

Simulation of a PMSM Motor in COMSOL Environment

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Abstract: The paper presents simulation results of a two-dimensional Permanent Magnet Synchronous Motor (PMSM, PMS motor), which were calculated by the help of the Infolytica MotorSolve and of the COMSOL Multiphysics, as well. The simulation results were compared with each other focusing on the torque, the magnetic flux density and the magnetic potential of the PMSM motor.

Keywords: *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 engine development. The development of the electric motor is at the Széchenyi István University, as well. My part of this development is to design a PMSM [1] family and calculate their parameters by the help of finite element method [2-8]. These developed motors will be applied with bicycles and smaller motors.

The main essential of the PMSM development is to reduce the weight and the size of the engine but the torque and losses of the motor not to change. The aim of the development of the engine was to design PMSM which in low-speed case has about 10Nm torque. The Figure 1. shows the scheme of the developed permanent magnet synchronous motor which is designed by the help with Infolytica MotorSolve [9].

This motor was developed moreover it is under construction. The outer diameter of the motor is 205 mm furthermore 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 100RPM then the delivered torque is 11.8 Nm and the motor has 200 W power.

The aim of this work is to reproduce the MotorSolve simulation results in the COMSOL [10-11] environment focusing the torque, the magnetic potential and the

magnetic flux density of the developed permanent magnet synchronous motor in the case of 1000 RPM rotational speed.

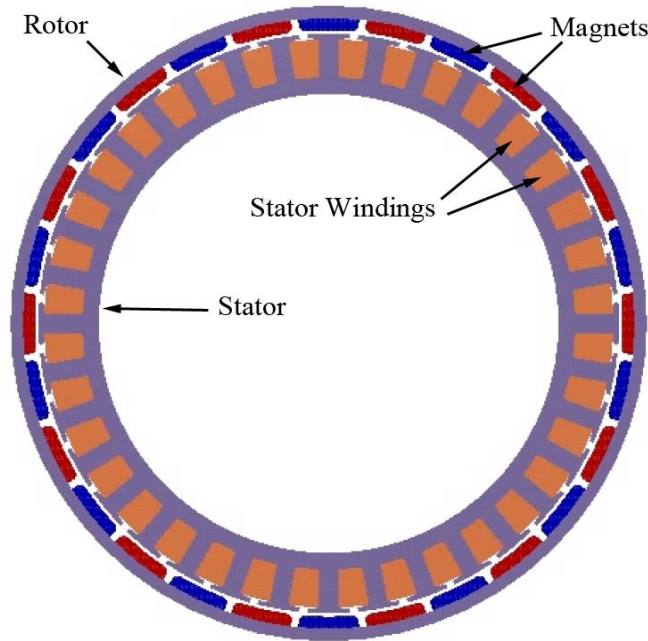


Figure 1. The scheme of the PMS motor

2. Simulation of the PMSM with Infolytica MotorSolve

The computer-aided design is usually the first parts of the electric engine development. There are more ways for the electric motor design, as well. For instance the Infolytica MotorSolve is an electric motor design software for brushless DC motor. In this case the motor design is made by the help with different templates. By the help of the change of the sizes of the schemes can have been designed the electric motor furthermore the Figure 2. shows some templates of the magnets of the rotor.



Figure 2. Templates for the rotor magnets



Figure 3. Templates for the stator slots

The Figure 3. shows some templates of the slots of the stator.

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 that the motor designing is possible by the help only with some defined templates, which means that there is no way to design a motor with optional geometry. The easy applicability is the advantage of the program.

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. The Figure 4. shows some possibility of settings.

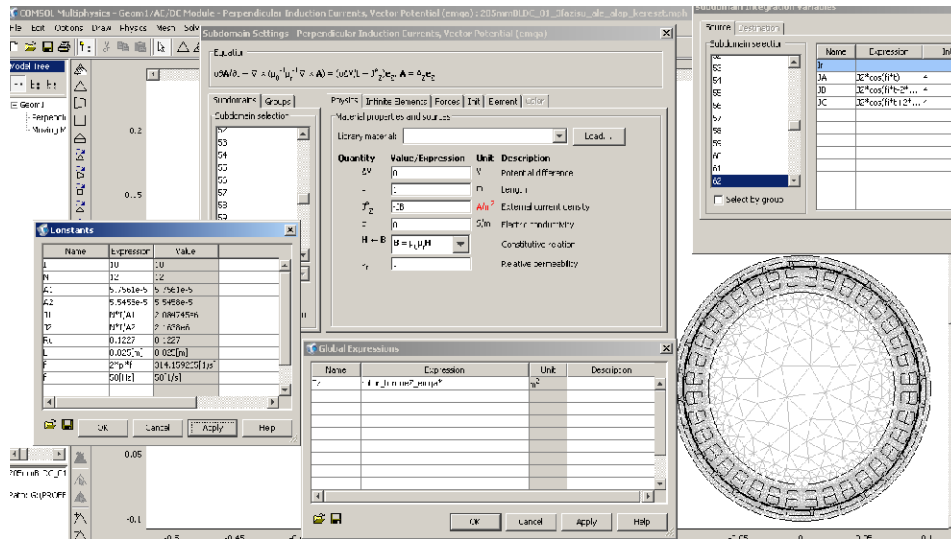


Figure 4. The graphical user interface of COMSOL

The simulated model has been modelled as a static magnetic field problem, where the following Maxwell's equations [2-8] can be used

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

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

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

$$\mathbf{H} = \begin{cases} \nu_0 \mathbf{B}, & \text{in air, } \Omega_0, \\ \nu_r \nu_r \mathbf{B}, & \text{in magnetic material, } \Omega_m. \end{cases} \tag{3}$$

Here ν_0 is the reluctivity of vacuum and ν_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 [2, 8]. This expression is 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 (3) constitutive relations can be obtained by the following partial differential equations:

$$\nabla \times (\nu_0 \nabla \times \mathbf{A}) = \mathbf{J}_0, \text{ in } \Omega_0, \quad (5)$$

and

$$\nabla \times (\nu_0 \nu_r \nabla \times \mathbf{A}) = \mathbf{J}_0, \text{ in } \Omega_m. \quad (6)$$

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 [2, 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

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

and

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

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 problem was calculated by the help with the (5) partial differential equation and the (13) and (14) boundary conditions.

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.

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

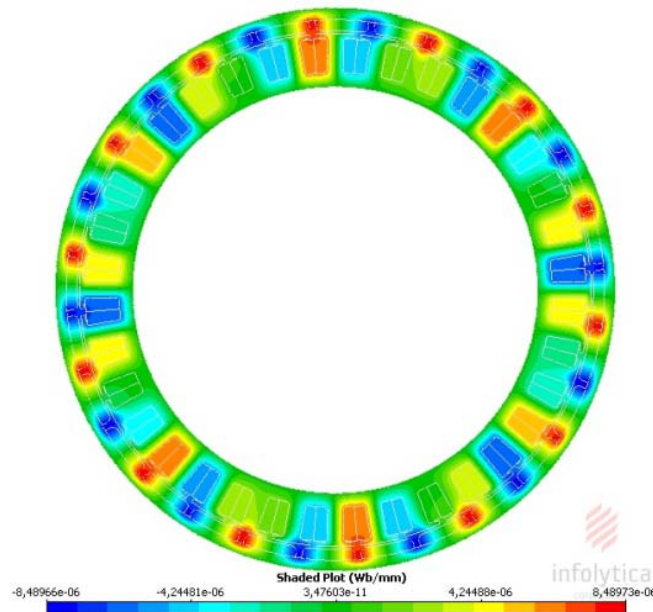


Figure 5. The magnetic potential calculated by Infolytica MotorSolve

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

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

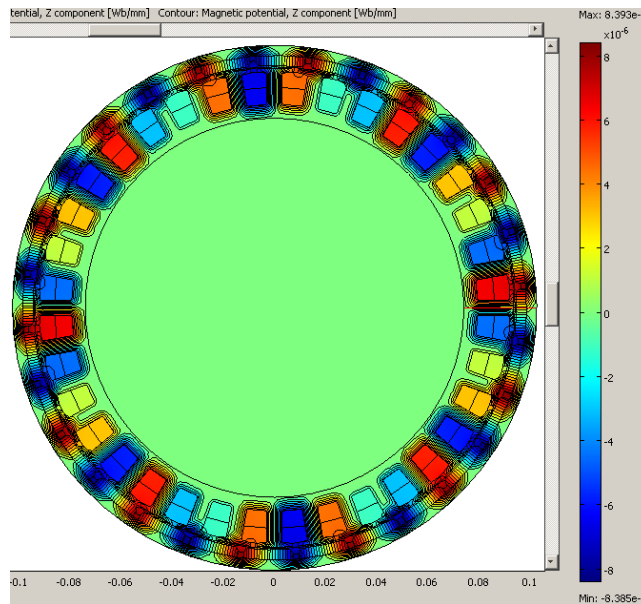


Figure 6. The magnetic potential calculated by COMSOL Multiphysics

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

The simulation results of the magnetic potential of the PMSM were compared along the same line as well. The Figure 7. shows the simulation result of the magnetic potential calculated by the Infolytica MotorSolve.

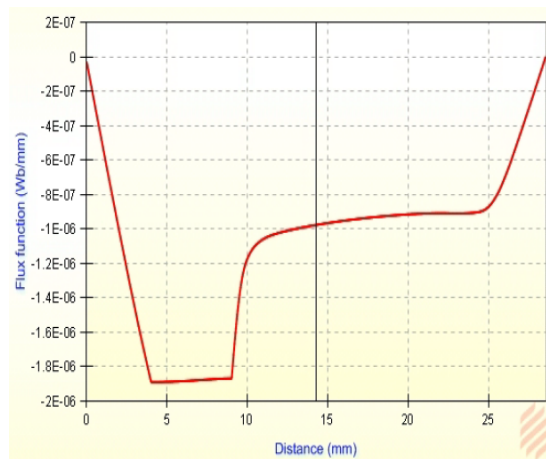


Figure 7. The simulation results of the magnetic potential with the help Infolytica MotorSolve

The Figure 8. shows the simulation result of the magnetic potential by the help of COMSOL Multiphysics.

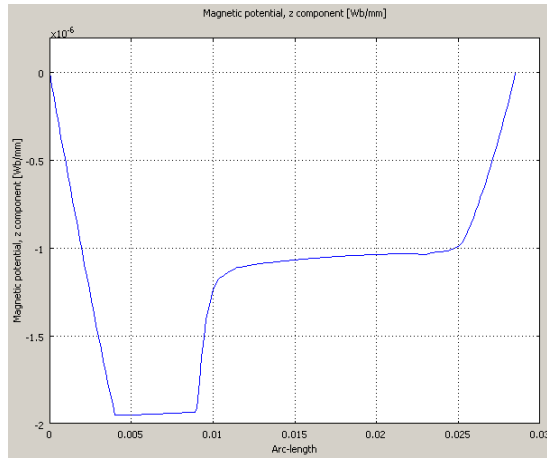


Figure 8. The simulation results of the magnetic potential with the help COMSOL Multiphysics

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

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

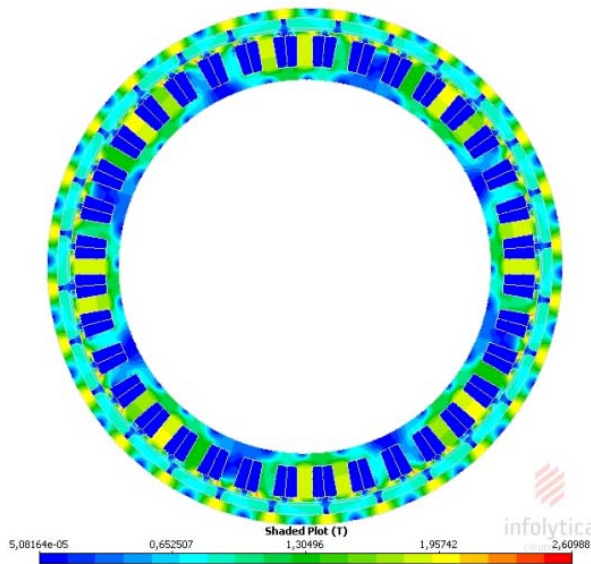


Figure 9. The magnetic flux density calculated by Infolytica MotorSolve

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

The Figure 10. shows the simulation results of the magnetic flux density of the PMSM which was calculated by the help of COMSOL Multiphysics.

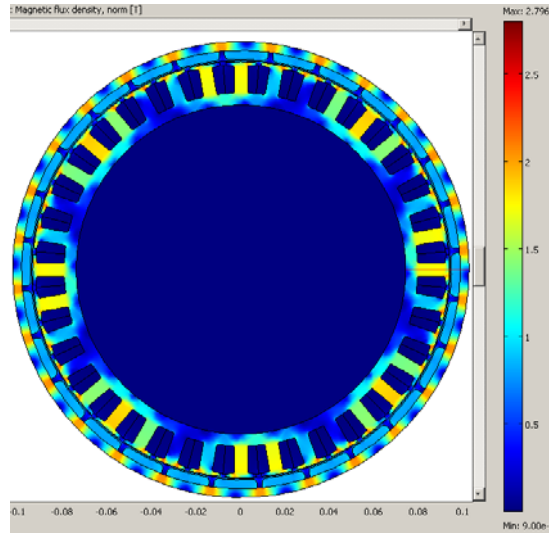


Figure 10. The magnetic flux density calculated by COMSOL Multiphysics

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. The Figure 11. shows the simulation result of the magnetic flux density calculated by the Infolytica MotorSolve.

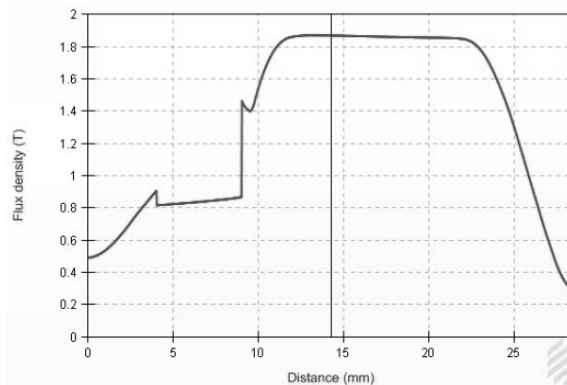


Figure 11. The simulation results of the magnetic flux density with the help Infolytica MotorSolve

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

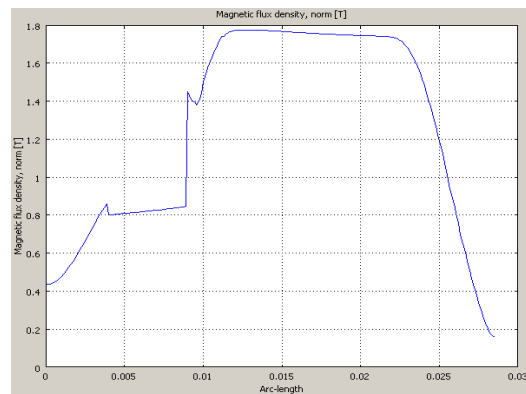


Figure 12. The simulation results of the magnetic flux density with the help COMSOL Multiphysics

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.

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.

6. Acknowledgement

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