# Steady-state Analysis of Salient Poles Synchronous Motor with Damper Based on Determination of the Magnetic Field Distribution

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**Abstract**— This paper deals with steady-state analysis of the magnetic field by using Finite Element Method (FEM) in salient poles synchronous motor with damper (SPSMD). The knowledge of electromechanical characteristics is very important in performance analysis of electrical machines, in general. In this paper it presents a methodology for numerical calculation of electromechanical quantities, starting with the determination of the magnetic field distribution and numerical computation of the electromechanical characteristics of SPSMD by using FEM.

## 1. INTRODUCTION

The Finite Element Method is very efficient tool for an electromagnetic field solution. The application of this method on the salient poles synchronous motor with damper (SPSMD) is described in this paper. This type of synchronous motor (SM) with damper ring (cage winding) on the rotor can be started by using asynchronous start without any additional technical starting equipment that is usually required for SM.

The FEM (Finite Element Method) in the recent years has been found as a very attractive method in the design and analysis of various types of electromechanical devices. By using this method almost all the necessary electric and magnetic quantities are determined for this type of electrical machine. In this paper it presents the methodology of using the FEM for computation of electromechanical characteristics.

For complex configurations as those in electrical machines, the FEM is powerful numerical method for solution of electromagnetic field problems. By the application of this method in the whole discredited domain of the machine under consideration, an important contribution to the magnetic field computation could be done. An optimal design of electrical machines requires the accurate calculation of the magnetic field distribution in the different cross-sections. This enables an accurate determination both the electromagnetic and electromechanical characteristics of the motor. The accuracy of the electromechanical characteristics depends on the precise calculations of electromagnetic field in the electrical machine.

# 2. MATHEMATICAL AND GEOMETRICAL MODEL OF THE MACHINE

CAD model of the machine is an essential basis for implementation of geometrical structure of the motor into the FEM calculation. For applied calculation of electrical machines, the appropriate geometrical CAD model of the machine and mathematical model are necessary. By precise determination of all coordinates of the structure, the 3D CAD model is created as is shown of Fig. 1.

The calculation of the magnetic field distribution in the SPSMD is started from the system of the Maxwell's Equations (1) and (2), which describes the magnetic field in closed and bounded systems. The main value that is calculated with FEM in entire structure of the machine is the magnetic vector potential A, expressed with the Maxwell equation:

$$B = rotA \tag{1}$$

as an auxiliary quantity. Knowing that

$$divB = 0 \tag{2}$$

the distribution of the magnetic field is expressed by the following non-linear differential equation known as Poisson's equation:

$$\frac{\partial^2 A}{\partial^2 x} + \frac{\partial^2 A}{\partial^2 y} + \frac{\partial^2 A}{\partial^2 z} = \mu J \tag{3}$$

where the  $\mu$  is magnetic permeability as function of magnetic flux density  $B(\mu = f(B))$ .

In the special case, when there are no current sources in the domain under consideration (J = 0), the right side term of Equation (3) is zero, and the equation is recognized as Laplace's.

To perform magnetic field computation with FEM, entire structural entity of the machine must be defined as mathematical model consisted of Maxwell's, Laplace's and Poisson's equations.



Figure 1: 3D CAD model of SPSMD.

Figure 2: Cross-section of SPSMD.

### **3. FEM APPLICATION**

As most suitable software for FEM calculation was ANSYS version 5.6 selected. Besides that this software has general application for FEM calculation like mechanical, structural integrity or thermal dissipation, it is quite convenient for computation of electrical and magnetic field dissipation in electrical machines.

In this software appropriate algorithm for calculation of all relevant characteristics of electrical machines is defined. The proposed algorithm is in this paper applied on the salient poles synchronous motor with damper (SPSMD), with rated data: 2.5 KW, 240 V, 1500 rpm, and delta stator winding connection. The SPSMD is heterogeneous, non-linear domain with particular B-H characteristics of magnetic core in stator and rotor, and with prescribed boundary conditions. Therefore, the Equation (3) in developed form, is the variable coefficient type, and can be solved by the numerical methods only. To realize this task, it is necessary that the proper geometrical CAD and mathematical modeling of the motor to be carried out. Therefore the geometrical cross-section of the motor is created from the CAD model which is presented in Fig. 2.

The beginning of the FEM calculations, it is requested to generate a correspondent mesh of finite elements. ANSYS is software that has option for generation of the most optimal finite element mesh



Figure 3: Finite elements mesh.



Figure 4: Middle line of the air-gap in SPSMD.

of the complex structures like SPSMD. The mesh must be dense enough for precise calculation and also optimal for not consuming a lot of the computational time.

After several attempts for optimal finite element mesh, the most appropriate mesh is generated. This mesh provides calculation with high precision and at reasonable computational time. In this case, the most convenient mesh type is chosen to be triangular, with 8195 nodes and 16344 finite elements, and is presented in Fig. 3:

The calculations are carried out as magneto-static case, at arbitrary rotor position. Computation has been performed for rated values of the currents in stator and rotor (excitation) windings in synchronous regime (damper winding is not active). Magnetic field distribution is shown (Fig. 5) for three characteristic cases:

a) When only the rotor winding is excited (the excitation winding) with nominal excitation current;

b) When only the stator winding is exited (armature winding) with nominal armature current;

c) And when the both stator and rotor winding are excited with nominal currents.

The rotor excitation winding is performed as concentrated over the pole body. The rated excitation current is  $I_f = 5.5$  [A] DC. The magnetic field distribution when only the rotor winding is energized at rated current is presented in Fig. 5(a).

In the stator slots, there are placed three phase distributed windings, in delta connection, and supplied by three-phase voltage source 240 [V] AC, with the rated current 4.63 [A]. The magnetic field distribution when only the stator windings are energized is presented in Fig. 5(b). (The current space vector lies in the quadrature axis).

The computations with FEM continue when both motor windings are energized at rated currents. The angle between the axes of the two previously excited fields is equal 90 degrees electrical (45 degrees mechanical in 4 pole machine). The Magnetic field distribution when both windings are energized is presented in Fig. 4(b).

## 4. MAGNETIC FLUX DENSITY

Besides the magnetic field distribution, the newest software calculation methods give opportunity for direct calculation of graphical presentation of all relevant electrical and magnetic quantities. Relation between the magnetic flux density B and the magnetic vector potential A is defined previously by the Equation (1). The values of the magnetic vector potential and its components in every node of the investigated domain of the salient pole synchronous motor with damper have been calculated as output results from the FEM. By using the procedure for numerical differentiation, over the Equation (1) in the developed form, the distribution of the magnetic flux density at the middle line of the air gap in the motor can be determinate (Fig. 6). The middle line of the air-gap in Salient Poles Synchronous Motor with Damper is shown on Fig. 4.

The curves of the magnetic flux density B, for the three different current flows, (previously defined with corresponding explanation concerning Fig. 5) are presented in the same manner in Fig. 6, respectively. For better understanding of the charts, the slotted segments of the stator magnetic core as well as the rotor, including damper winding slots, are presented along one pole pitch, i.e., for an angle  $\alpha$  of 180 degrees electrical (90 degrees mechanical).



Figure 5: Magnetic field distribution for three cases of stator and rotor excitation.



Figure 6: Distribution of the magnetic flux density B in the air gap along the one pole pitch.

Main flux  $\Phi$  can be determined from the distribution of the magnetic vector potential A based on the field theory by using numerical integration of the magnetic vector potential

$$\Phi = \int_{\Sigma} B \cdot ds = \int_{\Sigma} rot A \cdot ds = \oint_{C} A dr$$
(4)

hence,

$$\Psi = w \cdot \Phi \cdot l \tag{5}$$

The FEM calculated characteristic of the air gap flux  $\Psi$  per pole in function of the rotor excitation current  $I_f$  at given rotor angular position is given on Fig. 7:



Figure 7: Air gap flux  $\Psi$  characteristic of the motor obtained by FEM.

#### 5. CONCLUSIONS

In this paper, the methodology for the magnetic field calculation and analysis of electromagnetic characteristics of the salient poles synchronous motor with damper, by using the finite element method are presented. The calculations were carried out at given rotor position against the stator reference axis and for different excitation currents, i.e., the current in the stator windings only, in the excitation coil only and in both windings. The currents have the nominal value.

The results of the field computations are used for calculations of magnetic flux density B and air gap flux  $\Psi$  along the air gap. They are presented on the charts. All this characteristics can be used for a complex analysis of the motor behavior under different working conditions.

The extension of the work leads to the analysis of electromagnetic characteristics and determination of the parameters of the motor in different working conditions. Upon that, the main inductance in the air-gap of the salient poles synchronous motor with damper could be computed. The most interesting issue is analysis of the damper winding role during the starting performance of the synchronous motor.

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