

SIMULATION OF A PMS MOTOR BY THE HELP OF TWO DIFFERENT DESIGN SOFTWARE TOOLS

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Abstract: *The paper presents simulation results of a two dimensional Permanent Magnet Synchronous Motor (PMSM or PMS motor), which were calculated by the help two different Finite Element based design software tools. The first one is the Infolytica MotorSolve which the model is calculated by the help an automated finite element solver. The second one is the COMSOL Multiphysics, which is a finite element based software for modelling and simulation of any physics-based system The simulation results were compared with each other focusing on the torque, the magnetic flux density and the magnetic potential of the PMS motor.*

Key words: *Permanent Magnet Synchronous Motor, Finite Element Method, Infolytica MotorSolve, COMSOL Multiphysics.*

1. Introduction

The computer-aided design is one of the most important parts of the electric motor development. The development of the electric machines is a research task at the *Széchenyi István University*. Our part of this development is to design a PMSM [7] family and calculate their parameters by the help of finite element method [1-4], [5], [6], [8]. These developed motors will be applied with bicycles and smaller motors.

The main essential of the PMS motor development is to reduce the weight and the size of the motor but the torque and losses of the motor not to change. The aim of the development of the engine was to design PMS motor which in low-speed case has about 10 Nm torque. Figure 1

shows the scheme of the developed permanent magnet synchronous motor which is designed by the help with Infolytica MotorSolve [11].

This PMS motor was developed moreover it is under construction. The outer diameter of the motor is 205 mm, the inner diameter of the motor is 187 mm. The rotor type is exterior and it has 28 Neodymium magnets. The stator has 36 slots with three phase double layers windings. The type of the rotor and the stator material is M19. The maximum power of the PMSM is 1200 W, as well as the maximum rotational speed of the motor is 1000 rpm. In this case the delivered torque is about -64 Nm. When the rotational speed is about 100 rpm then the delivered torque is 11.8 Nm and the motor has 200 W powers.

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The aim of this work is to do a comparative analyse between the MotorSolve simulation results and the results using COMSOL [9], [10] environment, focusing the torque, the magnetic potential and the magnetic flux density of the developed permanent magnet synchronous motor.

2. Simulation of the PMS Motor with Infolytica MotorSolve

The computer-aided design is usually the first parts of the electric motor development. There are more ways for the electric motor design, as well. For instance, the Infolytica MotorSolve is electric motor design software

for brushless DC motor. In this case the motor design is obtained applying different templates. By the help of the change of the sizes of the schemes can have been designed the electric motor. Furthermore, Figure 2 shows some templates of the magnets of the rotor.

The parameters of the electric motor are calculated by the help of an automated-FEA (Finite Element Analysis) solver, for example torque, losses, power, and the others. The disadvantage of the program is that the motor designing is possible by the help only with some defined templates, is that there is no way to design a motor with optional geometry. The easy applicability is the advantage of this program.

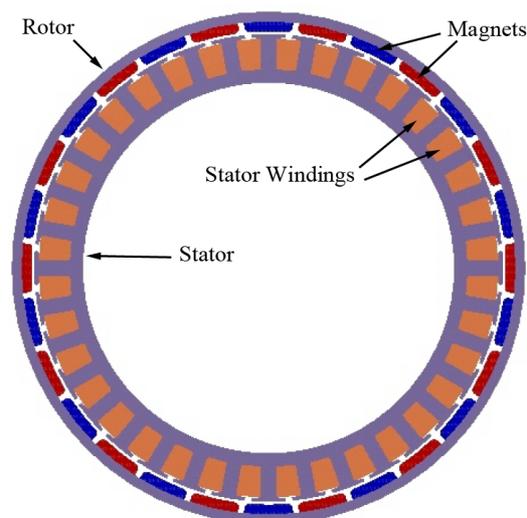


Fig. 1. *The scheme of the PMS motor*



Fig. 2. *Templates for the rotor magnets*



Fig. 3. *Templates for the stator slot*

3. Simulation of the PMS Motor with COMSOL Multiphysics

The COMSOL Multiphysics is a Finite Element Based software for the modelling and simulation of any physics-based system.

In this case calculations on optional geometry have been able to make with the program; however the preprocessing is more difficult for instance to draw the model, or to set the boundary conditions. Figure 4 shows some possibilities of settings.

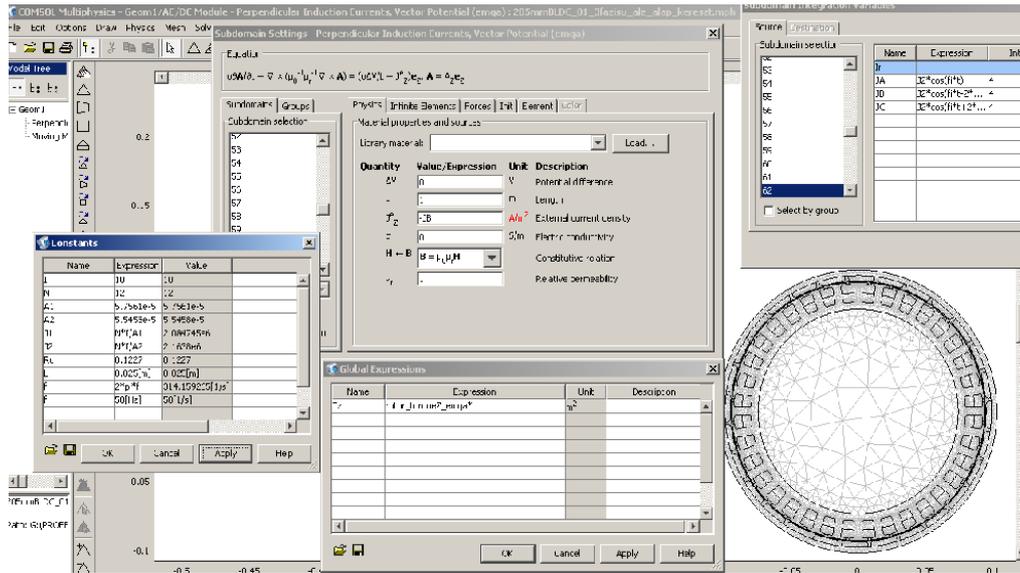


Fig. 4. The graphical user interface of COMSOL

The motor has been modelled as a static magnetic field problem, where the following Maxwell's equations [1-6], [8] are used:

$$\nabla \times \mathbf{H} = \mathbf{J}_0, \text{ in } \Omega_0 \cup \Omega_m, \quad (1)$$

and

$$\nabla \cdot \mathbf{B} = 0, \text{ in } \Omega_0 \cup \Omega_m. \quad (2)$$

Here \mathbf{H} is the magnetic field intensity, \mathbf{J}_0 is the source current density, \mathbf{B} is the magnetic flux density. The \mathbf{H} magnetic field intensity can be expressed as:

$$\mathbf{H} = \begin{cases} v_0 \mathbf{B}, & \text{in air, } \Omega_0, \\ v_0 v_r \mathbf{B}, & \text{in magnetic material, } \Omega_m. \end{cases} \quad (3)$$

Here v_0 is the reluctivity of vacuum and v_r is the relative reluctivity. The air region

is denoted by Ω_0 and the magnetically region is denoted by Ω_m . The magnetic flux density can be expressed as:

$$\mathbf{B} = \nabla \times \mathbf{A}, \quad (4)$$

where \mathbf{A} is the magnetic vector potential [1-6], [8]. This expression satisfied (2), because of the identity $\nabla \cdot \nabla \times \mathbf{v} \equiv 0$ for any vector function $\mathbf{v} = \mathbf{v}(\mathbf{r})$.

Substituting (4) to the (1) and (2) and using the constitutive relations in (3) the following partial differential equations can be obtained:

$$\nabla \times (v_0 \nabla \times \mathbf{A}) = \mathbf{J}_0, \text{ in } \Omega_0, \quad (5)$$

and

$$\nabla \times (v_0 v_r \nabla \times \mathbf{A}) = \mathbf{J}_0, \text{ in } \Omega_m. \quad (6)$$

The divergence of the magnetic vector potential can be selected according to Coulomb gauge:

$$\nabla \cdot \mathbf{A} = 0, \quad (7)$$

which is satisfied automatically in two dimensional problems [1-6], [8]. In two dimensional case the source current density has only z component, moreover the magnetic field intensity vector and the magnetic flux density vector have x and y components:

$$\mathbf{J}_0 = J_{0,z}(x, y) \mathbf{e}_z, \quad (8)$$

$$\mathbf{H} = H_x(x, y) \mathbf{e}_x + H_y(x, y) \mathbf{e}_y, \quad (9)$$

$$\mathbf{B} = B_x(x, y) \mathbf{e}_x + B_y(x, y) \mathbf{e}_y. \quad (10)$$

The magnetic vector potential has only z component:

$$\mathbf{A}_z = A_z(x, y) \mathbf{e}_z, \quad (11)$$

and the x and y components of the magnetic

flux density can be described as:

$$\mathbf{B}_x(x, y) = \frac{\partial \mathbf{A}_z}{\partial y}, \quad (12)$$

and

$$\mathbf{B}_y(x, y) = -\frac{\partial \mathbf{A}_z}{\partial x}. \quad (13)$$

The boundary conditions of a two dimensional static magnetic field problem can be formulated as:

$$(\nu \nabla \times \mathbf{A}) \times \mathbf{n} = \mathbf{0}, \text{ on } \Gamma_H, \quad (14)$$

and

$$\mathbf{n} \times \mathbf{A} = \mathbf{0}, \text{ on } \Gamma_B. \quad (15)$$

The partial differential Equation (5) and (6) and the Neumann type boundary condition (14) can be summarized in the following weighted residual formulation [1], [2], [6]:

$$\int_{\Omega} \mathbf{W}_k \cdot [\nabla \times (\nu_o \nabla \times \mathbf{A})] d\Omega + \int_{\Gamma} \mathbf{W}_k \cdot [(\nu_o \nabla \times \mathbf{A}) \times \mathbf{n}] d\Gamma = \int_{\Omega} \mathbf{W}_k \cdot \mathbf{J}_0 d\Omega, \quad (16)$$

where:

$$\mathbf{n} \times \mathbf{W}_k = \mathbf{0}, \text{ on } \Gamma_B, \quad (17)$$

and \mathbf{W}_k is a weighting function as well as the approximation function of the unknown vector potential and $k = 1, \dots, J$. The value of ν_o is equal to ν_0 in the air region Ω_0 , or it is equal to $\nu_0 \nu_r$ in the magnetic material

region Ω_m .

The second order derivatives in (16) can be reduced by using the following identity:

$$\nabla \cdot (\mathbf{u} \times \mathbf{v}) = \mathbf{v} \cdot \nabla \times \mathbf{u} - \mathbf{u} \cdot \nabla \times \mathbf{v}. \quad (18)$$

After using the identity (18) and the Stokes' theorem, the following equation can be obtained:

$$\int_{\Omega} [\nu_o (\nabla \times \mathbf{W}_k) \cdot (\nabla \times \mathbf{A})] d\Omega + \int_{\Gamma_H \cup \Gamma_B} [(\nu_o \nabla \times \mathbf{A}) \times \mathbf{W}] \cdot \mathbf{n} d\Gamma + \int_{\Gamma_H} \mathbf{W}_k \cdot [(\nu_o \nabla \times \mathbf{A})] \times \mathbf{n} d\Gamma = \int_{\Omega} \mathbf{W}_k \cdot \mathbf{J}_0 d\Omega. \quad (19)$$

After satisfying the boundary conditions, the following weak formulation can be given:

$$\begin{aligned} \int_{\Omega} [v_o (\nabla \times \mathbf{W}_k) \cdot (\nabla \times \mathbf{A})] d\Omega \\ = \int_{\Omega} \mathbf{W}_k \cdot \mathbf{J}_0 d\Omega, \end{aligned} \quad (20)$$

where $k = 1, \dots, J$.

The problem has been simulated by the help of the weak formulation (22) and the boundary conditions (14) and (15).

The presented PMS motor was designed by Infolytica MotorSolve. The designed geometry was imported to the COMSOL environment. The aim was to reproduce the simulation results of the MotorSolve calculation in COMSOL environment focusing the torque and the magnetic field results of the motor with the maximum rotational speed, which is 1000 rpm.

4. Comparison of the Simulation Results

In this work Infolytica MotorSolve simulation results were compared with COMSOL Multiphysics simulation results focusing the magnetic potential, the magnetic flux density and the torque of the PMSM in the case of 1000 rpm rotational speed.

Figure 5 shows the simulation results of the magnetic potential of the PMSM which was calculated with Infolytica MotorSolve.

In this case the magnitude of the magnetic potential is from $-8.48 \cdot 10^{-6}$ Wb/mm to $8.48 \cdot 10^{-6}$ Wb/mm.

Figure 6 shows the simulation results of the magnetic potential of the PMSM which was calculated by the help of COMSOL Multiphysics.

In this case the magnitude of the magnetic potential is from $-8.39 \cdot 10^{-6}$ Wb/mm to $8.38 \cdot 10^{-6}$ Wb/mm.

The simulation results of the magnetic potential of the PMSM were compared along the same line as well.

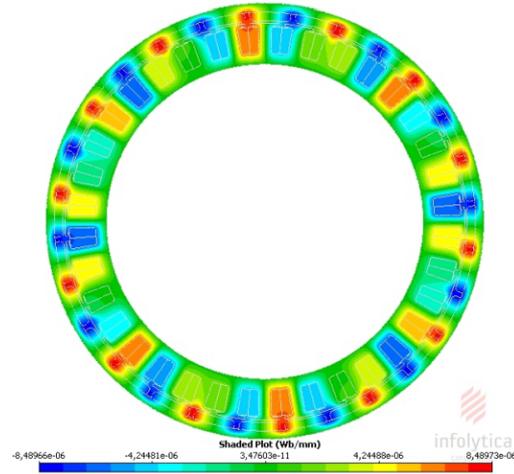


Fig. 5. The magnetic potential calculated by Infolytica MotorSolve

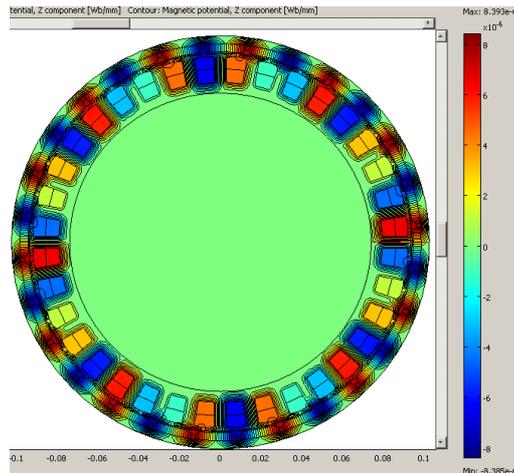


Fig. 6. The magnetic potential calculated with COMSOL Multiphysics

Figure 7 shows the simulation result of the magnetic potential calculated with the Infolytica MotorSolve.

Figure 8 shows the simulation result of the magnetic potential by the help of COMSOL Multiphysics. Comparing the simulation results which were calculated two different design software tools they are similar in the case of 1000 rpm rotational speed.

Figure 9 shows the simulation results of the magnetic flux density of the PMSM which was calculated with Infolytica MotorSolve.



Fig. 7. *The magnetic potential simulated with Infolytica MotorSolve*

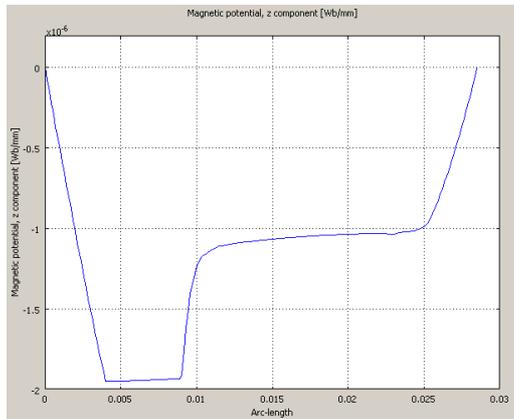


Fig. 8. *The magnetic potential simulated with COMSOL Multiphysics*

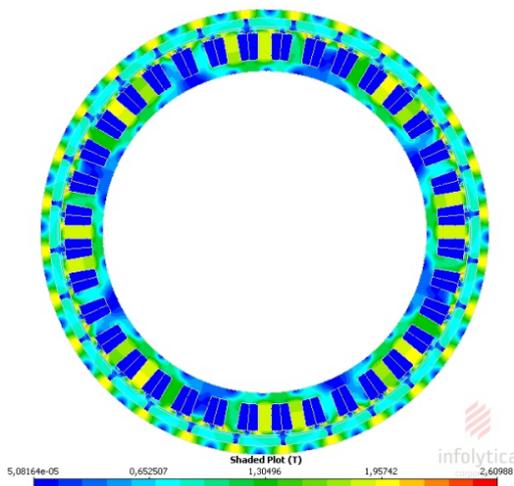


Fig. 9. *The magnetic flux density calculated with Infolytica MotorSolve*

In this case the magnitude of the magnetic flux density is from $5.08 \cdot 10^{-5}$ T to 2.61 T.

Figure 10 shows the simulation results of the magnetic flux density of the PMSM which was calculated by the help of COMSOL Multiphysics. In this case the magnitude of the magnetic flux density is from $9.00 \cdot 10^{-7}$ T to 2.796 T.

The simulation results of the magnetic flux density of the PMSM were compared along the same line as well. Figure 11 shows the simulation result of the magnetic flux density calculated with the Infolytica MotorSolve.

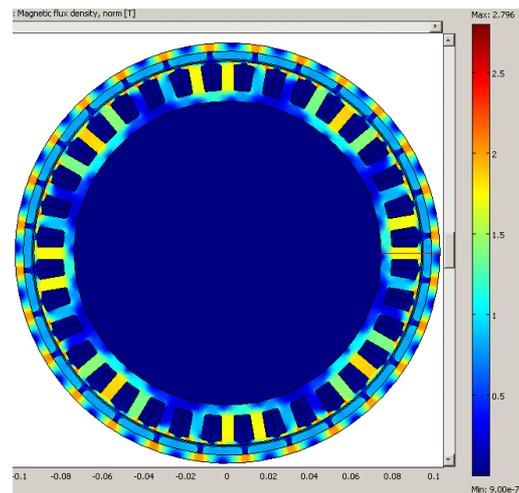


Fig. 10. *The magnetic flux density calculated with COMSOL Multiphysics*

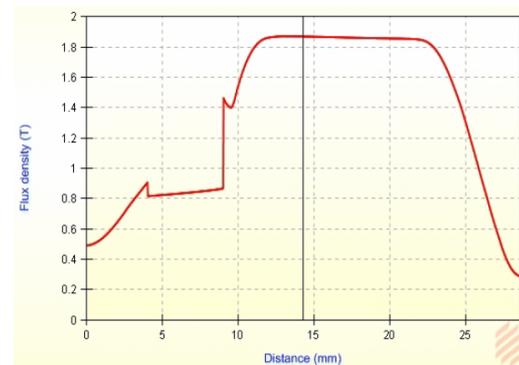


Fig. 11. *The magnetic flux density simulated with Infolytica MotorSolve*

Figure 12 shows the simulation result of the magnetic flux density by the help of COMSOL Multiphysics.

Comparing the simulation results which were calculated two different design software tools they are similar in the case of 1000 rpm rotational speed.

The simulation results of the PMSM were compared with each other focusing the delivered torque in the case of 1000 rpm rotational speed, as well.

Calculating the delivered torque with Infolytica MotorSolve is -68.4 Nm and with COMSOL Multiphysics is -67.25 Nm in the case of maximal rotational speed.

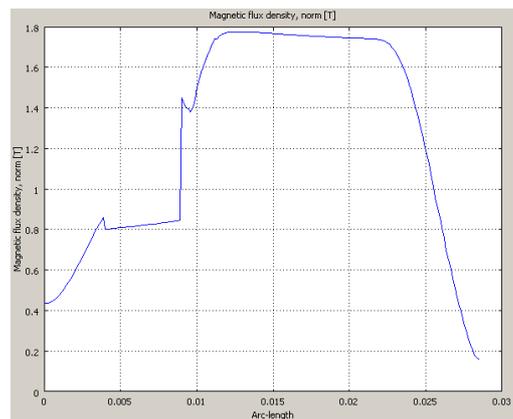


Fig. 12. *The magnetic flux density simulated with COMSOL Multiphysics*

5. Conclusion, Future Work

A developed PMSM was simulated with two different design software tools. The aim of the work is to reproduce the simulation results of the Infolytica MotorSolve in COMSOL Multiphysics environment. The paper presents comparisons of the simulation results with two different design software tools for the PMS motor focusing on the torque, the magnetic flux density and the magnetic potential. Comparing the simulation results are similar to each other which means the two different design software tools are

convenient to design PMS motors.

The main advantage of the Infolytica MotorSolve is that the development of the motor is easier than with COMSOL Multiphysics. Disadvantage of the first program is that the motor design is possible by the help with only some predefined templates. The main advantage of the COMSOL Multiphysics is the possibility of designing the PMS motors with optional geometries; however the method of this development is more difficult with COMSOL Multiphysics.

The future work is to improve the COMSOL model calculating in the case of low-speed the parameters of the developed PMS motor, for instance torque, losses etc.

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