MAGNETIC LEVITATION USING HALL SENSOR: A PROJECT USING SCILAB

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Abstract : *The magnetic levitation of a metallic object provides a high-impact demonstration of principles related to the electric engineering, such as electromagnetic, mathematical modeling and control techniques. This paper presents an experimental approach of control of a magnetic levitation system (MLS). We detail the building of a MLS, the dynamic analysis of the system and the project of the compensated phase-lead controller, using the software Scilab. We present a prototype and simulation of the system response to some disturbances. With the proposed procedure we get a robust device, which can be useful for experimental practices in control class.*

Keywords : *Magnetic Levitation, software Scilab, Control Design*

1. INTRODUCTION

The stable suspension of a metallic object in an electromagnet fifield has been a subject of considerable interest since the 30´s Hurley and Wolfle (1997); Barbosa et al. (2004). Thus is usually called Magnetic Levitation System (MLS).

The basic principle of these systems consists in using a current to manipulate the electromagnetic fifield which can suspend the weight of a steel object and keep it suspended in the air Shiao (2001). This systems presents nonlinear dynamics and an open-loop instability dynamic behavior over a large operation region Grimm (2002). Due to these characteristics, the control problem is usually quite challenging to the control engineers. Recently, many works have been reported in the literature for controlling a (MLS) Yang et al. (2004); Hurley and Wolfle (1997); Choi and Park (1999); Hol et al. (2006).

Actually, studies of the MLS has been widely applied in various fifields. The elimination of the friction between rail and wheels for the magnetic levitation allowed the building of high-speed trains, the Maglev (Magnetic Levitator) passenger trains. In Germany, they arisen in the decade of 70 and adopted the attraction electromagnetic system for their levitation Daltrini et al. (2002); Jung and Baek (2003). Other important application is to obtain an alternative and clean electrical energy using plasma as fuel in a Tokamak machine Barbosa et al. (2004). The plasma needs to be maintained at least as $5000^{o}C$. At this temperature the plasma could melt the inner parts of the machine, there for it needs to be levitated.

In this case study, we build a MLS that uses a hall sensor positioning and a power transistor as a current drive for the electromagnet coil. Our aim is to present a stronger and stable MLS and a proposal for the controller design, with the use of the free software Scilab The magnetic force is obtained by using a high magnetic permeability core. The controller, is designed by means of the root locus analysis.

The outline of this paper is as follows. In the Section 2, the MLS is presented, as well his building aspects (structure of support, electromagnet and sensor), mathematical modeling and the experimental system. In Section 3, we present the building details and values. In section 4 *The Scilab Environment*, as the analysis tool, and the analogic controller obtained are presented. The results are presented in Section 5.

2. SYSTEM DESCRIPTION

2.1 MLS characteristics

The physical structure of the MLS is composed by a wood cradle that was used to settle the electromagnet and the electronics components.

The electromagnet used in this MLS is made of a inductor mounted in a *E* shaped coil. The coil is made of cast steel sheet that has a high magnetic permeability. It may be found inside voltage transformer. The inductor has a total of 1800 tuns and its maximum current is 5*A*.

The position of the steel object is perceived by the use of a Hall sensor, made of a crystal current conductor. This sensor is fixed in the lower part of the electromagnet and the voltage on the terminals varies with the magnetic field. The magnetic field changes when a ferromagnetic material is placed near the coil.

This type of sensor is indicated for MLS because the position of the levitated object is controlled by the voltage measured on the terminals of the Hall sensor. So we can have more than one reference point for the controller. Thus, any variation of the position of the object causes a variation on the magnetic field.

The current driver used in this MLS was a power transistor 2*N3055*. The 2*N3055* serves as a switch where the base is connected to the control circuit, the collector to the magnet coil to control the current that generates the field.

2.2 MLS modeling

An object of mass *m* is vertically levitated in a gravity field by a MLS device under action of two forces: attraction, electromagnet force, *F(H, I)* and weight force, *W*:

$$F(H,I) = k\frac{I^2}{H} \qquad (1)$$

$$W = mg \qquad (2)$$

where H is the distance between the electromagnet and object; I the current of the electromagnet; k is an electromechanical conversion constant (k>0) and g the acceleration of gravity.

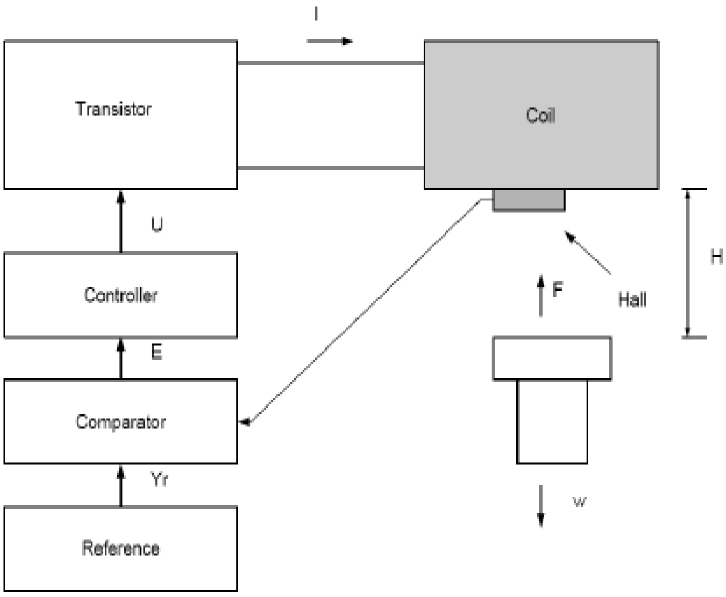

Figure 1- MLS Block Diagram

Using Newton's second law, we can write:

$$mg - k\frac{I^2}{H} = m\frac{d^2H}{dt^2} \tag{3}$$

The vertical movement of the levitated object is governed by a nonlinear dierential equation, Grimm (2002).

In Figure 1, it is showed the block diagram of the MLS. Once detected the distortion of the magnetic field the Hall sensor sends a small signal to the comparator who compare the received signal with the reference. This diference is the error signal injected in the controller block. The controller is connected to the base of a power transistor and this controls the current in the coil and therefore the magnetic field.

2.3 Linearization and transfer function

A simple linear controller based on a linearized model of the MLS may be used. A linearized dynamic equation can be obtained assuming that a levitated object operates around the equilibrium point, where the current *I* is kept at a constant value, I_0, and, respectively, $H=H_0$. *where H* is related to *I* by:

$$I = \rho U + \overline{I} \tag{4}$$

where *U* is the voltage in the current driver and $\overline{I}$ the current.

The relation between the voltage on the Hall sensor *Y* and the distance of the object *H* is given by:

$$Y = \gamma H + \overline{Y} \tag{5}$$

where $\bar{Y} > 0$ is a constant in the area of operation. It can vary from *6V* to *9V*.

Linearizing (3) by a first-order Taylor's and applying the Laplace's Transform, the MLS open-loop transfer function is

$$G(s) = \frac{A}{s^2 - \eta} \tag{6}$$

where

$$A = \frac{\beta\rho\gamma}{m} = \frac{2\rho\gamma}{H_0}\sqrt{\frac{kg}{m}} \tag{7}$$

$$\eta = \frac{\lambda}{m} = \frac{2g}{H_0} \tag{8}$$

and h> 0.

This transfer function shows that one pole is positive and, thus, the system is open-loop instable Grimm (2002); Chen (1999).

3 BUILDING THE MLS

The electric schematics of the MLS is shown in Figure 2. The *sensor* input in the schematics is the Hall signal. This signal varies between 0,5 and 0,7 *Volts* that is too small to work with. Therefore an amplification block was inserted. The *V*1 input was used as set point so the signal can be amplied. The *ref* signal is the input reference in the control block, it determines the set point do to the position of the object. *L*1 is the electromagnetic coil mounted in a high flux permeability metal.

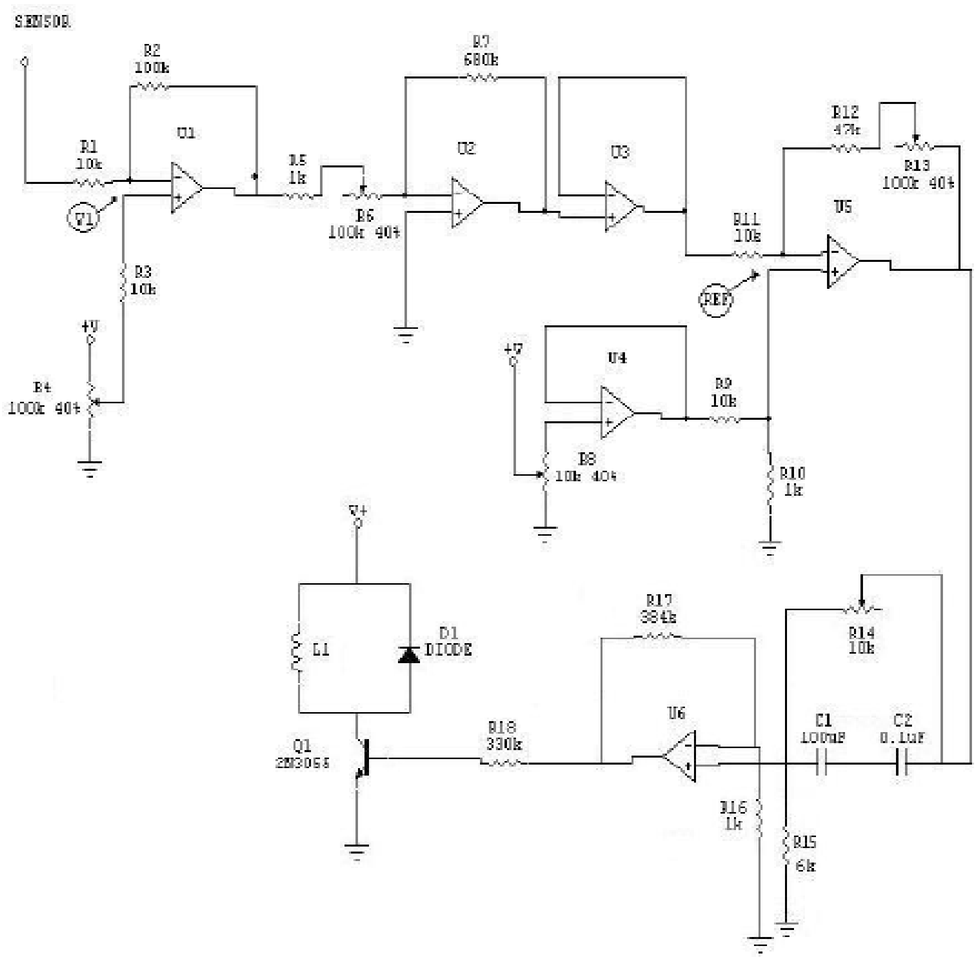

Figure 2- Schematics of the systems. In this gura, we present all electronic devices presented in the control structure. As one can see, all devices are easily obtained.

The Hall sensor Figure 3 is a current conductor crystal. A reference current is injected in one of the two pars of pins of the sensor, in the other is measured the potential diference caused by the interaction of the magnetic field of the current and the magnetic field of the coil.

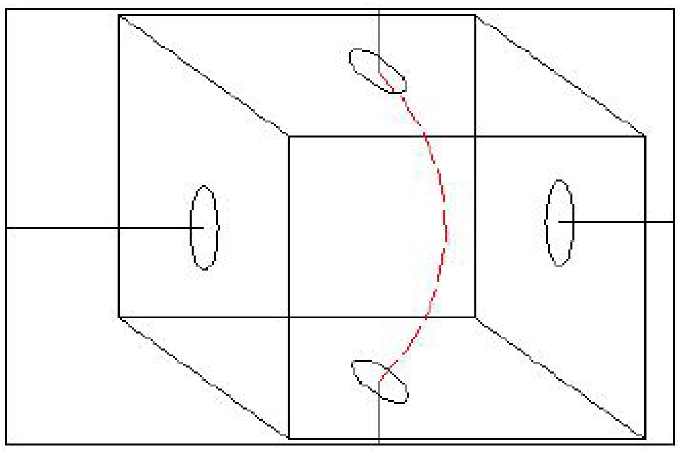

Figure 3- Hall Schematics

By direct measurement in the electric circuit we obtained the current necessary to levitate the object. With the distance and the current we obtained the linearized equation:

$$I = -0{,}000197814U + 0{,}332464106 \quad (9)$$

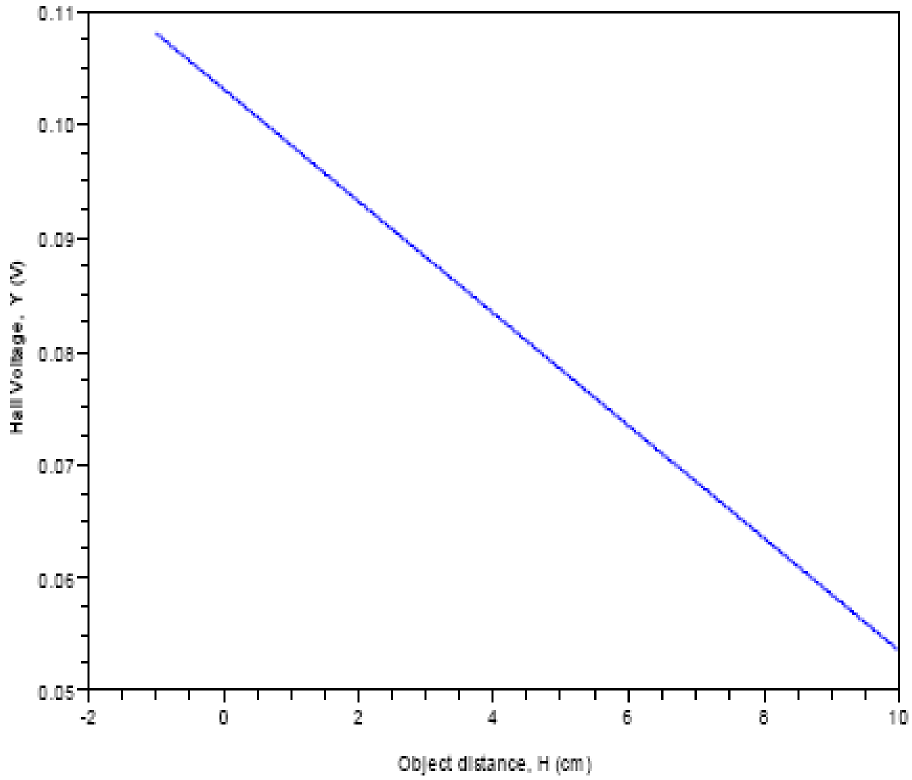

Figure 4- Hall Response HxY

$$Y = -0{,}3359H + 7{,}74 \quad (10)$$

$$G(s) = \frac{-0{,}03996}{s^2 - 1960} \quad (11)$$

Table 1 - Simulated Values

Mass m [*kg*]	Current I [*A*]
0,0010816	0,6
0,02	0,43
0,1557	1,2
0,35044	1,8
0,6323	2,4
0,9734	3

Table 2 - The MLS parameters

Parameters	Values
Ho	0,01*m*
I_0	0,43*A*
m	0,02*kg*
k	1,06 x$10^{-4}$$Nm^2/A^2$
g	-0,3359
r	-0,0001978

4. DYNAMICAL MODEL ANALYSIS

4.1 Analysis tool: the Scilab environment

Scilab is a scientific software package for engineering and scientific applications. Developed since 1990 by researchers from INRIA and ENPC is distributed freely and open source via the Internet since 1994. Scilab is currently being used in educational and industrial environments around the world.

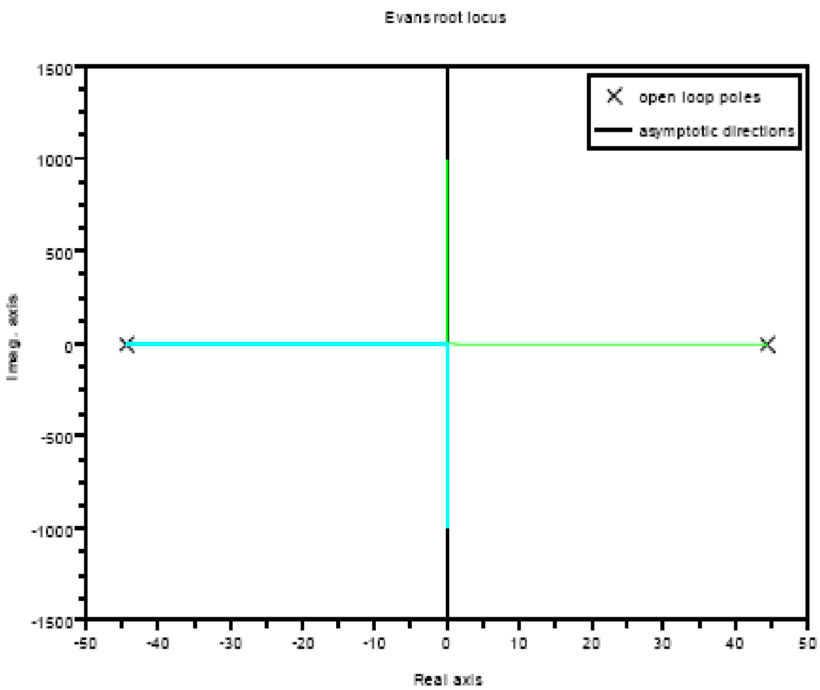

Figure 5- MLS uncompensated root locus

Scicos (Scilab Connected Object Simulator) is a Scilab package for modeling and simulation of dynamical systems. More specically, Scicos is a simulation environment in which both continuous systems and discrete systems co-exist and it can be used to model and simulate hybrid dynamical systems. Scicos provides a hierarchical *graphical editor* which can be used to build complex models by block diagrams which represent either predened basic functions defined in Scicos libraries (palettes) and user dened functions. Written in Fortran, C and Scilab language, it comes with complete source code. Scicos provides many functionalities available in Simulink and System Build Nikoukhah (2004).

Therefore, Scilab & Scicos are an alternative for use of the software suite Matlab developed by Math Works, Inc.. In our research group, we have adopted Scilab.

4.2 Phase-load compensated controller

The Equation 11 shows that the system has two symmetrical real roots: one is stable and the other is instable.

A way to analyze this system is to plot the Root Locus Diagram. This diagram shows the location of the poles and zeros of the characteristic equation of the system in the complex plane (*s* Plane), supplying information about its stability. This graphic shows the MLS is naturally instable as in Figure 5. A simplest way to stabilize the MLS is to use a phase-lead compensated controller Shiao (2001); Barbosa et al. (2004). In Figure 6 we have the block diagram of the controller using scicos.

The phase-lead compensated controller transfer function was obtained like shown in Grimm (2002) as:

$$Gc(s) = 47{,}40 \frac{s + 249{,}96}{s + 800} \qquad (12)$$

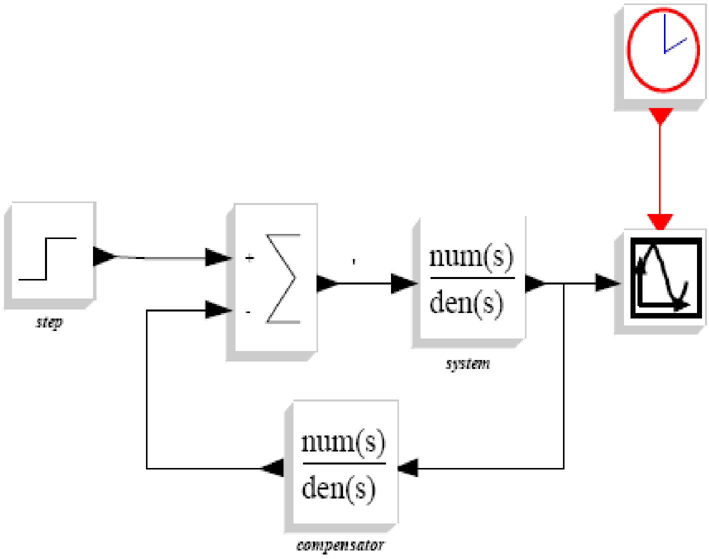

Figure 6 - Step Response Block Diagram using Scicos

After the setting time the object goes to a stable position as shown in Figure 7.

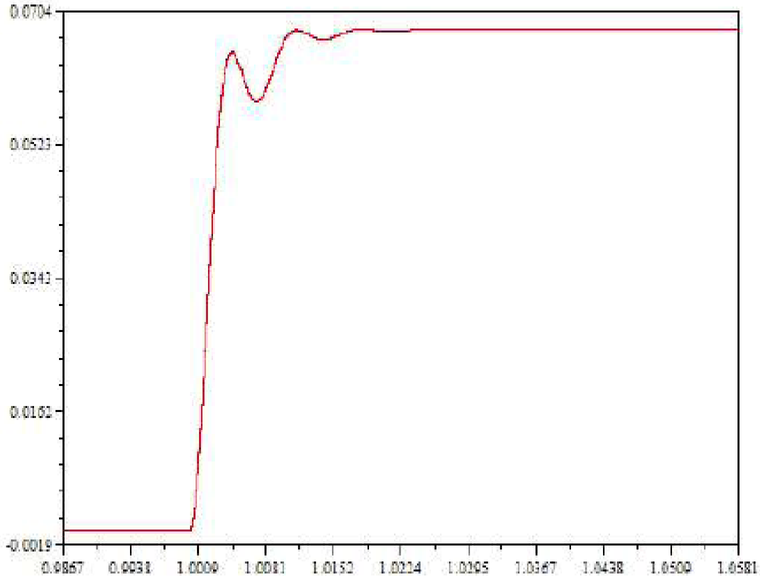

Figure 7 - Step Response

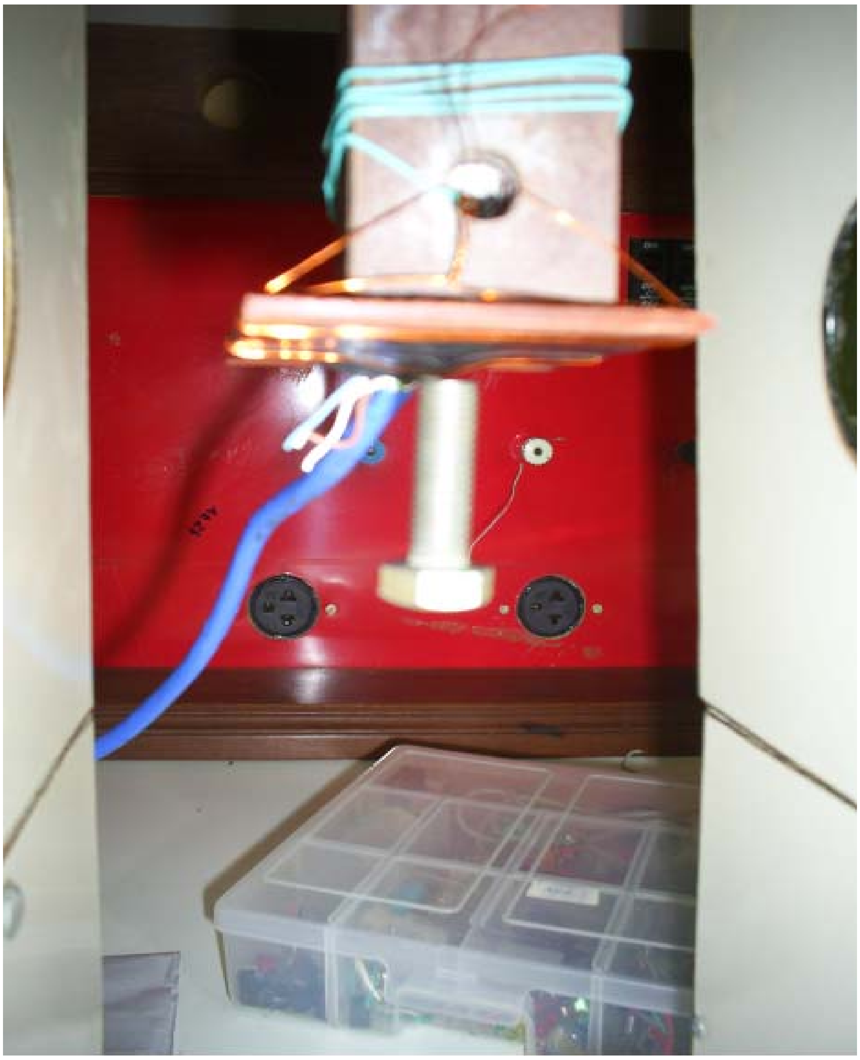

Figure 8 - Levitated Object

5. CONCLUSIONS

From the analyzes, we can conclude that the positioning system made by the Hall sensor has shown very eficient since it does not sufer interference from agents such as light (of any nature). However for high frequency the Hall sensor has shown low accurate. We were able to obtain an magnetic levitation stability for a object with 0,02*kg*, a current of 0,43*A*.

The use of the computational tools *Scilab* allows a larger freedom when testing the controller, without the necessity of building a new electronic circuit.

The vertical control positioning is crucial to the levitation of trains as the *MAGLEV* or other devices that use electromagnetic levitation. For instance the Tokamak project Barbosa et al. (2004) in Brazil that can be a new source to obtain a clear energy.

With the development of this project we were able to make a study of magnetic metals and alloys for a strong ferromagnetic meterial for the core also we obtaind datas for making strong eletromagnets. The eletromagnetic levitator described in this paper can be used for teaching control theory, we used a phase-lead controller but can also be done by PID as seen on control classes.

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