

# MODELING OF PERMANENT MAGNET DIRECT-CURRENT MOTOR IN FEMM

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**Abstract:** This article deals with modeling of permanent magnet direct-current motor in FEMM program. Manipulation with this program is described here. More attention is put to creation of permanent magnet direct-current motor model in this program. Example of practice use is also included. In this example, innovation of permanent magnet direct-current motors according to requirement of these motors manufacturer is carried out with help of FEMM.

**Keywords:** FEMM, permanent magnet DC motor

## 1. INTRODUCTION

Many technical issues, including electric machines design, are possible to solve with help of personal computer due to great development of computer technology. Simulation of new designed electric machines are carry out in order to fault of design could be discovered before manufacturing of prototype. Therefore, part of manufacturing cost can be saved. Several programs can be used to carry out this simulation, for example ANSYS. These programs can carry out even very complex simulations, but they have some disadvantages as well. High price and high requirements for users' skills belong among disadvantages of these programs. But, there also exist other programs for computing technical issues than commercial ones, like FEMM. FEMM is finite element method program that can be free downloaded from internet. Requirements for users' skills are also less. Another advantage of FEMM is fewer requirements for hardware, compared with commercial programs. FEMM has also some disadvantages. Especially, it cannot solve more complex problems that can be solved by commercial programs. But, FEMM is fully sufficient for solving some technical problems in industry.

## 2. FEMM

FEMM (Finite Element Method Magnetic) is free program for solving several technical problems by finite elements method. It can be used for solving following problems [1]:

- Linear and nonlinear magneto-static problems
- Linear and nonlinear time harmonic electromagnetic problems
- Linear electrostatic problems
- Steady-state heat flow problems

Disadvantage of FEMM is that it works only with two dimensional models which make more difficult or even impossible solving of some complex problems. Of course, two dimensional designs can be extended to third dimension or turned around an axe, if model has an axial symmetry, in order to solving could be done. But geometry of the model can be created only in two dimensional areas.

Work in FEMM is similar to work in others programs employing finite element method. The first step is creation of a geometric model. This model can be created either directly in FEMM or in

some CAD program. If geometrical model is created in CAD program, it is necessary to save it like .dxf file and then download it to FEMM. This way of creating geometric model is very useful, especially when model has complicated geometry. The next step is definition and assigning of materials, boundaries and circuits. FEMM contains library of materials with predefined properties. Properties of materials in material library can be modified or it is possible to create new material with suitable properties. The next step is creation of finite element mesh. FEMM itself performs this task. Final design of finite element mesh can be influenced by user. For example, user can affect size of elements. Solving can be begun only when all of above steps are correctly accomplished. Results of solving can be displayed by color scheme and some calculation can be made after solving.

Very useful part of FEMM is Lua script. It is a scripting language which makes some calculations easier. The last version of FEMM – FEMM 4.2 – can cooperate with MATLAB. It means that instruction of the Lua script can be set with help of MATLAB. Therefore, the script can be made as M-file in MATLAB and obtained results can be utilized directly in MATLAB. Older version of FEMM can be supplemented by supplement that enabled this cooperation.

### 3. MODEL OF PERMANENT MAGNET DIRECT-CURRENT MOTOR IN FEMM

FEMM was used for calculations which are part of innovation of permanent magnet direct-current motor. Purpose of innovation is conversion of rotor in order to machine-made winding could be used. Machine-made winding can save part of manufacturing cost. Properties of motor, especially size of whole motor, should be unchanged. This project is solving together with the manufacturer of this motors, firm ATAS from Nachod.

First, characteristics of motor with handmade winding were measured and its simulation was made in order to comparison of original and new motor could be realized. Rotor whose winding can be made by machine was designed with help of FEMM. The next step is manufacturing of new motor prototype and its comparison with original motor. The above steps are described in following text.

#### 3.1. ORIGINAL MOTOR

It is direct-current motor with permanent magnets. Its nominal power is 200 W. This motor has rotor with twelve slots. Manufacturer equipment allows using only hand-made winding for this twelve-slot rotor. This is a big disadvantage because it increases production costs. This motor has a loop double-layer winding. Every layer of winding contains two coil sides. Every coil has five current-turns. Thus, every slot contains twenty conductors. Commutator is formed by twenty-four lamellas, as follow from above. Main parts of original motor are shown in Fig. 1.



**Fig. 1:** Rotor and stator of original motor.

Original motor analysis was begun by motor characteristics measurement with help of dynamometer. Obtained results are shown in Fig 2. Simulations of this motor were made with help of FEMM. Geometric model for simulation was created in AutoCAD and then exported to FEMM because drawing in FEMM is uncomfortable. Model with mesh and representation of magnetic flux density after solving is shown in Fig. 3.

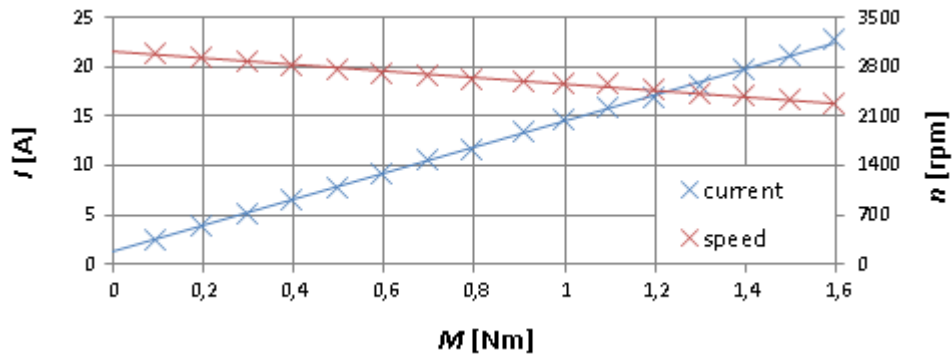


Fig. 2: Measured characteristics of original motor.

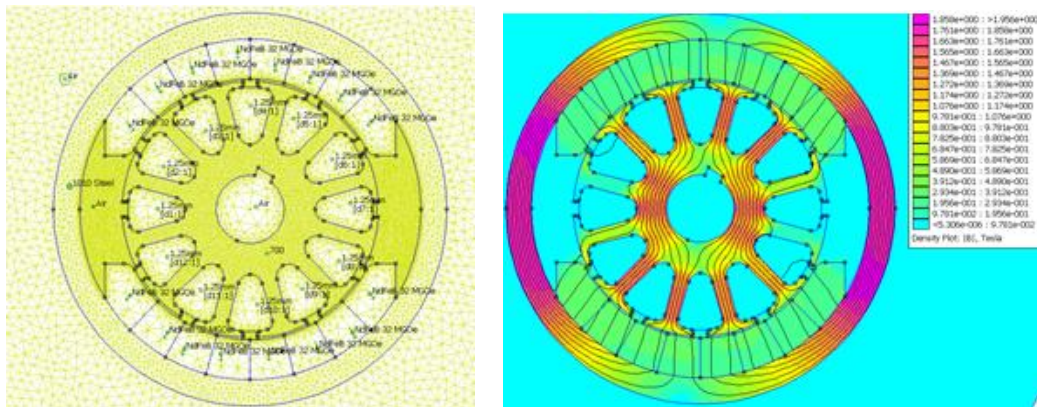


Fig. 3: Model of original motor in FEMM and representation of magnetic flux density in motor.

Motor contains two permanent magnets that have circular shape, as can be seen on figures above. These magnets have radial polarization. This fact must be respected during model creation. Because magnets design in model can very affect results of simulation. Magnets should be divided into several regions and polarization of these regions must be set according to real magnet. Impact of segments number is demonstrated in Fig. 4. Fig. 4 shows influence of segments number to average torque. Average torque was computed from time-waveform of torque. Those time-waveforms were obtained due to Lua script. All simulations were accomplished with considering current level of 10 A. The only differences among particular simulations were numbers of magnets segments. If number of magnet segments is five or more, average torque is unchanged. Results of measurement of real motor are conform to results of simulations if number of magnet segments is five or more. It can be seen from comparison Fig. 2 and Fig. 4 (torque computed by FEMM is internal electromagnetic torque).

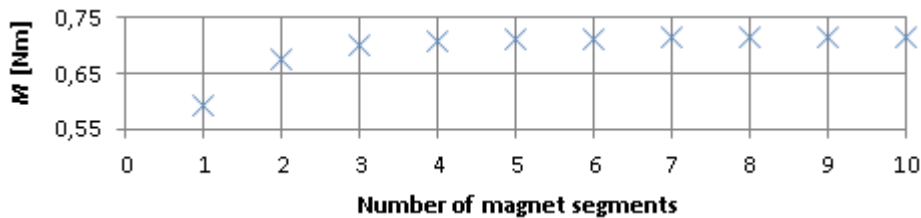
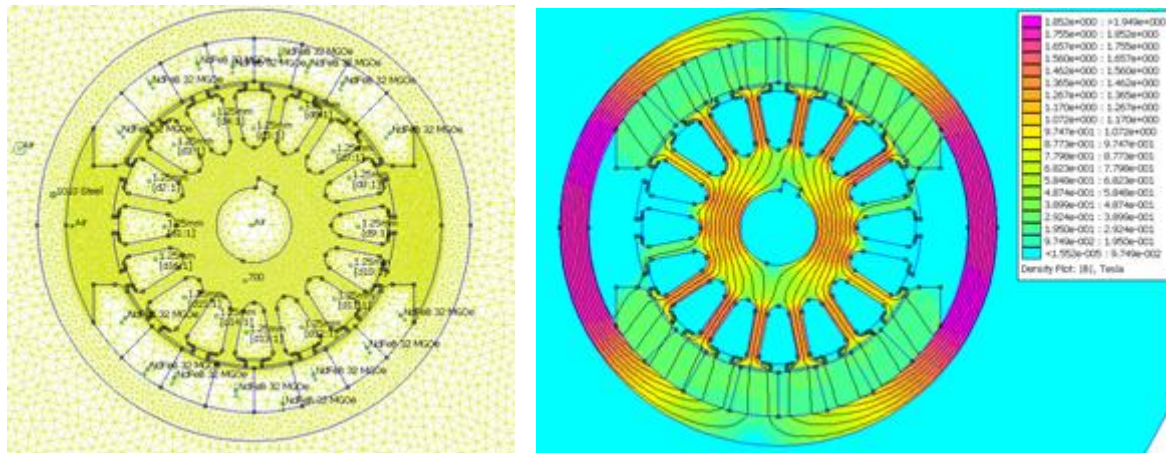


Fig. 4: Influence of number of magnet segments to average torque obtained from simulations.

### 3.2. NEW MOTOR DESIGN

New motor has to allow manufacturing of winding by machine. Characteristic of new motor and original motor should be identical. It is necessary modify only rotor, stator can be unchanged. Rotor has to contain sixteen slots in order to machine-made winding could be used. Of course, numbers of coils and turns have to be changed as well. It is used double-layer loop winding; every layer contains two coil sides; every coil is created by four turns. Thus, every slot contains sixteen conductors. Commutator is created by thirty-two lamellas. This construction of winding and commutator is necessary in order to preservation unchanged motor characteristics. It is possible to use another construction of winding and commutator. It can be used double-layer loop winding with half the number of coils and twice the number of turns in every coil than above. In this case, every layer contains only one coil side and commutator is created only by sixteen lamellas, but number of conductors in every slot is unchanged. However, time-waveform of torque is worse with this type of winding than with first mentioned winding. Filling of slots and slots opening have to be unchanged in order to winding could be made. Design of new rotor in FEMM is shown in Fig. 4.



**Fig. 5:** Model of new motor in FEMM and representation of magnetic flux density in motor.

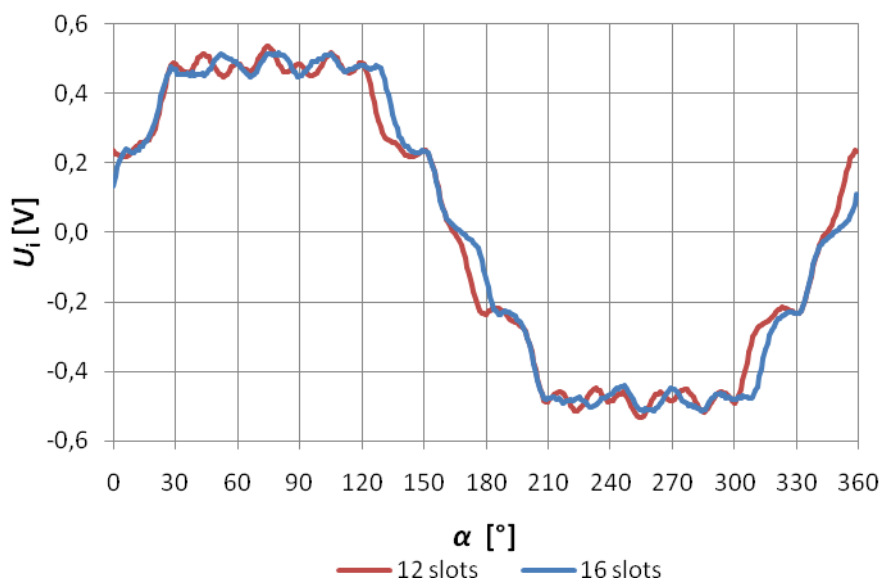
### 3.3. COMPARISON OF ORIGINAL MOTOR AND NEW MOTOR DESIGN

Unfortunately, prototype of new designed motor was not available in terms of consignment of this article. There, comparison of original and new motor is possible only due to simulations. Comparison is shown below. Torque that is computed by FEMM corresponds with internal electromagnetic torque. Torque on the shaft is less due to friction.

Parameters	Original motor	New motor
Number of slots	12	16
Number of commutator segments	24	32
Number of conductors in slots	20	16
Area of slot	78.1 mm <sup>2</sup>	56.7 mm <sup>2</sup>
Filling of slots	0.32	0.35
Slot opening	3 mm	3 mm
Width of tooth in most narrow locality	3.2 mm	2.4 mm
The most magnetic flux density in rotor	1.52 T	1.47 T
Average torque	0.69 Nm	0.74 Nm

**Tab. 1:** Comparison of original and new motor.

Induced voltage of original and new motor was computed with help of Lua script in order to properties of both motors could be compared (Fig. 6). Both induced voltages were computed for revolutions of 3000 rpm (about unloaded original motor revolutions – see Fig. 2). As can be seen from Fig. 6 shape of induced voltage in one turns is almost unchanged and size of both induced voltages are very similar as well. From comparison of averages torques in Tab. 1 can be seen that motor constant is little changed. This change of motor constant follow from induced voltage comparison as well – size of induced voltage in one turns is almost this same but total number of turns is changed. Both average torques in Tab. 1 were computed with considering current level of 10 A. Original motor revolutions in this current level are about 2700 rpm (se Fig. 2). Anticipated new motor revolutions in this current level are approximately 2400 rpm.



**Fig. 6:** Induced voltage in one turns of original and new motor (by LUA script).

#### 4. CONCLUSION

Using of FEMM to design of permanent magnet direct-current motor is shown in this article. Original motor was analyzed and new motor was designed according to requirement of motor manufacturer, firm ATAS Nachod, with help of FEMM. As follow from article, FEMM is sufficient for this job and its using is relatively easier than using other finite elements method programs. But, some issues, like permanent magnet modeling, have to be deal with little bigger attention. The big advantage of FEMM is that it can be free downloaded and used.

#### ACKNOWLEDGEMENT

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