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Numerical Analysis of the Electromagnetic Brake

Abstract.*This article deals with numerical analysis of the electromagnetic brake in Ansys Workbench software by finite element method and proposes a general classification of the electromagnetic brakes. In the context of this article the winding data on the existing electromagnetic brake are determined and all the geometry of the armature and the yoke is measured. This data are included in the numerical model of the electromagnetic brake. The purpose of the numerical analysis in Ansys software is to determine the distribution of the magnetic field within the electromagnetic brake and to determine magnetic flux linkage and electromagnetic force characteristics.*

Streszczenie. *W artykule przedstawiono analizę numeryczną hamulca elektromagnetycznego metodą elementów skończonych w oprogramowaniu ANSYS oraz propozycję ogólnej klasyfikacji hamulców elektrycznych. W kontekście tego artykułu dane uzwojenia istniejącego hamulca zostały określone i geometria armatury i jarzma została zmierzona. Dane zostały włączone do modelu numerycznego hamulca. Zastosowanie analizy numerycznej na platformie ANSYSa ma określić rozkład pola magnetycznego wewnątrz hamulca elektromagnetycznego oraz określić strumień magnetyczny sprzężony i charakterystykę siły elektromagnetycznej.* ***Analiza numeryczna hamulca elektromagnetycznego***

Keywords—numerical analysis, electromagnetic brake, magnetic flux linkage, electromagnetic force, ANSYS
Słowa kluczowe – analza numeryczna, hamulec elektromagnetyczny, strumień magnetyczny sprzężony, siła elektromagnetyczna, ANSYS

Introduction

Electromagnetic brakes (EMBs) are most commonly used in elevators, trains, lifting cranes, automotive industry, mining and wind power plants for braking or stopping the rotors of electrical machines.

Generally speaking electromagnetic brakes are electrically activated but transmit torque mechanically [1]. The advantages of EMBs compared to conventional mechanical brakes are:

- large braking torques,
- stable braking at high temperatures,
- fast response times (accurate engaging and clean releasing),
- low noise and cheaper production.

Because of these advantages the number of manufacturers and providers of EMBs on the market is increasing.

According to the principle of operation we know mechanical, hydraulic, air, vacuum and EMBs. The EMBs can be further classified according to the principle of operation or according to the type of a power source (AC or DC). According to the principle of operation we know:

- steel spring EMBs,
- single or multiple disc EMBs,
- hysteresis EMBs,
- f particle EMBs and
- eddy current EMBs.

The principle of operation is similar for these types of EMBs, they differ only in the way of creating the braking torque [2].

This paper consequently presents a numerical analysis of a DC EMB with steel springs. It consists of a [3]:

- magnetically nonlinear iron yoke,
- magnetically nonlinear iron armature,
- copper winding,
- friction brake pad and
- steel springs.

The cross-section of the actual EMB, discussed in this article, with all of the before mentioned components is presented in Fig. 1.

There are several approaches for solving electromagnetic problems. In solving electromagnetic problems computer supported numerical methods have an extremely important role. The analytical approach of solving electromagnetic problems can be very complex due to the nonlinearity of magnetic materials. During the literature review, we have found several articles [3-5] dealing with numerical analysis by finite element method (FEM). In the next section a procedure of numerical analysis of the EMB is presented.

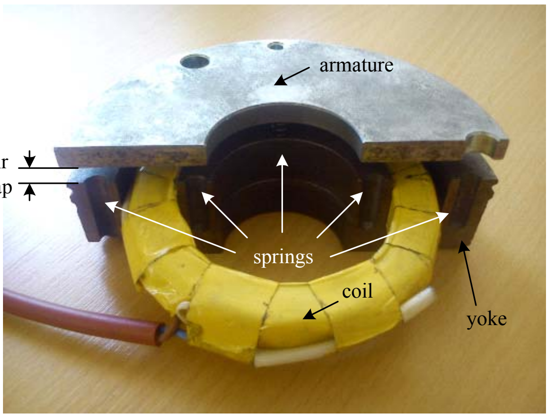


Fig. 1. The cross-section of the actual EMB.

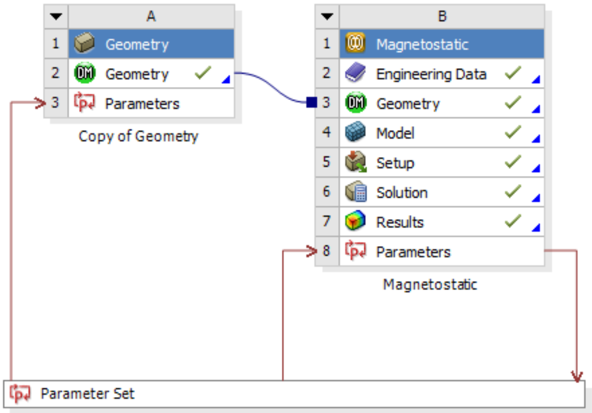
Numerical analysis with Ansys Workbench

Software package Ansys [6] is a high-performance tool for conducting numerical simulations using FEM. Such simulations are very useful in the design and optimization of complex systems. The virtual environment of Ansys software provides a cost effective way for analyzing the behaviour of products or processes. Hereinafter the basic modelling and result visualisation of the numerical analysis is presented.

For a 3D numerical analysis of the EMB we have chosen the magneto-static type of solver in Ansys Workbench. The project schematic diagram of the magneto-static simulation is presented in Fig. 2. Generally speaking the magneto-static simulation process consists of three steps:

- pre-processing,
- processing and
- post-processing.

In the pre-processing phase we are dealing with creating the physical environment. We have thus created the numerical model of the EMB and defined all the materials and their characteristics. We have defined the *B*/*H* characteristics for two different materials (armature and yoke).


A
1 Geometry
2 Geometry ✓
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B
1 Magnetostatic
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7 Results ✓
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Fig. 2. The project schematic diagram of the numerical simulation.

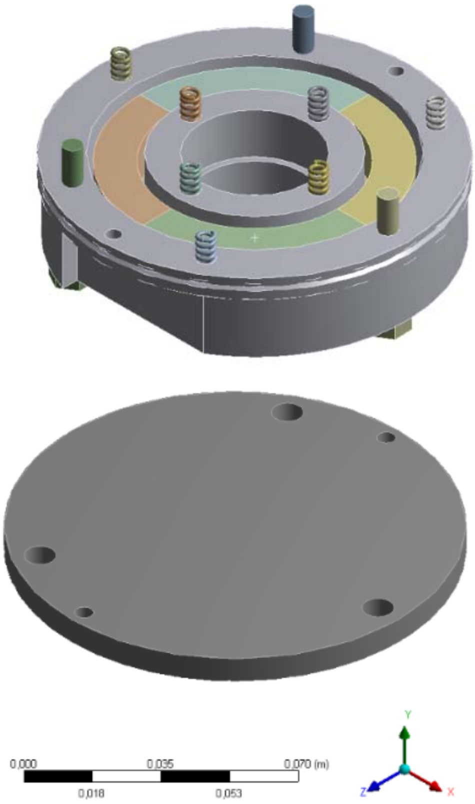

Fig. 3. 3D model of the EMB.

For the coil winding we also had to determine the number of coil turns (*N*) and define the amplitude and direction of the electric current. Since physical counting of coil turns is almost impossible, we have thus measured the total winding resistance (R_{tot}), and than analytically determined the resistance for one turn of the coil (R_{n1}) by (1) on the basis of the known mean length of all coil turns (lmean), the coil cross-sectional area (A_{Cu}) and specific resistance (ρ_{Cu}) of the copper winding.

$$(1)\quad R_{\mathrm{n1}}=\frac{\rho_{\mathrm{Cu}}l_{\mathrm{mean}}}{A_{\mathrm{Cu}}}=\frac{1.75\cdot10^{-8}\cdot0.2596}{2.2\cdot10^{-8}}=0.2065\ [\Omega]$$

Knowing the ohmic resistance for one turn of the coil, we were able to calculate the total number of coil turns using (2):

$$(2)\quad N=\frac{R_{\mathrm{tot}}}{R_{\mathrm{n1}}}=\frac{899}{0.2065}=4353.51\doteq4354$$

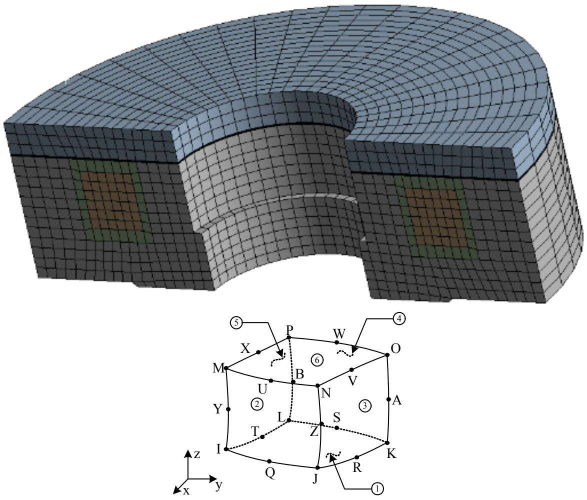

Fig. 4. Simplifed 3D model of the EMB.

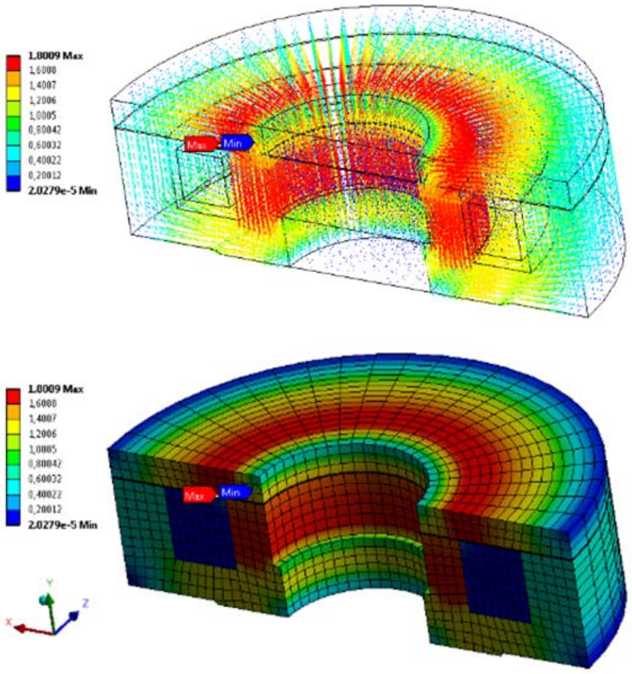

Fig. 5. The distribution of magnetic flux density within the EMB.

After defining all the materials and their characteristics we have applied the boundary conditions and meshed the model. The Dirichlet boundary conditions were defined on the outer surfaces of the surrounding air. Fig. 3 is showing a 3D model of the EMB.

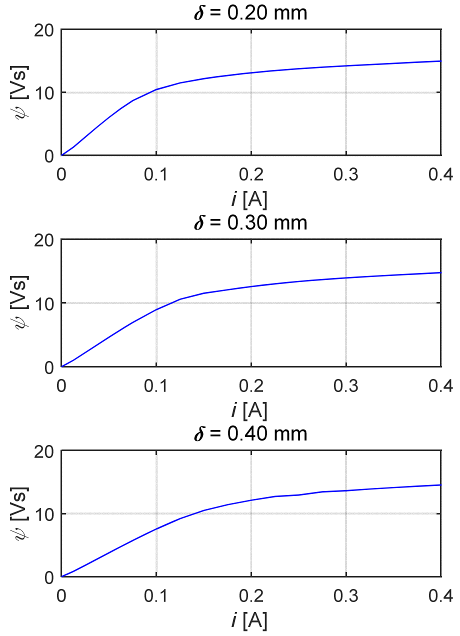

Fig. 6. Magnetic flux linkage characteristics.

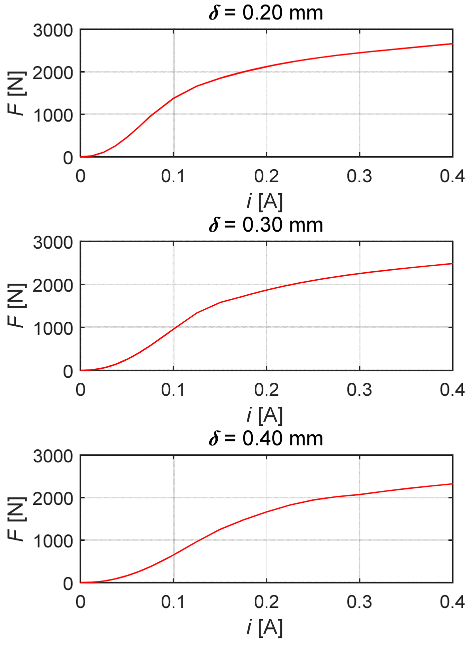

Fig. 7. Electromagnetic force characteristics.

In order to reduce computation time of the simulation (processing phase) we have simplified the EMB model and defined the boundaries of symmetry. The simplified EMB model is presented in Fig. 4 with element Solid236 which was chosen for the numerical analysis.

Extra attention was given when modelling the air gap. This proved to be particularly appropriate in meshing phase due to the compliance of nodes on the border between the yoke, air gap and the armature [2]. Denser mesh (number of elements and nodes) affects the accuracy and the time of calculation of numerical simulations, and therefore the complexity of calculation.

In post-processing phase of the numerical analysis we have dealt with the visualisation of the results. Fig. 5 is showing a vector displayed distribution on the left and a contour displayed distribution of magnetic flux density on the right due to current excitation. The maximum value of the magnetic flux density occurs in the thinner part of the yoke. For proper evaluation of the results of a numerical analysis extensive knowledge and experiences are required.

Based on the numerical model of the EMB the magnetic flux linkage (ψ) and electromagnetic force (F) characteristics for different air-gap thicknesses (δ) and current excitation (i) are determined. The magnetic flux linkage and electromagnetic force characteristics are presented in Fig. 6 and Fig. 7.

Conclusion

This article presents a general classification of EMBs and the basic procedure for magneto-static FEM analysis. A DC EMB with steel springs was presented and the main steps for conducting a numerical analysis in Ansys Workbench were shown.

The most important factors for conducting a qualitative numerical analysis are the electromagnetic field theory background and experiences with modern numerical programs such as Ansys Workbench. As the result the distribution of the magnetic flux density within EMB has been presented and magnetic flux linkage and electromagnetic force characteristics were determined.

For a more detailed analysis, additional numerical simulations with different air gap thicknesses are needed. Numerically obtained results should also be experimentally validated. The numerical model will be used in further numerical analysis with the purpose of obtaining magnetic parameters for the nonlinear dynamic model of the EMB. The simulation results of the numerical analysis and the dynamic time responses will be useful for a more comprehensive study.

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