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Using Perturbation Force Analysis for the Design of a Levitron© : an Application of Magnetic Levitation

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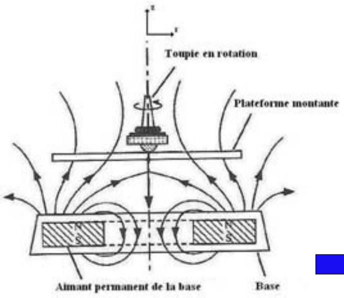
Objective: developing a FEM-based design procedure for the realization of a Levitron© in laboratory, using second-hand components.

Issues:

- generation and tuning of COMSOL© models for available permanent magnets,
- perturbation analysis on magnet models, in order to derive a configuration which allows stable magnetic levitation,
- force computation on magnets from finite element models.

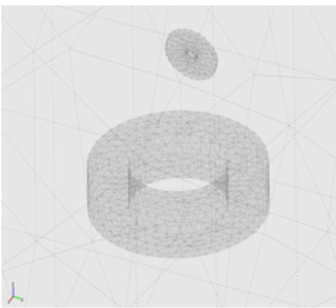
1. The Levitron©



- Earnshaw's theorem: no stable equilibrium allowed for static fields,
- Levitron© : gyroscopic torques maintain the top in nearly vertical alignment (flipping phenomenon)

→ Stable equilibrium area along z axis

2. Numerical model



- ***AC/DC module - Magnetostatics - No currents*** *(3D)*:

$$\Omega: \quad -\mu_0\vec{\nabla}\left(\vec{\nabla}\psi\right)+\mu_0\vec{\nabla}\vec{M} = 0$$

$$\Gamma: \quad \frac{\partial\psi}{\partial n} = 0$$

(total magnetic scalar potential ψ)

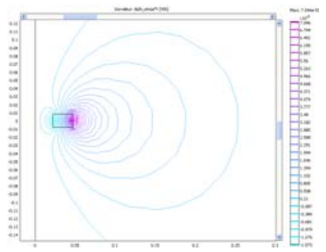
- ***Constitutive law***:

$$\vec{B}=\mu_0\left(\vec{H}+\vec{M}\right)$$

3. Magnetic component identification

Measurements using a gaussmeter

VS



COMSOL© finite element models

→ Tuning of M_z to fit simulation results with measurements

4. Perturbation analysis

- ***two models for M***

$\vec{M} = M_z\vec{u}_z$ — ***(M₁)***: rigidly z oriented

$\vec{M} = M\frac{\vec{H}}{\left\|\vec{H}\right\|}$ — ***(M₂)***: same direction as base magnetic field (flipping motion)

- ***Equilibrium***
  - ***Stability***: obtained when axial (*z* oriented) and radial (*r* oriented) excursions of the top around equilibrium are simultaneously compensated by opposite perturbation forces f_r and f_z
  - ***Static***: magnetic force exerted on the top is balanced by gravitation

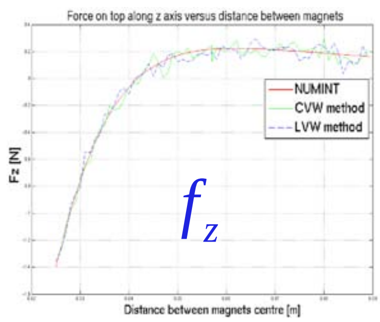
5. Force computation

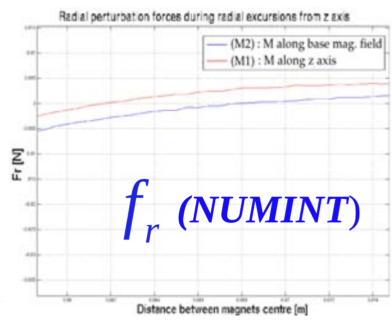
- $\vec{F}=\mu_0\iiint_{\Omega}\left(\vec{M}\vec{\nabla}\right)\vec{H}d\Omega$ ***(NUMINT)***

Three methods:

- $F_i = \left.\frac{\partial W'}{\partial i}\right|_{\psi=ct}$ (based on Virtual Work theorem)
  - All nodes displaced « en bloc » ***(CVW)***
  - One node displaced at a time ***(LVW)***

6. Results





	Stability Area [mm]	Top mass [g]
Our approach (M_2)	62 – 68	22.3 – 22.8
Mag. dipole app. ([1])	61 – 66	19.7 – 20.3
Exp. results	62 – 68	25.9 – 26.2

- ***Stability area***: in good agreement with experience,
- ***Top mass*** : better than [1] (integration over entire top), but smaller than experience (measurement errors)

References

[1]: Z. De Grève, C. Versèle, and J. Lobry: « Étude Théorique, Simulation et Réalisation d'un Lévitron à l'aide du Logiciel de Calcul par Éléments Finis Comsol Multiphysics», to appear in *Proceedings of the CETSIS Conf.*, October 2008