power size is up to 100 MVA.

The design and construction of this machine is a large treatment subject for more time, and special contributions have been made from the starting of the XX century [1]. The design phase is based –on the preliminary step of procedure design- is based on the model of electric circuit equivalent scheme, when several assumptions are taking into consideration [7]-[8]. On this step the design is powerful depended on practical experiences [8]. Usually, the practical dependences are obtained for the already build electrical machines and are based on a multitude of prototype cases. The graphical dependences are organized as a curve named monograms of design. This kind of approach is a traditional one and, in the least time, when advanced development has been performed of materials field, early monograms curves may not be useful [3]-[6]. In this situation an up to date of these curves is necessary.

The design procedure of electrical machines is usually divided in several computing steps [1]-[5], [8]-[16]: electromagnetic computing, thermal computing, mechanical computing and performances tests obtained by running the operational characteristics etc. (sometimes for electrical machines supplied by power invertors, a checking of acoustic state is needed). Between all this steps is a powerful dependence, and if the performances tests is not fulfilled, the design must resumed. From this point of view, the real design process is an iterative one.

2. Computing of Inner Diameter at Salient Poles Synchronous Machine

In the general design methodology of electrical machines, electromagnetic computing is based on the searching of electromagnetic stress that ensures the possibility of torque development. Usually, the electromagnetic stress is related on electric stress as current density J_1 [A/mm^2] and linear current density A_1 [A/mm], and magnetic stress as magnetic flux density on the air gap B_δ[T] [8]. By founding these electromagnetic stresses -at an imposed electromagnetic torque- the geometric dimensions are also founding.

The electromagnetic stress, and electric one -in special-, may be considerate as an additional constraint - according to protection degree [13-[14]:

$$A_1 \cdot J_1 \approx 3000(I.P.44) \div 3200(I.P.23)\left[\frac{A^2}{mm^2}\right]. \tag{1}$$

Based on this result, a thermal flow constraint may be defined by [13]-[14]:

$$Q_{1T} \approx 3000(I.P.44) \div 8000(I.P.23)\left[\frac{W}{m^2}\right], \tag{2}$$

where the thermal flow of active part of stator winding is defined according to relationship [13]-[14]:

$$Q_{1T} = \rho_1 A_1 J_1, \tag{3}$$

where ρ_1 represents the cooper resistively.

The starting point on the classical design methodology is about the sizing relationship between apparent inner power and main geometric dimensions:

$$S_e = \sqrt{2}\Omega_1 (A_1 \hat{B}_\delta)(L\pi D^2 / 4), \tag{4}$$

where D and L represents the main geometric dimensions (inner diameter of stator and the ideal length of machine).

Or, if is used the Arnold-Esson constant, we have:

$$S_e = n_1 C D^2 L = (\Omega_1 / 2\pi) C D^2 L, \tag{5}$$

where the constant C is computed according to $C = \frac{\pi^2}{2} C_e = \frac{\pi^2}{\sqrt{2}} A_1 \hat{B}_\delta = \pi^2 \sigma_\delta$, and

$C_e = A_1 \hat{B}_\delta$ is the Postnikov constant.

From the relationship (5) the main geometric dimensions, as inner statoric diameter and ideal length of machine, may be expressed as a function of aspect ratio:

$$D(\lambda) = \sqrt[3]{\frac{2pS_e}{\Omega_1 C\lambda}} \tag{6}$$

$$L(\lambda) = \frac{\pi\lambda}{2p} D(\lambda) \cdot \tag{7}$$

The air gap in the middle axe of the pole may be computed according to next relationship:

$$\delta_0 = \gamma_\delta \tau \frac{A_1}{B_\delta}, \tag{8}$$

where the current linear density is expressed by:

$$A_1 = \frac{2m_1 w_1 I_{1ph}}{\pi D}, \tag{9}$$

and $\gamma\delta$ is a factor whose values are determinate by practice.

The reactive drop voltage reported on the rated one is definite according to relationship:

$$\varepsilon_r = \frac{\zeta}{\xi_1} \cdot \frac{E_r}{U_{ph}} \cdot \frac{A_1}{B_\delta} \tag{10}$$

In the Table 1 are presented the values of main factors from practice.

Table 1. Estimative values of ε_{rmin} [16]

Rotor type		Amortization winding	ε_{rmin}
Non-salient pole machine	Massive teeth	with	0.133
	Laminates teeth	with	0.126
	Massive teeth	without	0.119
	Laminates teeth	without	0.112
Salient-pole machine	Laminates polar piece	with	0.112
	Massive polar piece	without	0.098
	Laminates polar piece	without	

Based on an early time result in the synchronous machine designing field, the coefficient ζ may be computed by relationship [15]:

$$\zeta = 1.86\frac{\lambda_c}{q_1} + 1.86\frac{\lambda_d}{q_1} + 1.86\frac{\tau}{l_i}\cdot\frac{l_f}{\tau}, \tag{11}$$

where the ratio as λc/q1 and λc/q1 may be founded in specific tables [15].

We know that aspect ratio may be expressed as a function of covering factor of the frontal part of stator winding [13]-[14]:

$$\lambda = \frac{\alpha_{f1}}{k_{f1} - 1}. \tag{12}$$

And, in the sometime, the aspect ratio may be expressed by the classical relationship:

$$\lambda = \frac{l}{\tau}, \tag{13}$$

where the pole is expressed by $\tau = \pi D/2p$.

Based on the two least relationships, the ratio between length of frontal part of stator winding and ideal length of machine may be expressed as:

$$\frac{l_f}{l_i} = \frac{\alpha_{f1}}{\lambda}. \tag{14}$$

Now, from relationships (11) and (14) the coefficient ζ becomes as a function of aspect ratio:

$$\zeta = 1.86\frac{\lambda_c}{q_1} + 1.86\frac{\lambda_d}{q_1} + 1.86\frac{\alpha_{f1}}{\lambda} = f(\lambda). \tag{15}$$

Finally, from relationship (9), (11) and (15), the relationship of inner stator diameter becomes:

$$D_1(\lambda) = \frac{2}{\pi}3w_1 I_{1ph}\frac{\zeta(\lambda)}{\xi_1}\cdot\frac{1+\varepsilon_r\sin\varphi}{\varepsilon_r}\cdot\frac{1}{B_\delta}. \tag{16}$$

This relationship contains, in an explicit form, de dependence of the factor ε_r, which must be imposed. A still unknown variable is represented is represented by number of turns w1. In the order to find this value we will start from reactive voltage drop [15]:

$$E_r = \sqrt{2}\pi w_1\xi_1\left(\frac{2}{\pi}\tau l_i B_1\right)f. \tag{17}$$

From relationships (10) and (17), number of turns becomes:

$$w_1 = \varepsilon_r\frac{p}{2\pi}\cdot\frac{1}{fA_1\zeta}\cdot\frac{1}{Dl_i}U_{ph}. \tag{18}$$

Now, based on relationship (16) and (18), the relationship of inner diameter becomes:

$$D=\sqrt{\frac{3p}{\pi^2}\cdot\frac{1}{f}\cdot\frac{B_\delta}{A_1}\cdot\frac{1}{\xi_1}\cdot\frac{1}{l_i}U_{ph}I_{ph}(1+\varepsilon_r\sin\varphi)}\ , \tag{18}$$

or:

$$D=\sqrt{\frac{3p}{\pi^2}\cdot\frac{1}{f}\cdot\frac{B_\delta}{A_1}\cdot\frac{1}{\xi_1}\cdot\frac{1}{l_i}S_{ph}(1+\varepsilon_r\sin\varphi)}\ , \tag{19}$$

or as a function of aspect ratio:

$$D=\sqrt[3]{\frac{1}{\lambda}\cdot\frac{2}{3\pi}\cdot\frac{1}{f}\cdot\frac{B_\delta}{A_1}\cdot\frac{1}{\xi_1}S_{ph}(1+\varepsilon_r\sin\varphi)}\ , \tag{20}$$

3. Case study on simulation of salient poles synchronous machine

In the order to prove our theoretical approach, from pervious paper section, in the current section is performed a case study for a salient poles synchronous machine. A simplified of the topology of salient poles synchronous machine is depicted on the Figure 1.

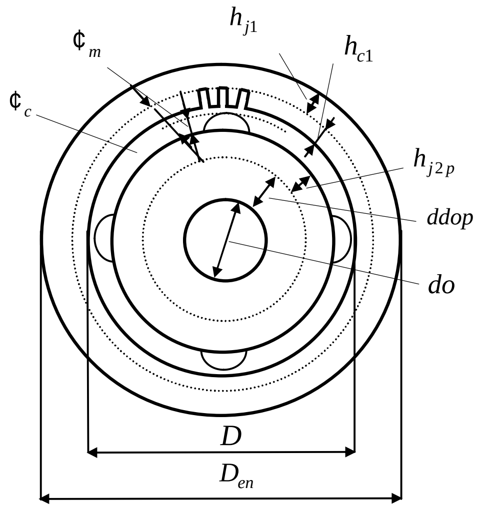

Figure 1. Topology of permanent magnet synchronous machine

In this figure are hightailed the main geometric dimensions of the machine in a cross section.

The study is based on the vector Poynting algorithm. Let be a salient pole synchronous machine design project theme with the next requirements:

- Rated power: P_n=550 [kW];

- Rated voltage: U_n=6000[V];
- Rated efficiency: η_n=0.93[ad.];
- Rated power factor: cosφ_n=0.92 [ad.];
- Pairs of poles: p=2 [ad.];
- Protection degree: IP 44;
- Insulation class: F.

For the considerate machine the efficiency, stator current and power factor have been represented in Figure 2.

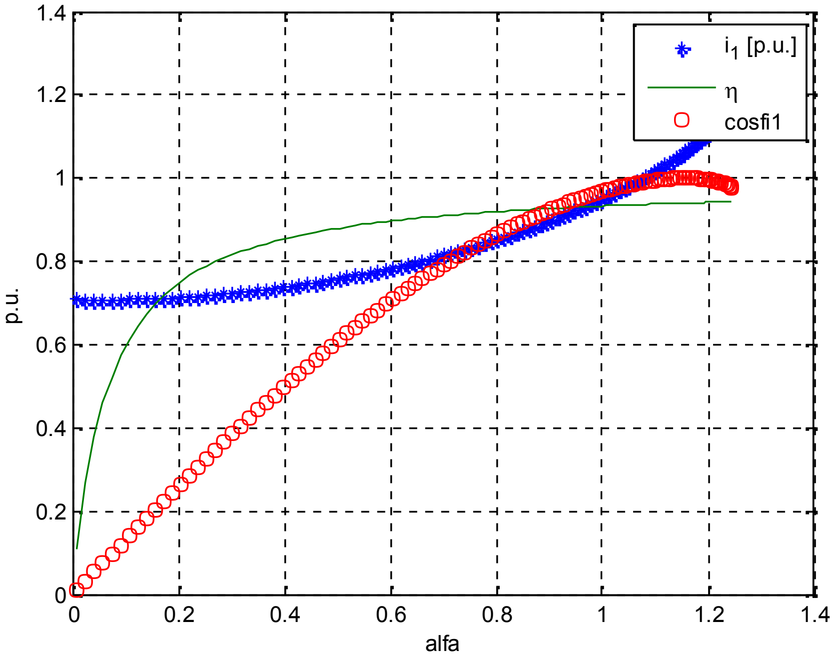

Figure 2. Efficiency, stator current and power factor

From the above figure, a slight difference may be highlighted.

The characteristics dependent on internal angle (mainly internal angle characteristic – by different approaches) were represented in the Figure 3.

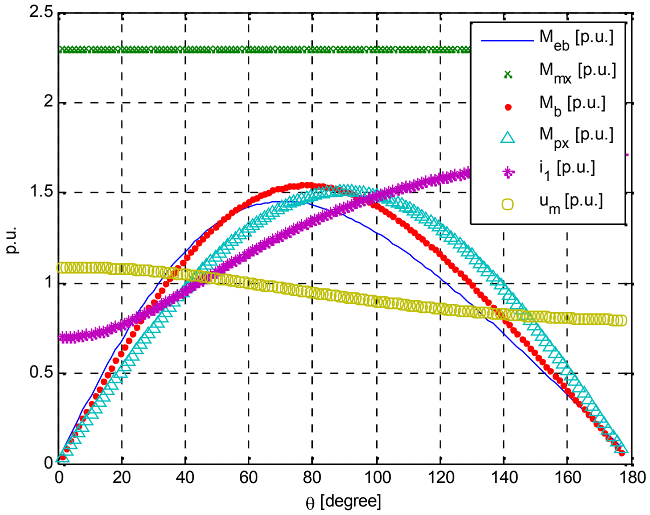

Figure 3. Characteristics dependent of internal angle

In Figure 4 where represented the main stator geometric dimensions. An important attention is paid on inner diameter curve. Thus by d_c is denoted the inner diameter computed by classical approach, while by d_a is denoted the inner diameter computed by the approach developed in the paper. From the figure may be seen that is a good concordance of inner diameter curves.

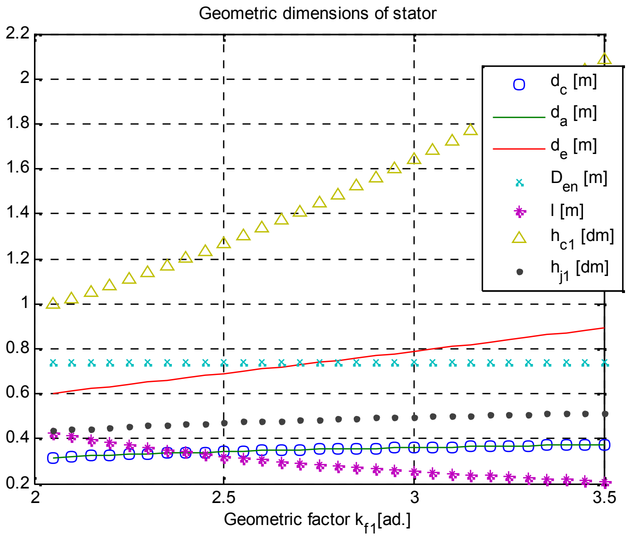

Figure 4. Stator geometric dimensions

Rotor geometric dimensions are represented as a function of geometric factor.

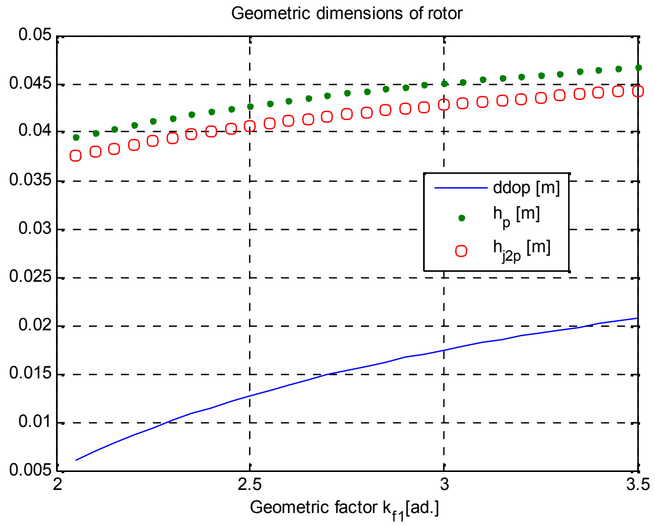

Figure 5. Rotor geometric dimensions

The main curve of cost and consumption of active materials (Fe and Cu) are represented in figure 6.

In this conditions the minimal point of total specific consumption c_{mp} or cost k_{mp} are obtained for a machine with minimal inner diameter.

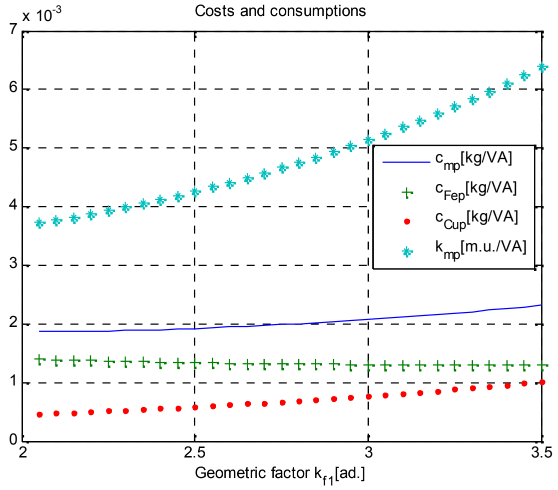

Figure 6. Specific cost and consumptions of active materials

4. Conclusion

Design of salient poles synchronous machine involves solving of a system with a large number of variables and constrains. The constraints are imposed by practical experiences of designer.

An alternative design approach must be the situation when the fault consideration is taking into account by imposing relative reactive voltage drop. In this situation an adequate relationship for inner diameter is deduced.

Numerical simulation for a concrete case of salient poles synchronous machine show a good concordance between classical approach and the one developed in this paper.

The future approach is based on the developing of other dependences relationship.

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