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# Integration of the Volume Segmentation Method into an Optimization Process.

## Application to the sizing of a Micro-Actuator for Deformable Mirrors.

H.L.Rakotoarison, F.Wurtz, J.Stepanek, B.Delinchant, O.Cugat

Laboratoire d'Electrotechnique de Grenoble (LEG)

INPG/UJF-CNRS.UMR 5529 ENSIEG-BP 46

38402 Saint Martin d'Hères, Cedex, France

Lalao.Rakotoarison-Harijaona@leg.ensieg.inpg.fr

**Abstract--** This work comes from the demand of the optimization of an elementary micro-actuator of a deformable mirror. First, we have created a generator which package an electromagnetic solver based on the volume segmentation method into a standard software component. An experiment and a FEM simulation are done to validate the model of elementary micro actuator. And finally, a process of optimization and Pareto methodology are used to chose the efficient coil shape between two suggested structures.

### I. INTRODUCTION

Microsystems designers meet some problems when they want to manufacture prototypes of electromagnetic micro-actuators. This is caused by the cost and the time that they spend, so it is necessary to optimize the shape of the device before its manufacturing.

Electromagnetic microsystems are frequently made of micro-magnets and micro-conductors. To optimize effectively such a structure, a modeling using the volume segmentation method such as Dipole3D [1] is efficient.

However, it is not evident to connect Dipole3D directly into our optimization software, because the optimizer needs a model based on a software standard.

So, an automatic model generator is build to satisfy this requirement. It allows the capitalization of our approach to other micro-actuator modeling.

After the model has been generated, a validation on a FEM simulation and on an experiment is presented.

Finally, the paper discusses the optimization process and the methodologies used to compare two suggested structures.

### II. DESCRIPTION OF THE INTEGRATION OF THE MODEL IN A OPTIMIZATION SOFTWARE

#### A. The modeling approach used

Dipole3D[1] solves systems made of magnets and conductors by subdividing the system into elementary magnetic dipoles and elementary electric conductors, and then computing the interactions of each element by applying the Biot&Savart and magnetic moment theorems. Finally a summation of all these elementary interactions (fields, forces or torques) is made.

#### B. Packaging the model into a standard software component

To ensure the standardization of the models to be optimized, our laboratory strives to establish a software framework in which any form of model (analytical equations, finite element model, volume segmentation model, etc...) could be integrated in software components known as Computation OBject or COB [2]: physically it is a file with a ".cob" extension.

This software component has to compute the output parameters of the model as well as the associated sensitivity. So, the COB can be illustrated by a box with inputs ( $E_i$ ) and outputs ( $S_j$ ) and their respective differentials ( $dE_i$ ,  $dS_j$ ).

As shown in figure 1, to standardize the model, three software layers are added to the core of Dipole3D.

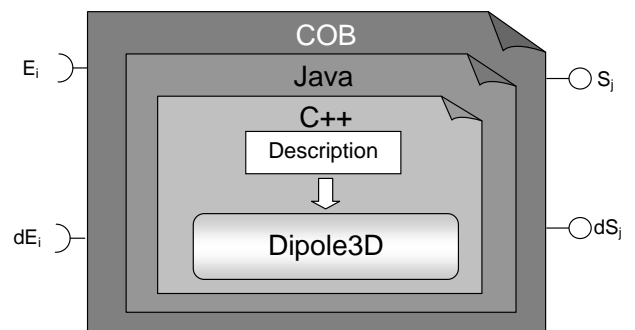


Fig.1. The component model for sizing.

In our case, the inputs of the COB match the geometric parameters of the device, the currents flowing within the conductors and the magnetization of the magnets. The outputs represent magnetic fields, forces or torques.

The architecture around the COB can be divided into two complementary software parts (Figure 2): on one side several generators, which produce the COB, and on the other side, services which use the COB such as optimizers and calculators.

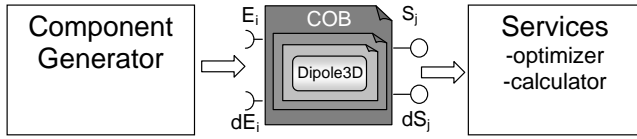


Fig.2. The component architecture.

### C. Sensibility calculation

The optimizer needs the differentials of the outputs because it exploits a gradient based algorithm [3]. In our case, the calculation of these differentials is done by finite differences, of which the method is evoked below:

The first step is to compute the partial derivative for each output  $S_j$  (1):

$$\frac{\delta S_j}{\delta E_i} = \lim_{h_i \rightarrow 0} \frac{S_j(E_1, E_2, \dots, E_i + h_i, \dots, E_n) - S_j(E_1, E_2, \dots, E_i, \dots, E_n)}{h_i} \quad (1)$$

In data-processing code, this formula is valid for a value of  $h_i$  which should be selected judiciously: sufficient small compared to  $E_i$  but not too small compared to the precision of the computer [6].

The expression of the differential is (2):

$$\delta S_j = \frac{\delta S_j}{\delta E_1} \times dE_1 + \frac{\delta S_j}{\delta E_2} \times dE_2 + \dots + \frac{\delta S_j}{\delta E_i} \times dE_i + \dots + \frac{\delta S_j}{\delta E_n} \times dE_n \quad (2)$$

## III. THE AUTOMATIC MODEL GENERATOR

### A. The purpose: ease of modeling

The use of Dipole3D, its integration into a COB and the computation of the differentials require a solid knowledge in programming languages. But the microsystems designer may not be a good programmer: so the automatic generator gives an easy way to model their magnetic micro-actuator with a minimum waste of time.

### B. No need to code full programs...Use the generator.

The designer writes a text file which contains the description of his device, its shape, the magnetization of magnets or the current density of conductors. Descriptions are some simple keywords derived from Dipole3D: its writing is not difficult but requires respecting some rules. After defining geometric and physical properties of his device, the user only needs to click on a button of the generator to generate his model.

Figure 3 shows the internal structure of the generator.

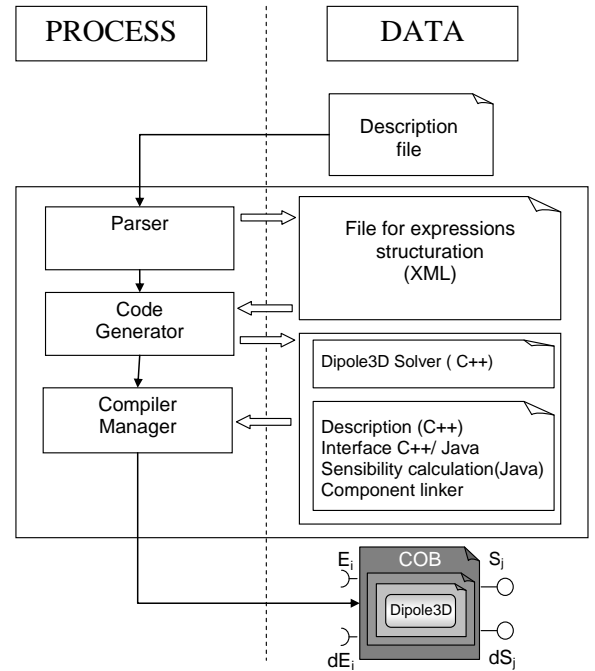


Fig.3. Internal architecture of the automatic generator.

## IV. APPLICATION TO THE MODELING OF A MICRO-ACTUATOR FOR DEFORMABLE MIRROR

### A. The deformable mirror

The goal of adaptive optics in astronomy is to compensate in real time degradations on the images caused by atmospheric turbulences. A deformable mirror (Figure 4) equipped with electromagnetic micro-actuators [4] is a device used for this purpose.

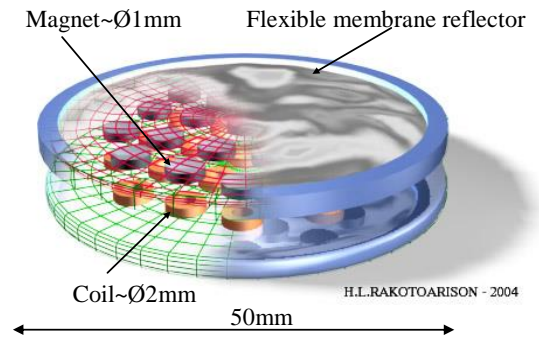


Fig.4. The electromagnetic deformable mirror.

The objective of our analysis was to find the ideal configuration of the elementary micro-actuator of this mirror making it possible to develop the maximum of force while consuming a minimum electric power, for a given dimension. Micro-magnets are stuck under the reflective membrane.

Fixed micro-coils are placed respectively opposite each magnet to control the local deformation of the membrane. Each magnet/coil couple constitutes an elementary electromagnetic micro-actuator.

### B. Electromagnetic micro-actuator

Our analysis (modeling and optimization) has helped designers to choose the best structure between two coils shape as shown in figure 5: the planar structure (left) and the solenoid structure (right).

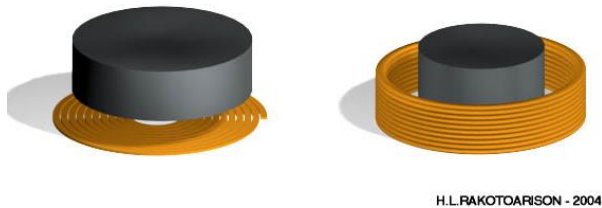


Fig.5. Two types of elementary micro-actuators.

### C. Experimental validation and Finite Element (FLUX2D) simulation

The time necessary to optimize the model is related to objects subdivision (magnet, coil) which constitute the model. According to the desired precision, this time can increase considerably. So, before starting the optimization process, it is significant to validate the model by experimentation on a prototype and/or by simulating a model on a FEM software[8] (Figure 6).

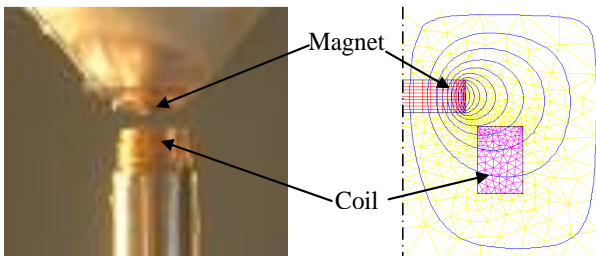


Fig. 6. Experimentation (left) and FLUX2D simulation (right)

The magnet of the prototype is made of NdFeB with 1T of magnetization, the coil contains 95 turns, and the wire diameter measures 0.1mm.

Modeling in FLUX2D and Dipole3D also takes into account the fill factor of the coil. Figure 7 gives a comparison and allows the validation of the model.

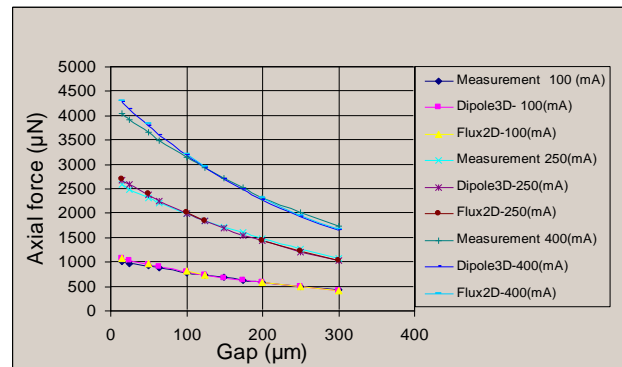


Fig.7. Comparison between measurements, dipole3D modeling, and FLUX2D simulation.

### D. Model generation

Figure 8 shows the graphic interface of the generator with commands script used to model the micro-actuator, some comments (text preceding by a “//”) are typed in addition to clarify the model.

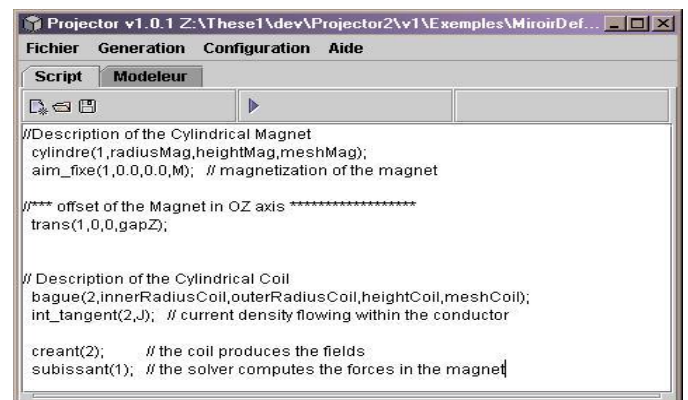


Fig.8. The modeling command script for the automatic generator

The two command lines after the comment are the geometrical and physical description of the magnet.

The next command line adds a spatial translation to the magnet.

The next two command lines create the geometry of the coil and add a parameter: the current density.

The last two command lines indicate that the computation of the force is on the magnet.

### E. Model specifications

The device is intended to correct images. The first significant factor is the resolution: as the surface occupied by each micro actuator is smaller, the resulting image improves.

The constraints on the input parameters (Table I) of the model are shown below.

TABLE I

Input parameters	Unity	Planar	Solenoid
gapZ	mm	0.02	$\pm 0.01$
Coil Radius	mm	[0 ; 0.85]	[0.5 ; 0.85]
Coil height	mm	[0 ; 0.4]	[0 ; 1]
Magnet height	mm	[0 ; 0.5]	[0 ; 0.5]
Coil Current density J	A/mm <sup>2</sup>	[0 ; 100]	[0 ; 100]
Magnet magnetisation M	T	1	1

With the preceding constraints, come to be added constraints on the outputs (Table II) of the model: the force developed by each micro actuator and the heat losses by the coil which also is the objective function.

TABLE II

Output parameters	Unity	Planar	Solenoid
Axial force	mN	1	1
Heat losses	W	minimum	minimum

#### F. Optimization results.

After having plugged the model into the software optimizer (CDI-Optimizer [5]) and configured its input and output parameters according to specifications, the optimization process was launched: an algorithm based on SQP approach was chosen [7] in the software optimizer. Figure 9 shows the geometrical evolution of the two structures before and after optimizations.

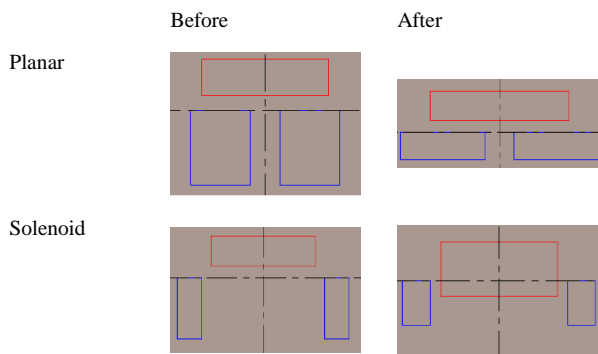


Fig.9. Geometry evolution before and after optimization

#### G. Multi objective optimization

With the same specifications on the input parameters, each model was optimized for several output parameters (For several values of given force, the values of the Joule losses

were minimized).

Hence each optimization process gives a new shape to each structure. This method is known as the Pareto border. The result demonstrates (figure 10) that for any given force, at a constrained diameter, the associated planar structure is more efficient than the solenoid structure.

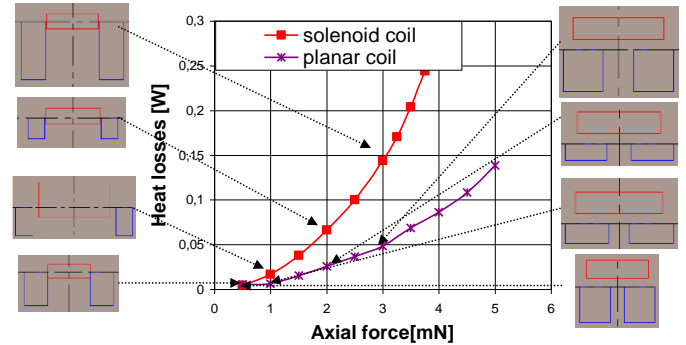


Fig. 10. A comparison showing the effectiveness of the planar coil.

## V. CONCLUSIONS

The integration of the volume segmentation method (implemented in Dipole3D) into an optimization software was done to meet the demand for microsystems modeling. The automatic generator was created in the aim to offer to microsystems designers a handy tool which helps them to size their devices. It was applied to the modeling of the micro-actuator for the deformable mirror. The optimization result gives the best structure between two coils shape.

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