Consideration on new theoretical solutions of special electric machines using specialized soft of electromagnetic field numerical analysis

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Abstract. Special electric machines have a large field of application and actual requirements for electromechanical systems clam new and very performing solutions.

There are a lot of papers on this subject, but anytime is mandatory to do something else to help users to develop high level systems.

Main intention of the authors for this paper is to present a modality to analyze and to design a new solution of electric machine only through finite element method.

Actually, the users are asking for very performing electric machines, having high density torque that means to develop as higher as possible torque in a relative small volume, relative to the usual electric machines. To design such electric machines there is only one way – to use numerical methods based on finite element method.

The most part of specialists that present these aspects are working in the field of special electrical machines since more than 30 years, developing many solutions and designs for high performances special electric machines.

Key words: finite element method; special electric machine; high performances; pancake; direct drive

1. General considerations

Our purpose for this paper is to present some aspects on special electric machines – high density torque and power. More exactly, the attention will be focused brushless motors used in very accurate drive systems, high performances.

The necessity to do compact drive systems and actual world economical situation determine the manufacturers to concept special integrate drive systems, where it is found less three fundamental requirements: minimal specific weight (kg/W), high reliability and low manufacturing costs.
For this purpose has to be developed a brushless servomotor having a factionary number of slots per magnetic pole.

As the team that presents this paper had researched, had designed and had produced such kind of systems, will describe in this article the methods used in development.

2. Brushless servomotors with factionary number of slots per magnetic pole versus classic concept

In most part of applications, are using, in special electric drive systems, servomotors based on permanent magnets, high energy.

It is known the general theory of electric machines, three phase, in accordance with that we need minimum one slot per pole and phase. So, for a machine with two poles we need minimum 6 lots, only to do right winding, not to obtain high performances, but minimum minimum number of slots is 3 for two poles. To have medium performances, we need three slots per pole and phase, that is to say 18 slots for a machine with two poles. But in practice, the machines are designed with many poles, usually 6 poles or 8 poles. There are and special machines, having more than 40 poles. On this way, we need from 48 slots to 72 slots, or even to 360 slots.

If we are based only on classic theories and methods, sometimes it is impossible, or very difficult to design a special servomotor. Setting out from the above, to be on market and to be a competitive partner, a producer must search for and find no conventional solutions. The general idea for this action is to use any actual acknowledgements, but to create new theories and methods, that are viability in certain restrictive conditions for the main electric, energetic and mechanical parameters that the application imposes to the electric drive system, respectively to each component of system.

Our team has now many no conventional solutions for special brushless servomotors, from that some aspects will be presented more detailed below.

First of all, please find below a schema to explain operating principle of a servomotor controlled by Hall sensors.

Fig. 1 Schema to explain operating principle of a servomotor controlled by Hall sensors.

The example is for a two pole pair servomotor and is starting from the most simplified solution for a classical motor: 3 slots for 2 poles. Even it is not considered as normal and classic winding, this solution is not enough good when a very high density of torque (torque versus total weight or total volume) is required. In this situation, our team have developed a stronger solution, able to do a very high torque density: 3 slots for 4 poles. This solution is basic solution, because for certain application can be used a multiplication factory, from two to one hundred, depending of: density of torque; dimensions; accuracy etc. The example from below is referring to a mathematic model for numerical analysis of electromagnetic field based on 6 slots and 8 poles. [1,2,3]

The servomotor can be considered as a certain number of complex electric and magnetic circuits (having resistive and inductive elements sitting in a magnetic field. [4,5,6]

Using an adequate numerical analysis of electromagnetic field method can be computed any interested magnitudes (torque, back e.m.f., density flux, speed, magnetic potential etc.). By using of other mathematic methods, can be pre-determined some of these magnitudes, to be possible to do a proper model for numerical analysis of electromagnetic field method. The following example is to pre-determine back e.m.f. It is considered as referential one of windings, for that phase shift is considered zero degrees. The back e.m.f. diagram is as follows:

\[
e(\alpha) = \frac{5}{\pi} \cdot \alpha \cdot E_{\text{max}},
\]

for \( \alpha \in \left(0; \frac{\pi}{5}\right) + 2k\pi \)
Taking into consideration that phase shift between any two phases is $2\pi/3$ electrical degrees, can be expressed the formula for the other two phase back e.m.f.

$e_1(\alpha) = e_1(\alpha)$

$e_2(\alpha) = e_1\left(\alpha - \frac{2\pi}{3}\right)$

$e_3(\alpha) = e_1\left(\alpha - \frac{4\pi}{3}\right)$

The above relations are used to express operating electric circuit relations (simplified forms, used to pre-determinate parameters):

$$u_1 = R_1 \cdot i_1 + \frac{d}{dt}(l_1 \cdot i_1) - N_1 \frac{d}{dt} \varphi_{e1}$$

$$u_2 = R_2 \cdot i_2 + \frac{d}{dt}(l_2 \cdot i_2) - N_2 \frac{d}{dt} \varphi_{e2}$$

$$u_3 = R_3 \cdot i_3 + \frac{d}{dt}(l_3 \cdot i_3) - N_3 \frac{d}{dt} \varphi_{e3}$$

To characterize a dynamic operating regime, it has to be added and an equation of dynamic balance of torques:

$$J \cdot \frac{d\Omega}{dt} = m - m_f - m_s$$

or:

$$\frac{d}{dt} \Omega = \frac{1}{J} \left(m - m_f - m_s\right)$$

The notations adopted for electric parameters from relations (1) – (11) are the classical one from general theory of electric machines, those in transitional regime.

3. Modeling and results using finite element method

Fig.3
Excitation field as is the result of numerical analysis of field- finite element method (Radial model for special electric machine in the configuration of 6 slots and 8 poles) [7,8,9]
Fig. 4
Winding field as the result of numerical analysis of field - finite element method (Radial model for special electric machine in the configuration of 6 slots and 8 poles)

Fig. 5
Superposition between excitation field and winding field as the result of numerical analysis of field - finite element method (Radial model for special electric machine in the configuration of 6 slots and 8 poles)

Fig. 6
Normal excitation magnetic flux density diagram, as the result of numerical analysis of field - finite element method (Radial model for special electric machine in the configuration of 6 slots and 8 poles)

Fig. 7
Normal winding magnetic flux density diagram as the result of numerical analysis of field - finite element method (Radial model for special electric machine in the configuration of 6 slots and 8 poles)

Fig. 8
Normal component of superposition between excitation field and winding field as the result of numerical analysis of field - finite element method (Radial model for special electric machine in the configuration of 6 slots and 8 poles)
Fig. 9 Diagram of magnetic flux on A, B and C phases
(Radial model for special electric machine in the configuration of 6 slots and 8 poles)

Fig. 10 Diagram of back e.m.f. and supply current on A, B and C phases
(Radial model for special electric machine in the configuration of 6 slots and 8 poles)

Fig. 11 Module of excitation magnetic flux density diagram, as the result of numerical analysis of field - finite element method (Radial model for special electric machine in the configuration of 6 slots and 8 poles)

Fig. 12 Module of winding magnetic flux density diagram as the result of numerical analysis of field - finite element method (Radial model for special electric machine in the configuration of 6 slots and 8 poles)

Fig. 13 Module of superposition between excitation field and winding field as the result of numerical analysis of field - finite element method (Radial model for special electric machine in the configuration of 6 slots and 8 poles)

Fig. 14 Vector potential of excitation magnetic field diagram, as the result of numerical analysis of field - finite element method (Radial model for special electric machine in the configuration of 6 slots and 8 poles)
4. Conclusion

The parameters represented in diagrams from fig. 6 to 16, obtained using finite element method, were experimental proved through direct tests on the physical prototype manufactured designing the motor according with the results of the model.

Method rightness was highlighted by experimental measurements that validated the theoretical results obtained using this method.

Configuration 3 slots and 4 poles seems apparently can not be used to develop and to design an electric machine. There is not a classic method to demonstrate certainly the possibility to use this configuration. Only numerical analysis of electromagnetic field, using finite element method, offers any elements, clearly, demonstrating the power of this method. Based on numerical analysis method results, it was designed and manufactured such kind of electric machine and test results on this machine have shown that it is one of the most powerful solutions.

References:


