



HAL
open science

Gradient based optimization of semi-numerical models with symbolic sensitivity: Application to a simple ferromagnetic MEMS switch device

Benoît Delinchant, Harijaona Lalao Rakotoarison, Vincent Ardon, Olivier
Chadebec, Orphée Cugat

► To cite this version:

Benoît Delinchant, Harijaona Lalao Rakotoarison, Vincent Ardon, Olivier Chadebec, Orphée Cugat. Gradient based optimization of semi-numerical models with symbolic sensitivity: Application to a simple ferromagnetic MEMS switch device. 10th International Workshop on Optimization and Inverse Problems in Electromagnetism (OIPE 2008), Sep 2008, Ilmenau, Germany. pp.192-193. hal-00324091

HAL Id: hal-00324091

<https://hal.science/hal-00324091>

Submitted on 24 Sep 2008

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Gradient based optimization of semi-numerical models with symbolic sensitivity: Application to a simple ferromagnetic MEMS switch device

B. Delinchant, H.L. Rakotoarison, V.Ardon, O. Chadebec, O. Cugat

G2ELab : Grenoble Electrical Engineering Lab
 ENSIEG - BP 46 - 38402 Saint-Martin-d'Hères FRANCE
 E-mail: Benoit.Delinchant@G2ELab.inpg.fr

Abstract: This paper is about electromagnetic modelling dedicated to constrained optimization needs. A modelling tool based on a ferromagnetic MEMS switch device is presented which allows semi-numerical modelling with symbolic gradient computation. A multi-level optimization strategy is used to ensure quick and robust convergence.

Keywords: Optimization, Gradient, Sensitivity, Multi-level, MEMS.

I. Introduction

Designing an electromagnetic device requires optimization algorithms and models. In this paper, the virtual design of a ferromagnetic MEMS switch -and especially its preliminary sizing- is addressed, using MacMMems software [1] for the modelling and CADES framework [2] for the optimization. The modelling software can produce parameterized semi-analytical modelling of the device with symbolic sensitivity. Thanks to accuracy parameters, a multi-level strategy can be deployed in the optimization framework.

The ferromagnetic switch (also called "magnetic latch") is used as an optical switch in our case ; it is based on the rocking actuation of a ferromagnetic plate under the influence of a magnetic field variation. In our device, the static magnetic field is produced by a permanent magnet and altered by planar coils, as sketched in Fig. 1.

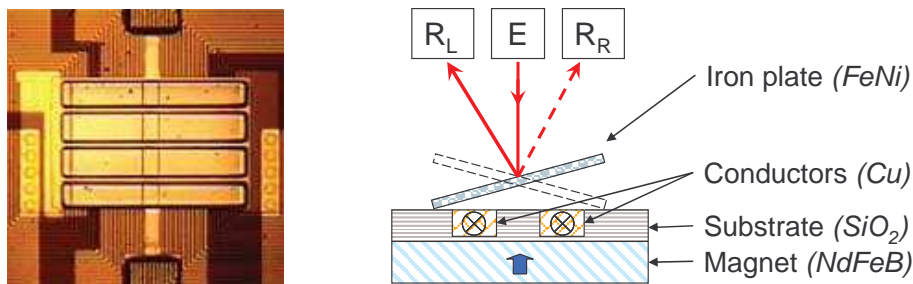


Figure 1: Photo of a Mag-Latch switch (©MicroLab / MagFusion Inc.) and schematics.

II. Modelling

II.1 Modelling software

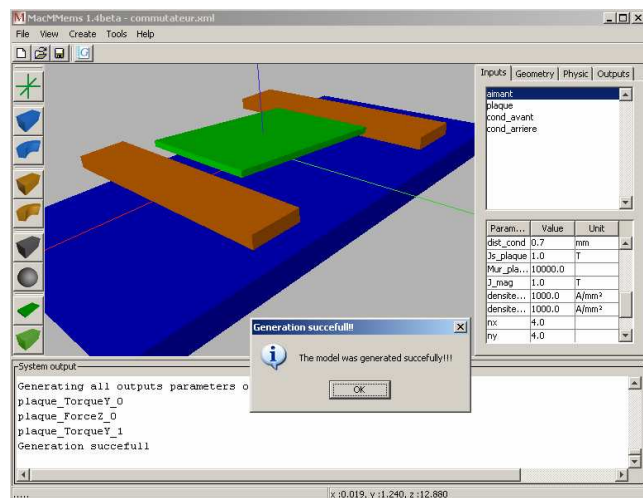
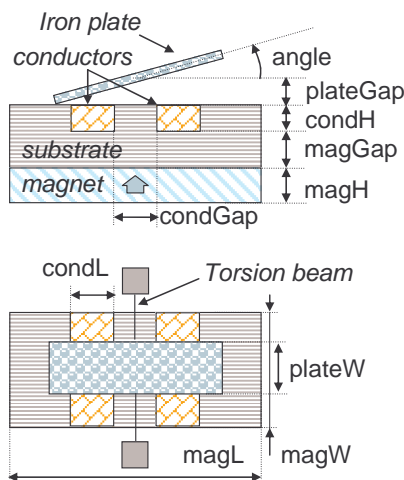


Figure 2: Left: Mag-Latch Parameters. Right: MacMMems (Macro Modeller for Magnetic MEMS)

II.2 Semi-numerical modelling

II.2.1 Modelling magnetic fields from permanent magnets and coils

Magnetic fields are computed from field sources using pure algebraic equations, thanks to basic geometries. A Coulombian equivalent surface charge approach is used for magnets. For conductors, the Biot and Savart law leads also to simple equations (these equations are not given here since at least one full page would be required).

II.2.2 Computing torques on the ferromagnetic material

The ferromagnetic plate is discretised along the X,Y and Z axes, then the Method of Moments (MoM) is applied to compute a uniform induced magnetization in each elementary block [3]. The material is defined by an H(B) curve, parameterized by the saturation induction and initial permeability. After the convergence of a Newton-Raphson implicit solver, each block magnetization is obtained, and the torque can then be computed.

II.2.3 Symbolic derivation

First of all, CADES framework is able to compute formal sensitivities from algebraic equations. For numerical solvers such as integrals (needed to compute torques and forces or fields produced by more complex shapes) or such as the previous MoM, a specific sensitivity solver is added [4]. This sensitivity solver provides a quicker and more robust approach than the finite differences which are generally used for gradient based optimization algorithms.

III. Comparison with FEM

To plot the curve on Fig.3, the FEM solver runs during 2 hours; in contrast, the MacMMems model needs only 5 seconds for a ferromagnetic part decomposed in 6x3x1 blocks.

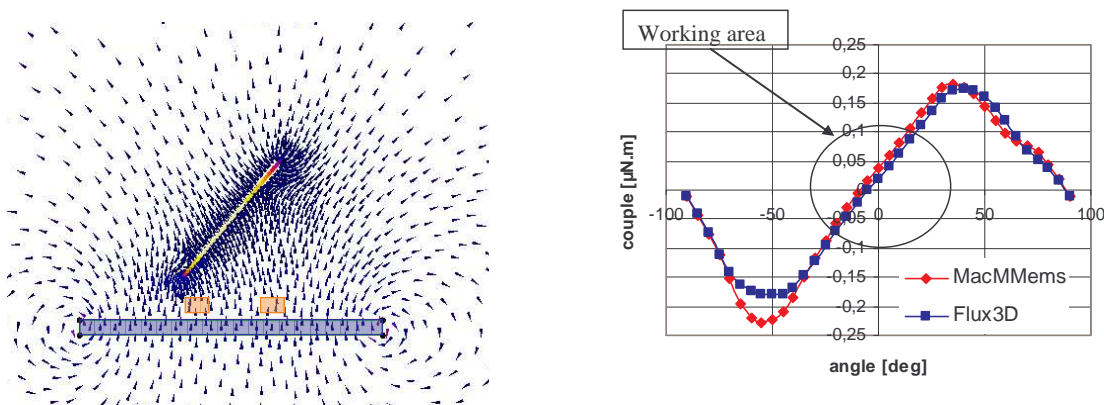


Figure 3: Left: 3D FEM solver (Flux3D). Right: comparison between FEM and semi-analytical solvers

IV. Optimization and Conclusions

The main goal of the optimization was to dimension the actuator and its electrical control so as to minimize Joule losses, while respecting constraints such as the minimal torque guarantying commutation. A stochastic multi-start strategy on Quasi-Newton optimization (SQP) was applied on a coarse model (6x3x1=18 blocks) to avoid local minima; a fine model was then used (12x6x2 = 144 blocks) from the previous result, in order to converge rapidly to an accurate solution as shown in Table 1. Global optimization time was 10 minutes.

TABLE 1: OPTIMIZATION RESULTS

Parameters	Multi-start (10) SQP on Coarse model	SQP on fine model
Joule Losses (mW)	12	14
Iterations number	1450	12
Duration (min)	8	2

In this paper, the use of semi-numerical modeling with symbolic sensitivity has demonstrated its usefulness in the area of gradient based optimization to design electromagnetic devices based on simple shapes like MEMS.

REFERENCES

- [1] H. L. Rakotoarison, B. Delinchant, O. Cugat "Methodology and tool for generating semi-analytical models used to pre-design electromagnetic MEMS", CEFC 2006, Miami, FL USA - April 30th - May 3rd 2006
- [2] B. Delinchant, D. Duret, L. Estrabaut, L. Gerbaud, H. Nguyen Huu, B. Du Peloux, H.L. Rakotoarison, F. Verdiere, F. Wurtz, "An optimizer using the software component paradigm for the optimization of engineering systems", COMPEL Vol 26, Issue: 2, 2007
- [3] O. Chadebec, J. L. Coulomb and F. Janet, "A Review of Magnetostatic Moment Method", IEEE Transactions on Magnetics, Vol: 42, No: 4, April 2006, pp.515-520.
- [4] H. L. Rakotoarison, V. Ardon, O. Chadebec, B. Delinchant, S. Guerin, J. L. Coulomb "Formal Sensitivity Computation of Magnetic Moment Method", to be published in IEEE Transaction on Magnetics, April 2008