Solenoid Actuator Parametric Analysis and Numerical Modeling

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***Abstract*—The aim of this paper is to find the force that act on the solenoid actuator core and the its inductance in terms of the core position and in terms of current values that follow the actuator coil. To fulfill this objectives require a parametric analysis of the solenoid actuator in terms of core position and current value involving a preliminary classical numerical modeling. This study starts by solenoid actuator analysis using a two-dimensional numerical modeling program, after that the analysis are extended to tridimensional. The conclusions end this paper.**

***Keywords*—solenoid actuator; numerical modeling; parametric analysis.**

I. Introduction

An actuator is a controllable execution element that transform the input energy (electrical, magnetic, thermal, optic, and chemical) mechanical work. The conversion of the input energy (electrical, thermal, magnetic, optical, and chemical) into useful output energy and dissipation heat is achieved through electric and magnetic fields as a result of natural phenomena such as piezoelectric, magnetostrictive and diamagnetism phenomenon. The actuator mechanism transforms, amplifies and transmits motion by agreement with technological specific parameters purpose. A solenoid actuator is an actuator that has a solenoid as a component part represented by a wire coil having cylindrical shape. The solenoidal actuators have a steel armature that represent the mobile part of the actuator. In the case of solenoidal actuators the armature moves along a straight line and thus produce a linear motion [1].

Fig. 1. Liniar solenoidal actuator.

The main objective of this paper is to find the force that act on the solenoidal actuator core and to find the coil inductance in terms of the core position and of the value of the current that follows the actuators coil. So in Fig. 2 is shown a two-dimensional view of the solenoidal actuator that is studied in this paper where can be identified his component elements: core, bonnet, yoke, coil and plugnut. In Fig. 3 is presented a longitudinal section of the tridimensional solenoidal actuator.

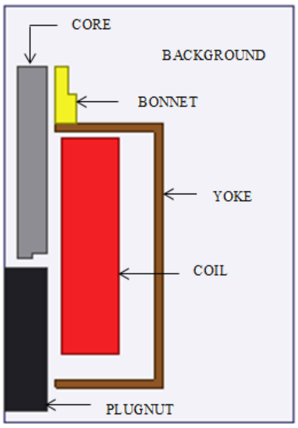

Fig. 2. The studine solenoidal actuator – 2D view.

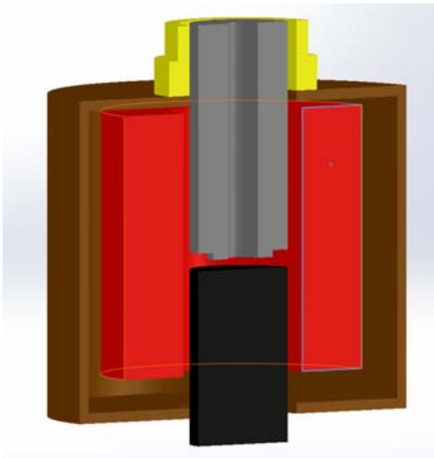

Fig. 3. The studine solenoidal actuator – 3D view.

II. Parametric Analysis by Numerical Modeling of a Solenoidal Actuator

To establish the force variation depending on the position of the solenoidal actuator core and mount of the current that is flowing through its coil is necessary to perform a preliminary classical numerical modeling of the actuator.

To this aim the two-dimensional geometry of the actuator presented in Fig. 2 is implemented in the software program dedicated to numerical modeling of electromagnetic field ANSYS-Maxwell 2D [2], program based on finite element method. For these analysis was used the *Magnetostatic* module of the program and taking into account the geometry of the studied device was used the axial symmetry. Regarding the materials used for the component elements of the actuator were use: cooper for yoke, cold rolled steel for bonnet, for core was create a new material Neo35 (permanent magnet), and for plugnut was create a nonlinear material SS430. For the classical numerical modeling of the coil was consider the current to be 1000 A. In Fig. 3 is presented the force that act on the solenoidal actuator core value obtained by numerical modeling of the actuator using the program mentioned above. It thus appears that the net force acting on the core is about 111 newton, acting negative along the Z axis (the vertical direction) (Fig.4). In other words, this force is pushing the core inside the solenoidal actuator.

The amplitude and vector representation of the magnetic field on the component of the actuator are shown in Fig. 5 and in Fig. 6 is plotted the vectors for current density distribution in coil.

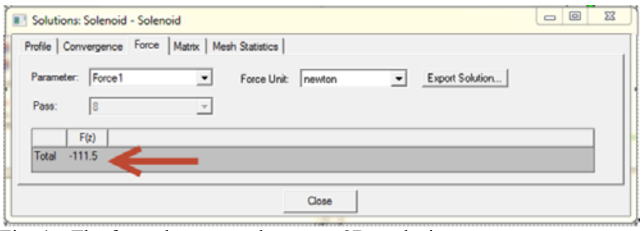

Fig. 4. The force that act on the core – 2D analysis.

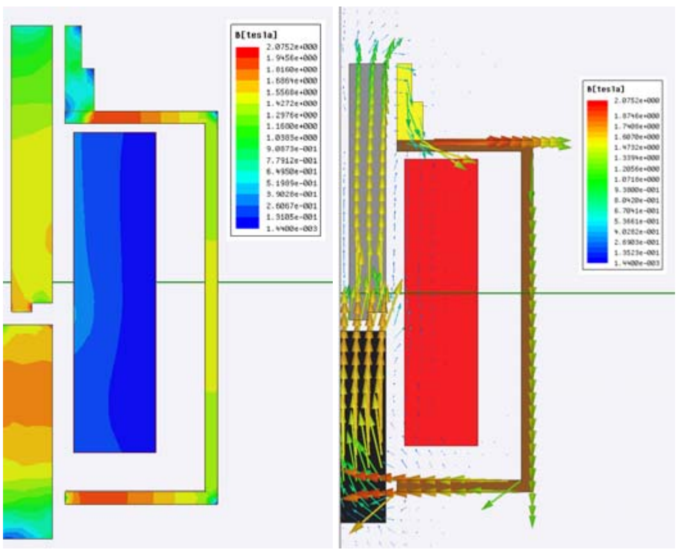

Fig. 5. Amplitude and vectors for magnetic fields.

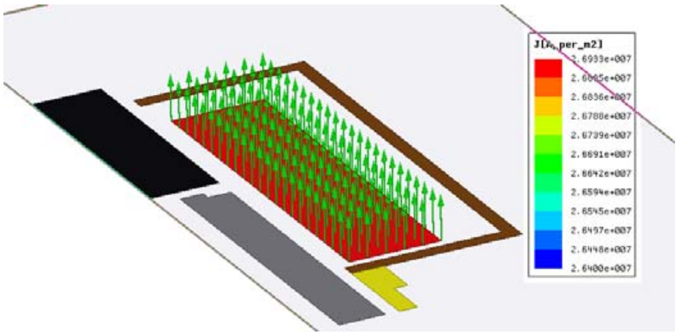

Fig. 6. Vectors of current density in coil.

Once the initial numerical modeling of the solenoidal actuator is completed the study can proceed to the parametric analysis of the actuator depending on the core position and on the current value.

Thus it is necessary to define the core position as being a variable, meaning it is necessary to add a geometrical variation to the model, more precisely to the core. This variation will basically impose the fact that the distance between the core and the plugnut is a variable which can be modified during the numerical solution determination process. Also, a variable current source will be defined and will be assigned to the coil.

In Fig. 7 the relative position between the core and the plugnut is sketched observing the initial conditions of the model whose parametric analysis will be done. As it can be observed, in order for the core never to touch the plugnut, an initial start distance of 0.08 cm is imposed. The minimum offset step was chosen to be 0.25 cm and the maximum step is considered to be 1.5 cm. During the numerical modeling of the solenoidal actuator using the program ANSYS Maxwell 2D [3], the offset difference is set to vary between 0 cm and 1.25 cm, the value virtually representing the space between the core and the plugnut which varies from 0.25 cm to 1.5 on the graphical model.

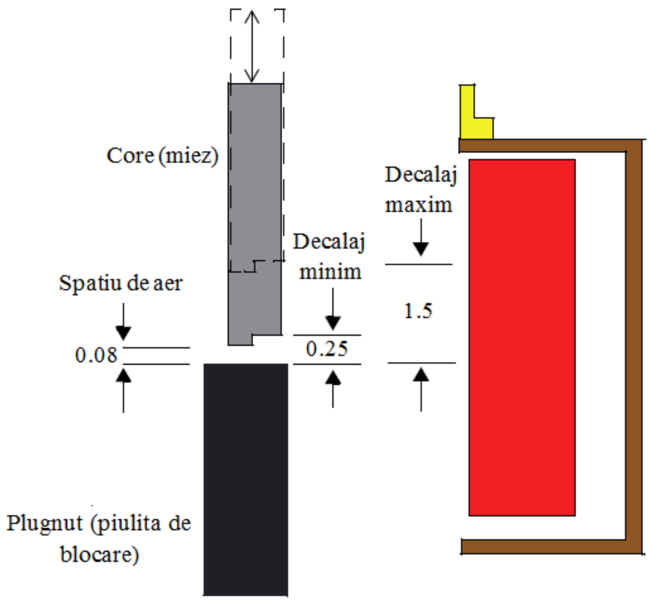

Fig. 7. Explanatory figure for the 2D parametric analysis geometrical model.

In this researches, as it was mentioned above, the calculation of the force acting on the core and the calculation of the core's inductivity will be required from the numerical modeling software program, depending on the core position and on the value of the current which is flowing through the coil. Thus, in Fig. 8 the variation of the force acting on the core of the actuator depending on the core position, for a 1050 A current, is graphically represented. The results are obtained from the numerical modeling of the actuator with the ANSYS Maxwell 3D software program [2]-[3]. The coil inductance variation depending on the core position is presented in Fig. 8. Following the obtained results it can be noticed that, as expected, the increase of the distance between the core and the plugnut leads to the force value minimization and also to the coil inductance value minimization.

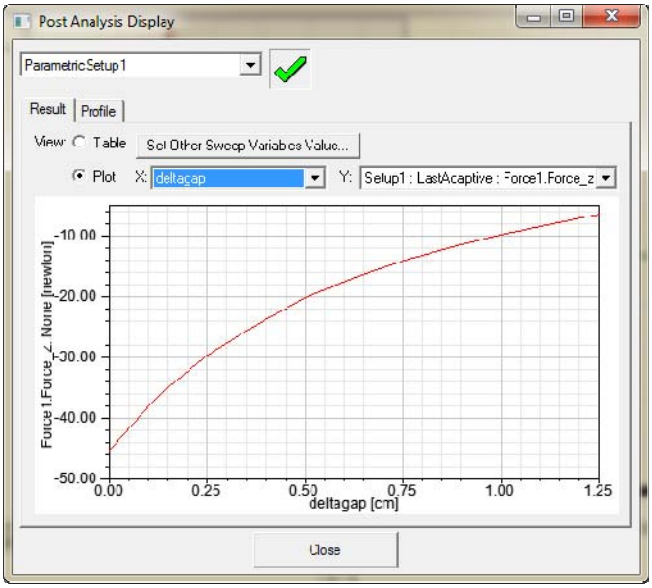

Fig. 8. Force acting on the actuator's core depending on the core position for a current with a value of 1050 A.

In order to analyze the way in which the current flowing through the coil influences the force which is acting on the core of the studied solenoidal actuator, a ratio of the force variation depending on the core position for different values of the electrical current which is flowing through the coil is presented in Fig. 10.

Also, in order to highlight the effect of increasing the distance between the core and the plugnut on the magnetic induction distribution, the graphic and vector distribution of the magnetic induction in the component elements of the studied solenoidal actuator for the maximum distance of 1.25 cm at a 1500 A current are presented in Fig. 11. Fig. 12 presents the vector distribution of the current density through the coil in the case of the maximum distance between the two elements.

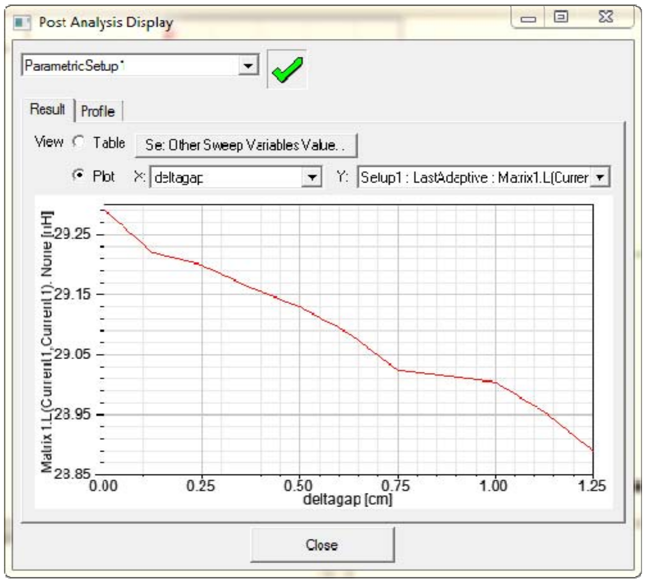

Fig. 9. Coil inductance variation depending on the core position for the studied solenoidal actuator.

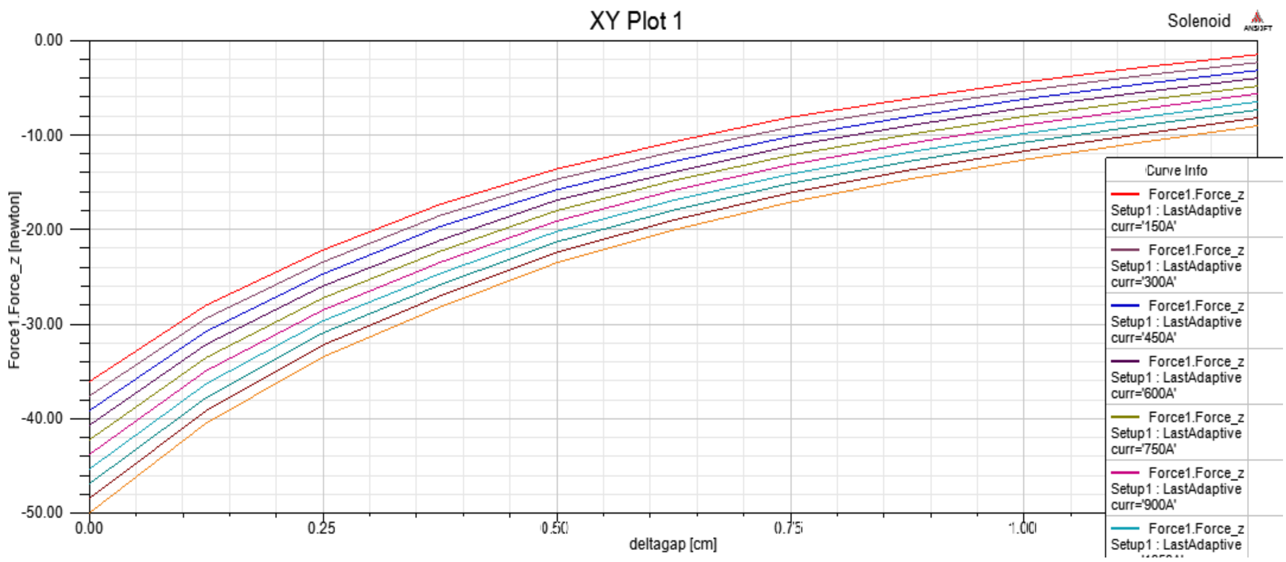

Fig. 10. Graphic representation of the variation of the force acting on the actuator's core depending on the core position for different current values.

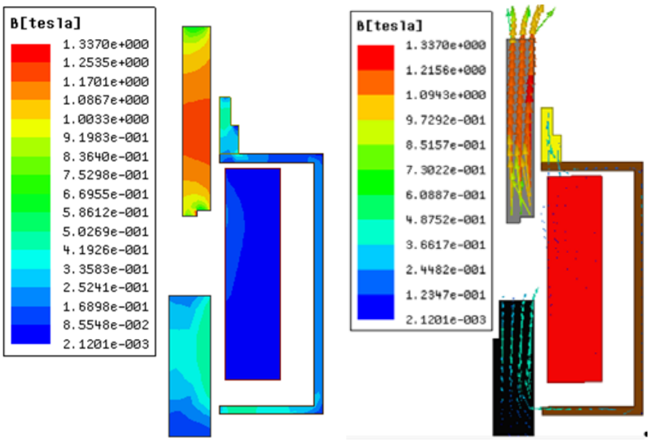

Fig. 11. Graphic and vector representation of the magnetic induction distribution from the elements of the actuator for a maximum distance of 1.25 cm for a current of 1500 A.

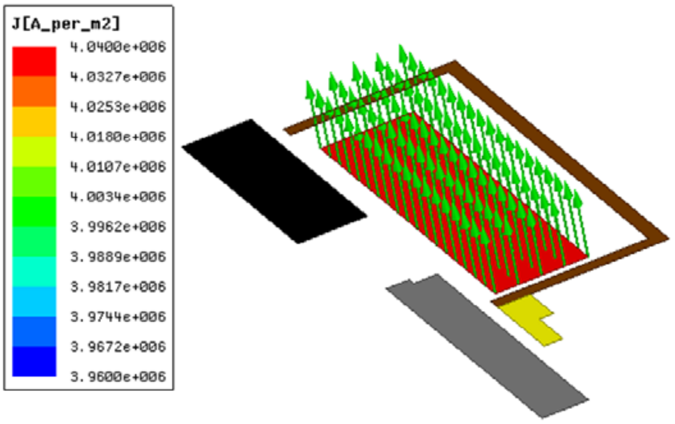

Fig. 12. Vector representation of the current density distribution through the coil.

Following the results presented in the above images it can be stated that the increase of the distance between the core and the plugnut leads to the decrease of the magnetic induction and current density values.

III. Parametric Analysis through Three-Dimensional Numerical Modeling of the Solenoidal Actuator

Once the principle of electromagnetic device parametric analysis proposed by the authors is tested through 2D numerical modeling, the study continues to its validation through three-dimensional numerical modeling. For this step the three-dimensional geometry of the solenoidal actuator presented in Fig. 3 was implemented in the numerical modeling software program ANSYS Maxwell 3D in order to achieve its parametrical analysis depending on the core position and on the current value. As it was mentioned in the previous paragraph, the parametric analysis requires a previous classical analysis. Thus, the obtained results following the actuator's numerical modeling for a fixed position of the core and a fixed value for the current are presented in Fig. 13 – 15. Comparing these results with the obtained results through 2D numerical modeling a very good agreement between these results is revealed.

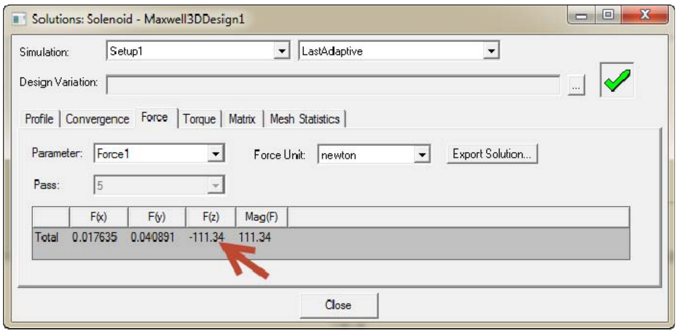

Fig. 13. Force acting on the core –3D analysis.

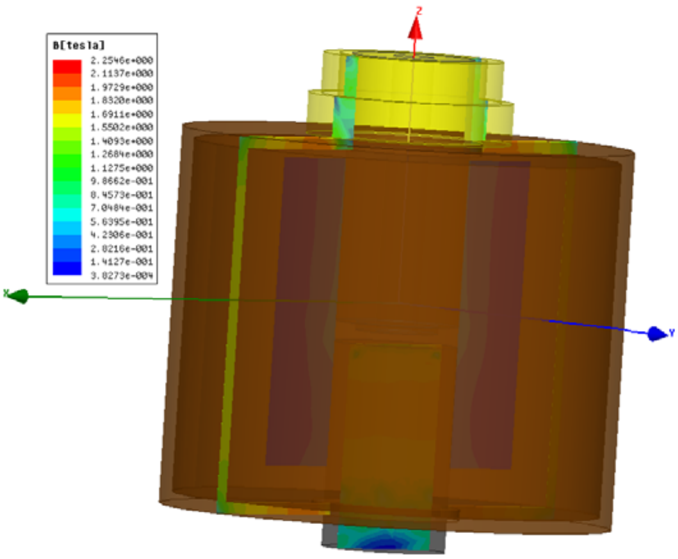

Fig. 14. Graphic representation of the magnetic induction distribution in the component elements of the actuator –3D analysis.

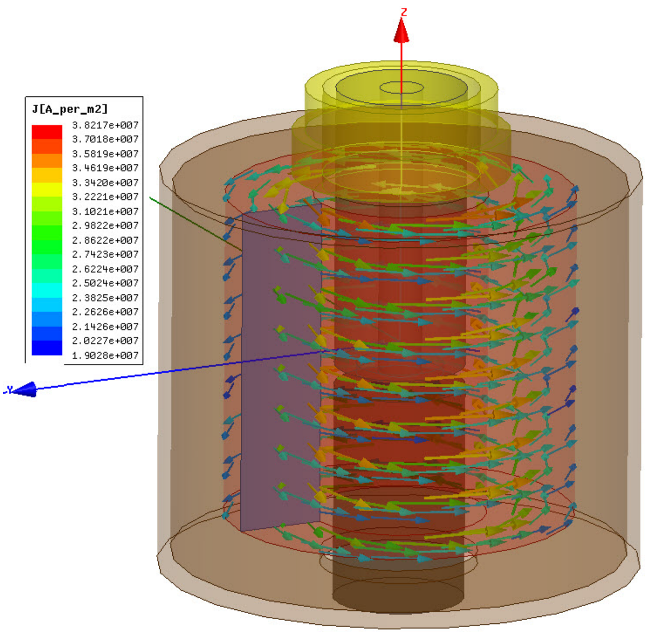

Fig. 15. Vector representation of the magnetic induction distribution in the coil of the actuator –3D analysis.

Like in the case of the bi-dimensional numerical modeling, in the case of the three-dimensional numerical modeling the initial numerical modeling completion of the solenoidal actuator allows the transition to its parametric analysis. Thus, here the core position definition as being a variable it is also necessary, meaning it is necessary to add a geometrical variation to the model, more precisely to the core, and defining a variable current source which will be assigned to the coil.

Also in 3D numerical modeling is imposed an initially distance of start of 0.08 cm so that the core do not touch in any situation the plugnut. The minimum step of gap was choose to be 0.25 cm, and the maximal step of gap as being 1.5 cm.

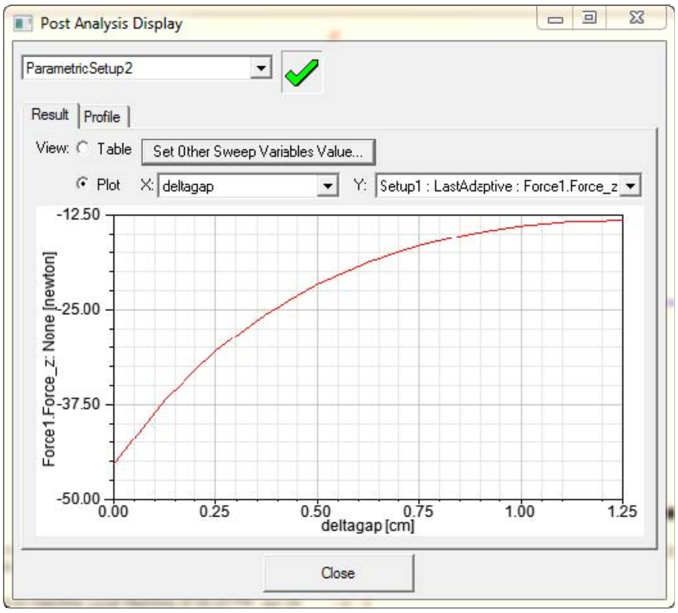

Fig. 16. The force that act on the actuator core depending on the core position for a current of 1050 A.

It is aimed also in this case to find who the distance between the core and the plug influence the force that act on the core (Fig. 16) and respectively the inductance [5] of the coil of the solenoidal actuator (Fig. 17). In the second part of the research work is found the force and inductance variation in terms of both core position and of different values of the current that follow the actuator coil (Fig. 18).

For a very complete analysis of solenoidal actuator is modeled also the magnetic induction distribution in the component elements of the actuator and last but not the least the vector distribution of the current density in coil, for the case of maximal distance between the core and the plugnut presented in Fig. 19 and respectively in Fig. 20.

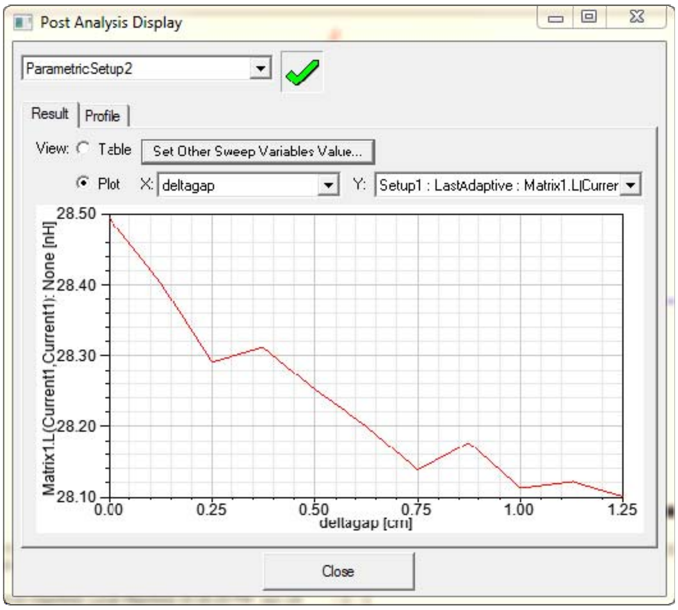

Fig. 17. Coil inductance in terms of core possition.

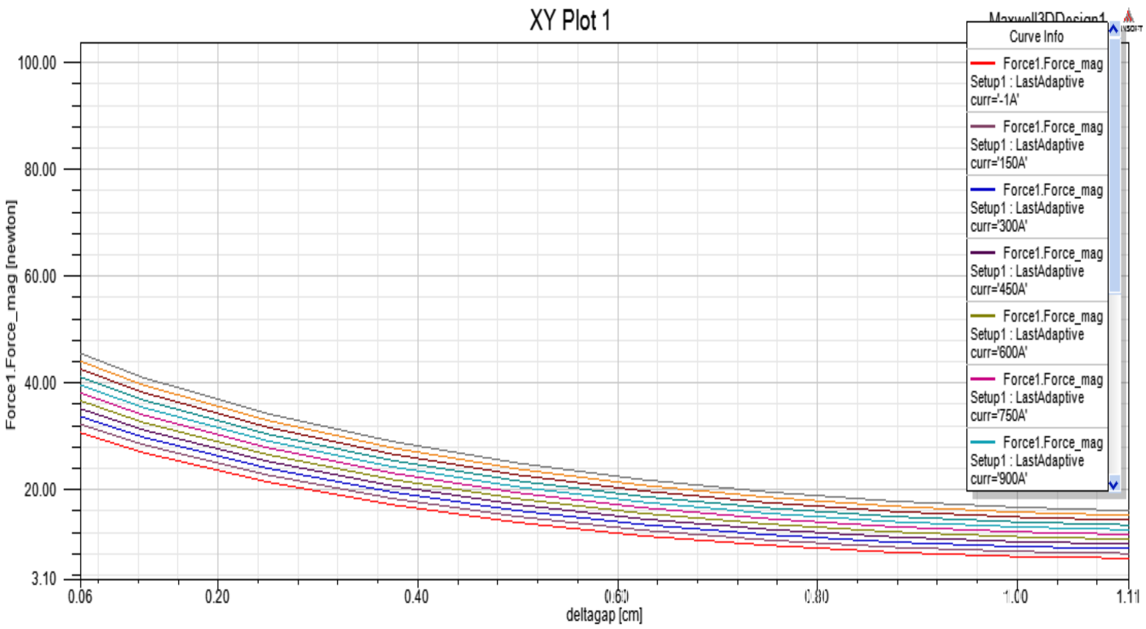

Fig. 18. The representation of the force that act on the actuator core variations depending on the core possition for different current values.

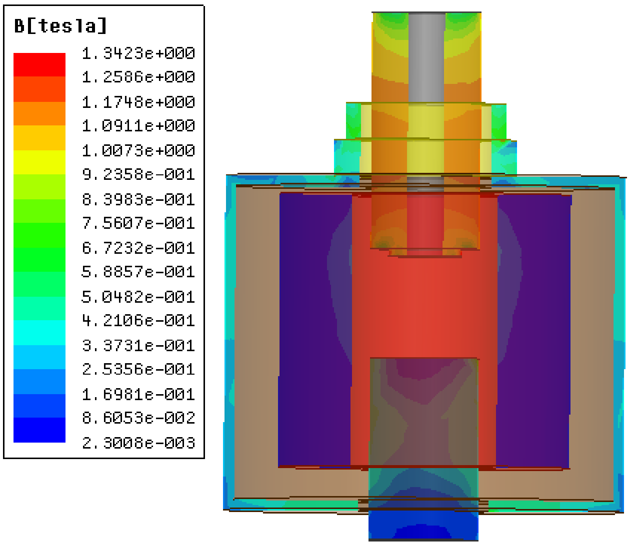

Fig. 19. Magnetic induction distribution in the actuators elements for maximal distance of 1.25 cm for current of 1500 A.

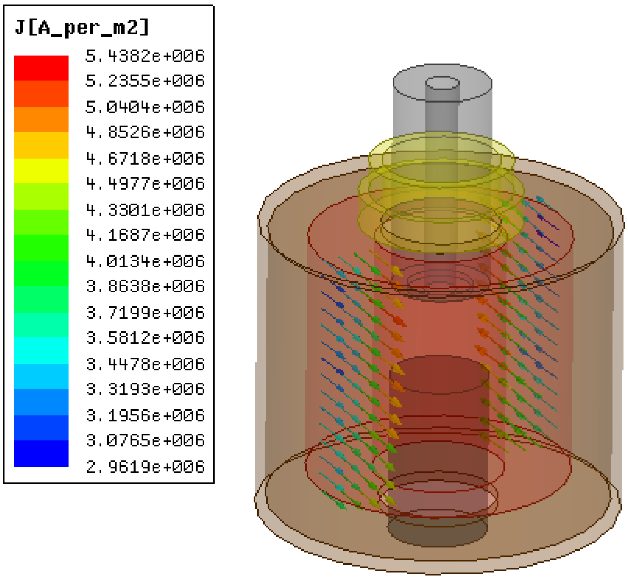

Fig. 20. Vectors of current density for coil.

Comparing the results of the parametric analysis of the solenoidal coil by two-dimensional numerical modeling and respectively tridimensional one reveals a great similarity between them.

IV. Conclusions

In this paper we aimed to numerical modeling of a solenoidal actuator pursuing both a classical analysis depending on the core position and the value of the current that follow the coil. To test the principle proposed by the authors to perform a parametric analysis using ANSYS-Maxwell 2D/3D software program was first started from the 2D study. Once validated the principle of implementation to achieve a parametric analysis in two-dimensional numerical modeling was passed to three-dimensional numerical modeling of the solenoidal actuator based on the same principle as in two-dimensional modeling. In the parametric analysis we aimed to determine how the force that act on the core, the coils inductance and the magnetic field are varying in terms of the position of the core and of the value of the current that passes through the coil of the studied solenoidal actuator. Comparing the results obtained from the two-dimensional and three-dimensional numerical modeling of the solenoidal actuator is proved the accuracy of the numerical modeling using ANSYS-Maxwell 2D/3D in order to do parametric analysis for various types of electromagnetic devices.

Acknowledgment

This paper was supported by the Post-Doctoral Programme POSDRU/159/1.5/S/137516, project co-funded from European Social Fund through the Human Resources Sectorial Operational Program 2007-2013.

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