FEM-Laboratory for students in the 4-th year, Experiences and Results

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Abstract

The paper provides ideas and practical experiences in teaching using a FEM-CAD-program at the electrical engineering department in the field of electrical machines. The FEM-CAD-program is used in laboratory design sessions for different types of electric and magnetic energy transducers.

Introduction

After two years of education in basic sciences and one year in mostly general technical courses, the students of the fourth year of the masters program in electrical engineering have to take the course of "Electrical machines - part 2". An educational complement of this course is the FEM-CAD-laboratory dealing with machine design. The aim of the FEM-CAD-laboratories at the electrical engineering research group is dual. At the one hand the FEM-CAD-laboratories are used to design different types of electrical machines, at the other hand the FEM-CAD-laboratories show the students what they can do with a FEM-CAD-program and how they can use it in practical situations.
There are 12 laboratory sessions, each taking 2.5 hours. The 12 sessions take place in the first and the second semester of the academic year, between October and April. The students can work together in groups of two or three.
In the first series of laboratory sessions the students have to design a DC-machine with permanent magnets. These first sessions are also a renewed acquaintance with the FEM-CAD-program already used in the third year for designing coils and transformers. In the second series of laboratory sessions they have to design a synchronous machine with permanent magnet excitation and they need to use the FEM-CAD-program in a more advanced way to calculate the operating behaviour of this type of machine.

Basic design

The FEM-CAD-laboratory is explained using the design of a DC-machine with permanent magnets as an example.

First the students get a short introduction into the FEM-CAD-program to refresh their theoretical knowledge and to examine what they retained from the introductory laboratory sessions they had in their third year.
After this phase they get the data of the machine to be analysed. These data are rated power P_m, rated voltage U, rated speed n, number of pole pairs p, number of parallel branches a and number of windings N. The students also get some basic geometry to which they have to adhere. Figure 1 shows a typical motor geometry.

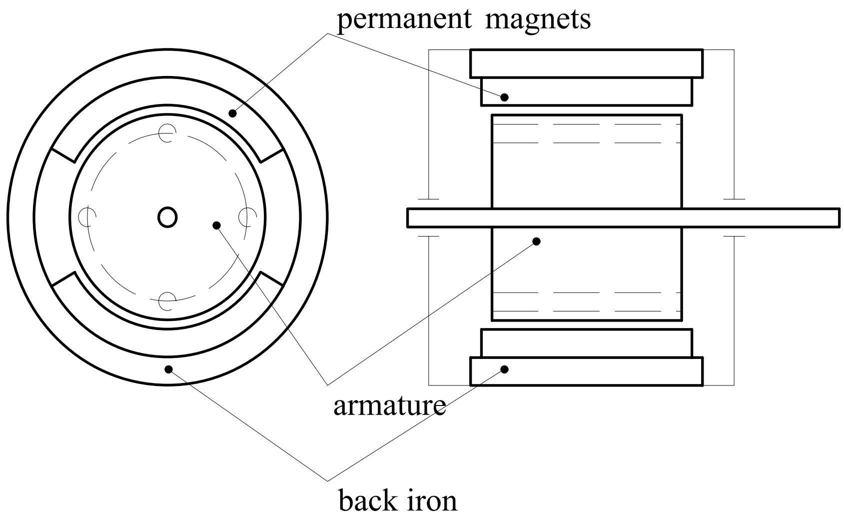

Fig. 1: *Basic geometry of the DC-machine with permanent magnets*

In addition the students get also technical data sheets from manufacturers. These technical data consist of experience based values for the design of permanent magnet DC-machines, realistic values of motor frames, armature diameters, slot sizes, the relation between temperature rise and specific joule losses, the inner diameter of the back iron of the machine, characteristics of different types of permanent magnet material, magnetic characteristics of the laminations and realistic values of shaft bores.
From these data the unknown machine parameters can be calculated using of a spread sheet using an iterative process.
While choosing and calculating the proper machine and design parameters, some values can already be calculated that are later checked with the FEM-CAD-program.

FEM-CAD-program

The dimensions of the permanent magnet DC-machine as given by the final iteration step of the analysis are fed into the FEM-CAD-program. The FEM-CAD-program used at the electrical engineering research group is a commercial software package. The aim of using the FEM-CAD-program in this CAD-laboratory is to recalculate the DC-machine with permanent magnets, and to get some comparable values for the flux density in the airgap, the teeth and the back iron of the machine. The global parameters as inductance and torque of the machine have to be obtained from the solution data from the FEM-CAD-calculation and these values are compared with the required quantities given at the beginning of the design problem. The FEM-CAD-program consists of subprograms that are discussed here after.

First of all the students have to draw the machine with a CAD designing aid. Due to symmetry there is no need to take the whole machine into account for modelling. For the rotor one slot is sufficient and for the back iron of the machine one halve is sufficient. In this way, the students are trained to consider possible symmetry in a problem linked with the appropriate boundary conditions**.** Binary constraints at the symmetry-line of the machine and Dirichlet constraints at the outer diameter of the stator and at the shaft have to be applied.

After drawing the geometry the students have to generate a mesh for each part of the machine. The complete mesh is produced by assembling the separate parts (figure 2).

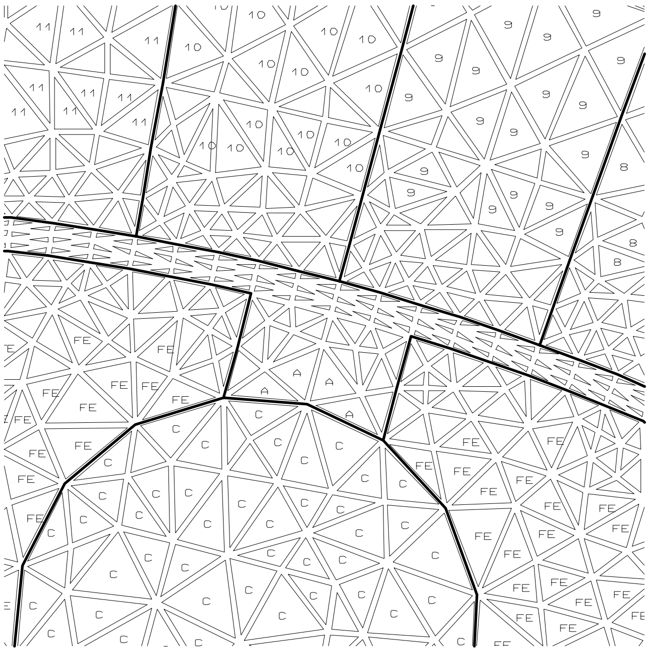

Fig. 2: *Part of the mesh of the DC-machine excited with permanent magnets*

As the students are free to choose the materials used in their design, it is possible that the chosen materials are not present in the materials library of the FEM-CAD-program. therefore it can be necessary to include new materials into the existing library. The representation of permanent magnets by their demagnetisation curve and a current sheet is shown.

After drawing, meshing and material building, the problem is defined. This means that the student has to decide which type of shape function is used to approximate the vector potential over a finite element. Elements up to fourth order are available. In this step of the pre-processing, the students have to set the parameters controlling the subsequent numerical solution process. In this way fundamental knowledge of the numerical treatment of linear or non-linear systems of equations are taught.
After experimenting in solving the field problem, different methods to compute forces and torques are introduced. The students have to proceed in the way that they compute solutions via the magnetic field co-energy (virtual work) and with the Maxwell stress tensor. Results have to be compared and discussed.

Then, the average flux density in the airgap and the maximum flux density in the teeth and the back of the machine need to be calculated. the value of the inductance, being very important in the dynamic behaviour, is also found.

The FEM-CAD-laboratory concerning the design of a synchronous machine with permanent magnet excitation, is based on the same principles. The aim of this laboratory is to determine the torque-load angle characteristics of the synchronous machine using the force-calculation method of Maxwell.

Conclusion and Future View

As a conclusion we can state that the aim of these laboratory sessions is double. The students learn how to design an electrical machine using advanced numerical techniques and they also get to know the possibilities and limitations of the FEM-CAD-program used in the research group. An additional benefit of this approach is that by using the program in an intensive way, the students get a good basis for the preparation of their master thesis. Due to this, the students do not lose too much time at the start of their thesiswork and more complex problems are possible to treat, offering the chance to tackle realistic engineering tasks.
In the future it is scheduled to extend these laboratory sessions to the design of an induction machine using a time-harmonic solution.

Acknowledgements

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