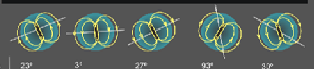
MEMS-based gradiomenter for the complete characterization of martian magnetic enviroment

Jose Luis Mesa* (1), David Ciudad (2), Michael E. McHenry (3), Claudio Aroca (2), and Marina Díaz-Michelena**(1)

(1) Instituto Nacional de Técnica Aeroespacial (INTA), Torrejon de Ardoz, Spain (mesaujl@inta.es), (2) Universidad Politécnica de Madrid, ISOM-ETSIT, Madrid, Spain, (3) Carnegie Mellon University, Pittsburgh, Pensylvania, USA

Planetary exploration

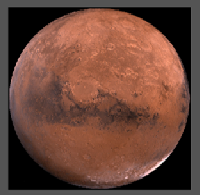
The measurement of planetary magnetic fields is an interesting way to determine some characteristics as atmosphere conditions, mineralogy, inner structure, etc. of planets and space bodies. Nowadays there is not available a system to determine it completely and accurately.

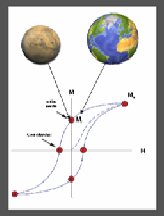


Tilt of rotation axis	23º	3º	27º	98º	29º
Tilt of magnetic axis	12º	10º	0º	59º	4.7º
Offset of magnetic axis	8%	10%	5%	31%	55%
Field at equator	31,000 nT	420,000 nT	22,000 nT	29,000 nT	13,000 nT
Magnetosphere	10 $R_{Mercury}$	65 R_{Earth}	20 R_{Saturn}	18R_{Uranus}	23 $R_{Neptune}$

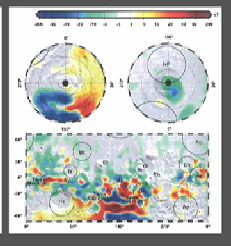
Mars case

The in-situ determination of the Martian magnetic field remanent in nature is one of the most important and ambitious objectives in Mars exploration, because its implications in paleomagnetism, tectonics and mineral determination. To place sensors on Mars is a complicated task, due to the extreme conditions of the planet surface and also because of the relative low budget devoted to this kind of instrument like power, mass, volume and the need to operate in a magnetically noisy environment.



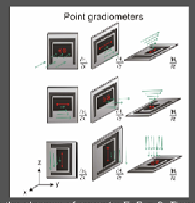


Model of the radial component of the magnetic field in Mars



Magnetic field: H+∇H

There are many developments of magnetometers with good characteristics either for space enviroment or on Earth applications, but the question about gradient is not that well solved and most gradient sensors are based on a couple of magnetometers separated a certain distance.



In the absence of currents: ∇xB = 0. Therefore, the gradient of the field is symmetric and to know six of the nine components is sufficient to reconstruct entirely the magnetic field gradient.

In this work we propose several point gradiometers for future planetary exploration with rovers.

Ideas for gradiometers

Physical principle:

$$F = \nabla(m \cdot B)$$

Knowing that ∇xB = 0 and that in our case:

$$\begin{cases} m = m_x \\ \nabla B = \partial B_x/\partial y \end{cases}$$

$$F = m_x \frac{\partial B_x}{\partial y}$$

This is the force experienced by the extreme of the cantilever.

Excitation:

Alternating magnetization:

$$m_x(t)$$

in the presence of a magnetic field gradient:

$$\frac{\partial B_x}{\partial y}$$

Detection:

Piezoelectric

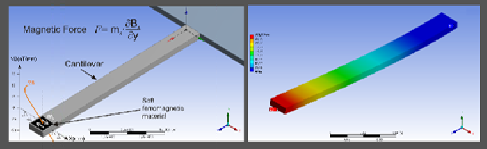
- Cantilever made of piezoelectric material.
- Phase and amplitude can be read electrically.

Optically

- Optical fiber
- Amplitude modulation and frequency / phase shift in the reflected light beam

Cantilever-based system

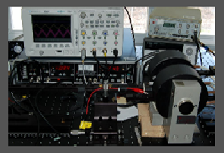
Every component of the system for gradient measure consists of a cantilever with an appropriate geometry, an excitation coil and a mechanism to generate a field gradient. The cantilevers are made of piezoelectric material (bimorph, with two piezoelectric layers) covered by a soft ferromagnetic material (of Iron-Nickel base).

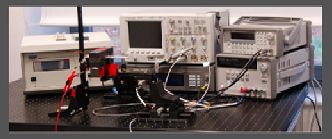


Developed system for gradient measures

First prototype | Second prototype

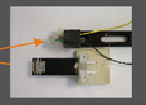
Complete set up





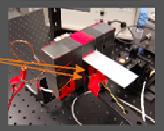
Cantilever Top View

Ferromagnetic ribbons



Gradient generation

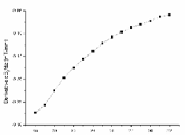
Permanent magnets

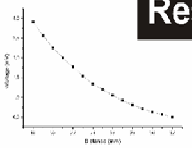


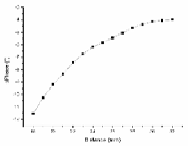
Results

First prototype: ·Hih stability
·Low resolution

External gradient generated by permanent magnets

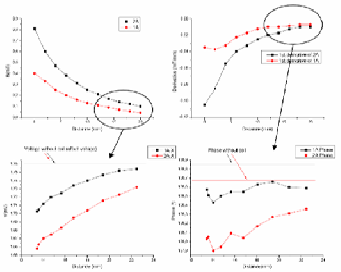






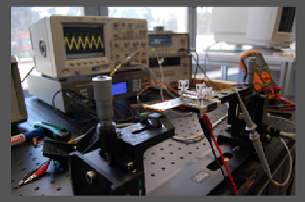
Second prototype: ·Low stability
·High resolution

External gradient generated by a coil



Future work

- New set up with
  - New excitation system based on microcoils
  - Optical detection
  - Cantilever resize towards a miniaturize system



- Ideas for measure procedure:
  - Double frequency modulation
  - Helical anisotropy properties of the ferromagnetic ribbons for magnetic force generation

Conclusions

In the present work it is presented the first steps for the construction of a gradiometer that measures directly the magnetic field gradient.

First prototype was very stable, but has the following handicaps:
- Limitations on its size.
- Low voltage signal, what did not allow us to reach the desired resolution (1nT/mm).
- Second prototype was more accurate and have higher resolution, nevertheless it was less stable implying low reproducibility.

Improvements and the future work suggested aims to build an appropriate operational gradiometer to be placed on board a rover for in situ determination of the complete magnetic enviroment of Mars.

Contact authors:* mesaujl@inta.es,** diazmar@inta.es

This work has been partially supported by the Spanish Ministry of Science and Innovation (MICINN) under the project reference PR-PIBUS 2011-1160.

References:

[1] Acuña, M.H.: Space-based magnetometers. Rev. Sci. Instrum. 73, 3717–3736. doi: 10.1063/1.1510570, Nov 2002.

[2] Marcoyn, J.M.G.; Kouzel, P.; Prendel, A.: Improved digital gradiometer of high stability and linearity, Sensor Actuat A-Phys., 120, 7–17, doi: 10.1016/j.sna.2004.11.014, Apr 2005.

[3] Lucas, L.; Michelena, M.D.; del Real, R.P.; de Manuel, V.; Plaza, J.A.; Dauta, M.; Jiménez, J.; Guerrero, M.: A New Single-Sensor Magnetic Field Gradiometer. Sensor. Lett., 7, 583–587, doi: 10.1166/sl.2009.1110, Aug 2009.

Contact autor:

Jose Luis Mesa Uña
Laboratorio de Magnetismo Espacial
Área de Tecnología de Cargas Útiles
Departamento de Cargas Útiles y Ciencias del Espacio
Instituto Nacional de Técnica Aeroespacial - INTA
E-mail: mesaujl@inta.es
Tlf: +34 915206351 ext: 5351