PRACTICA DE LABORATORIO DE BAJO COSTO PARA LA ESEÑANZA DE CONTROL EN INGENIERÍA ELÉCTRICA Y ELECTRÓNICA

Favio R. Masson and Osvaldo E. Agamennoni (*)

Instituto de Investigaciones en Ingenieria Electrica ¨Alfredo Desages¨
Departamento de Ingenieria Electrica - Universidad Nacional del Sur – Bahia Blanca – Argentina

Resumen: En el presente trabajo se describe un proyecto de laboratorio de bajo costo especialmente orientado a introducir conceptos de control de sistemas en alumnos de grado de ingeniería eléctrica y electrónica. El proyecto consiste en la utilización de un parlante utilizado como motor lineal el cual es controlado a fin de compensar la fuerza ejercida por una masa colocada sobre el mismo. Esta practica de laboratorio ha sido desarrollada por tres años en un curso de pregrado de control de sistemas y por un año en un curso de posgrado.

LOW COST LABORATORY PROJECT FOR CONTROL EDUCATION

IN ELECTRCAL AND ELECTRONIC ENGINEERING

Abstract: In this work we present a low cost laboratory project specially oriented to introduce control system concepts to undergraduate electrical and electronic engineer students. The project consists of controlling a loudspeaker used as a linear motor to compensate an external force generated by any mass placed over it. This project has been implemented for three years in an initial control course and for one year in an advanced one.

***Palabras claves*—Controls, Electromagnetic.**

1. INTRODUCTION

For control education, It is highly required the development of experimental practice in order to allow students to apply different control theories and techniques that provide them a good insight into process dynamics and control (C. Hang and T. Lee, 1990; P. Wellstead, 1990; J. Kocijan et al, 1997; J. Shields et al, 1999 and J. Jung et al, 2000). Although the importance of this practice has been recognized for a long time, there are limitations in the use of experimental devices for educational purposes. As the costs of these devices are generally high, they are prohibited for many institutions, specially if a large number of students is involved. Besides, the maintenance could also be expensive. On the other hand, it is an important challenge to motivate control systems students with an electronic background, by introducing them into the development of simple hand made control dynamical systems.

It is well known that one approach to overcome this challenge is using simple and affordable electrical an electronic laboratory elements. In the Universidad Nacional del Sur, Argentina different topics of Control Systems are under the curricula of

O. E. Agamennoni is also with the C.I.C. (Comision de Investigaciones Científicas). Provincia de Buenos Aires, Argentina.

Electronic Engineering, and for these students, electromagnetic and electronic systems are well known. With these premises in mind, a control a project based in the use of a loudspeaker as an electromagnetic scale was developed. Is not obviously a prototype of a real problem, however, it has a number of interesting features to appreciate linear and nonlinear modeling and controlling problems and its low cost and simplicity allows the direct participation of all the students. Also, the introductory control course is based on the book of Franklin *et al.* [6] where the modeling of a loudspeaker is considered. The project has been implemented the last three years in a Fundamental Control course and one year in an advanced Digital Control course. All the components for the project implementation are provided by the Laboratory and the cost is less than 40U$S per prototype.

The paper is organized as follows: In section II, the physics aspects of the Electromagnetic Scale is described. Section III shows the control project. Section IV presents some result performed by the students and finally, some concluding remarks are presented in Section V.

2. THE ELECTROMAGNETIC SCALE

The system built by the students receives the denomination of Electromagnetic Scale and can be described as follows. A current applied to the coil compensate the gravitational force of a mass placed on the cone. By maintaining the position of the cone in a given reference point, the current supplied to the coil is directly related with the weight of the mass standing over the cone.

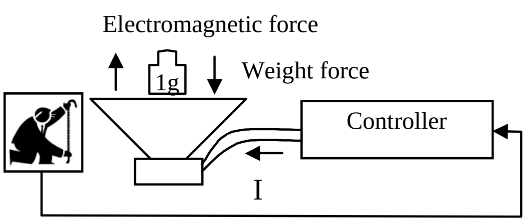

Figure 1: Sketch of the electromagnetic scale project.

The geometry of our electromagnetic scale is sketched in Figure 2. The permanent magnet generates a radial field in the cylindrical gap between the poles of the magnet. The force of a current flowing in the wire wound on the bobbin move up the plate over the cone. Then, the coil electromagnetic force can compensate the mass gravitational force by increasing the current. The necessary current to restore the plate to its initial position is proportional to the unknown weight. So there are two objectives: The control objective is to regulate the position of the cone, and then of the plate, in spite of the external perturbation (the unknown weight). The final objective is to measure the unknown weight through the measurement of the current necessary to compensate the perturbation.

To transform the loudspeaker (Figure 2) into a scale, the cone is opened in its center and an optical sensor is put inside it. A screw acts as a barrier for the light, allowing the adjustment of the reference position and a plastic pipe is used to transfer the movement of the coil to the scale surface. The loudspeaker is a bass type because a good response in low frequency is needed. The 50 watts loudspeaker allows scaling up to 250 gr.

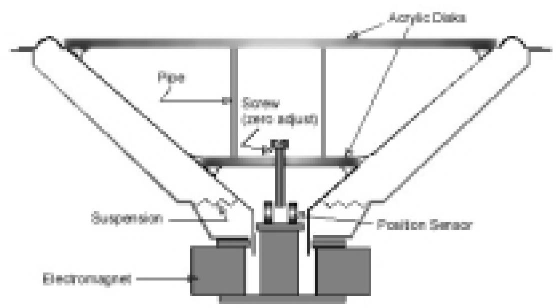

Figure 2: Electromagnetic scale scheme

2.1 Mathematical model of the plant

A free body diagram of the system can be seen in Figure 3. F_B is the force of the magnetic field and the current through the bobbin, F_b is the friction force, F_K the suspension force and F_g the gravitational force acting over all the moving mass. In Figure 3 positive position and displacements are also indicated.

Using Newton law the following differential equations may be written (1).

$$\begin{aligned} F_B + F_b + F_K - F_g &= -M\ddot{x} \\ BLi + b\dot{x} + Kx - Mg &= -M\ddot{x} \end{aligned} \quad (1)$$

where M is the total mass that include the mass of the plant and the mass of the weight, B is the magnetic field of the permanent magnet, L is the length of the wire of the bobbin, i is the current through it, g is the gravity acceleration and K is the elastic constant of the suspension of the cone.

The transfer function of the system is then obtained by applying the Laplace transform to Equation (1)

$$x(s) = \frac{-BLi(s)}{s^2\left(M_P + M_W\right) + bs + K} + \frac{\left(M_P + M_W\right)g}{s^2\left(M_P + M_W\right) + bs + K}. \quad (2)$$

This equation shows that the total mass M depends on the terms: M_P (plant mass) and M_W (weight mass).

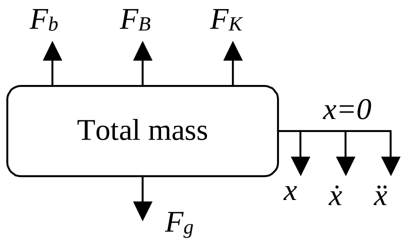

Figure 3: Free body diagram of the system.

From Equation (2) the following remarks can be derived:

1. A nominal function of the plant does not exist because the unknown presence of the unknown weight can change the poles location. In this sense, the system can be considered time variant.

2. The model is a linear approximation where some nonlinear effects, as the elastic suspension, have not been considered

3. In the present implementation, an optical sensor measures the position, and then equation (2) may be rewritten as follows:

$$V(s) = \frac{-BL\,i(s)\,K_s}{s^2 M + bs + K} + \frac{Mg\,K_s}{s^2 M + bs + K}, \quad (3)$$

where K_s is the constant that relates the position to the output voltage $V(s)$ in the optical sensor. As the gain of this sensor is very high, small displacements of few millimeters in the position produce an output voltage that spans all the dynamic range (from 0 to V_{CC}).

2.2 Identification of the System

To design a control law, the parameter identification of Equation (3) is needed. Due to the difficulties to know, for example, the length of the wire of the bobbin, a black box is used. The following general second order system with complex poles is considered:

$$output(s) = \frac{K_{sys} input(s)}{s^2 + 2\xi\omega_n s + \omega_n^2}, \quad (4)$$

where K_{sys} is the system gain, ξ is the damping ratio and ω_n is the natural frequency. A frequency response experiment may be implemented to search for the frequency that provides the maximum amplitude response and phase close to 90^0. The frequency value that provides this maximum is taken as ω_n. The damping factor is estimated by the evaluation of the transient response of the system when the input signal is disconnected at T_1. The shape of the envelope is:

$$v(t) = Ae^{-\xi\omega(t-T_1)}, \quad (5)$$

being A the amplitude prior to disconnect the signal. Let T_2 the time where the amplitude decays in A/e. Then ξ can be determined as:

$$\xi = \frac{1}{(T_1 - T_2)\omega_n}. \quad (6)$$

Finally, the overall gain K_{sys} in steady state can be measured. The described procedure allows the evaluation of the model of the system for any weight conditions. The parameters without any weight on the scale are shown in Table 1.

TABLE 1 IDENTIFIED PARAMETERS

Parameter	Value
B.L	60376.787
K	3016800
B	15500
M_{Sys} (system mass)	36.12 gr

3 CONTROL PROJECT

The electromagnetic scale as a feedback control system can be appreciated in Figure 4. In the controller design process, the following objectives were stated:

1. Weight on scale from 0 to 250gr.
2. Setting time 2 seconds.
3. Overshoot less than 30%.
4. Zero steady state error to step perturbations.

Besides, in the final report it is required the evaluation of linearity, precision and repeatability properties. The different weights, within the required range, introduce a perturbation as well as a change in the parameters of the control system. To achieve a good comprehension of the involved dynamic, the identification of the system with different weights in the specified range may be required.

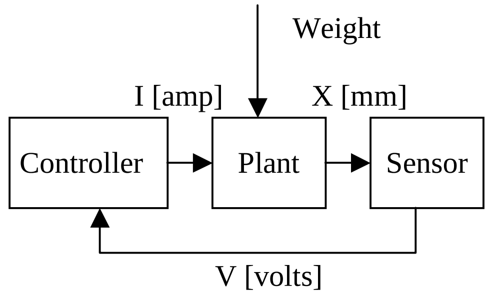

Figure 4: Sketch of the design problem: a plant with a perturbation

3.1 Controller Design

The general proposed controller is a PID (Proportional Integral Derivative). The controller transfer function is given in Equation 7,

$$D(s) = \left(\frac{1}{K_I s} + K_P + K_D s \right), \qquad (7)$$

where K_P, K_I and K_D are the proportional, integral and derivative parameters respectively. The controller structure (P, PI or PID) definition and the parameters evaluation is an open work to the students. They have to meet the design objectives using all the control background. The first students' approach to the design is made using root locus, by analyzing the weight change effect in the feedback loop.

3.2 Controller Implementation

A typical controller implementation is shown in Figure 5. This particular realization is done since electronic students are very comfortable using operational amplifiers.

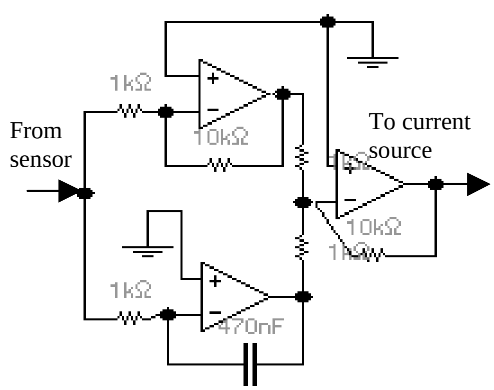

Figure 5: Circuit implementation of typical controller designed by the students

To maintain the system as a second order one, the output of the controller is directly connected to a current source. Working with voltage introduces an extra pole in (2) due to the electrical dynamics of the system.

4 Students Results

In this section, some students´ results that illustrate the three years experiences in a initial course of control and one year in a advanced one (Digital Control), are presented The laboratory equipment used by the students consist of a computer with an acquisition board and software especially designed and developed in our laboratory. Nevertheless, any ordinary data acquisition equipment may be used.

In Figure 6 a final report student measurement experience is presented. It can be appreciated the peaks introduced by the high gain of the optical sensor. The controller action removes the perturbation and the position returns to the reference in the required time. When the weight is removed, the system goes back to the normal position.

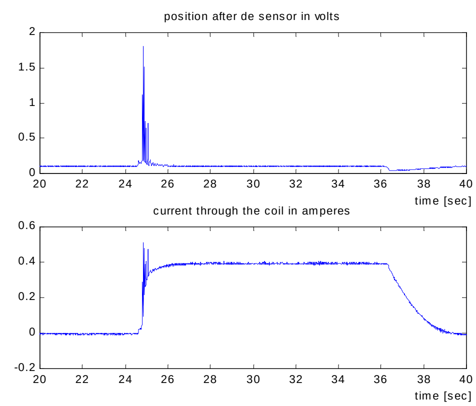

Figure 6: Position (up) and current (down) measured by one student.

Figure 7 shows a common implementation problem that reveals particular dynamic aspects. First, the position (solid line) does not return to the zero steady state, and then the perturbation is not rejected. But more interesting than this is the nonlinear behavior that can be appreciated. Although the current is growing (dashed line), the position is fixed. However, when the current achieves certain threshold value, the position tends to the stationary value. This effect is due to the nonlinear friction.

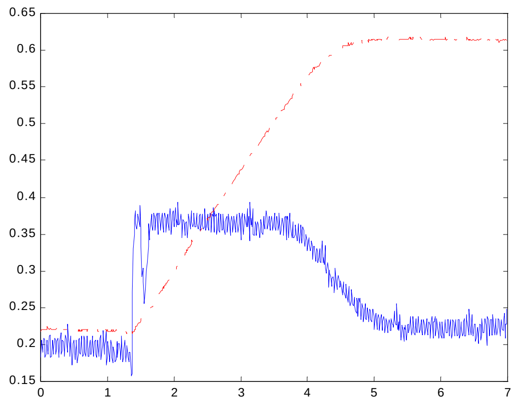

Figure 7: Position (solid line) and current (dashed line) reveals a nonlinear behavior.

5 COMMENTS AND CONCLUSIONS

The control project presented has some interesting features to be remarked. It is a simple and cheap system that can be easily built by a student and allows the appreciation of a number of control problems. The theory and practice needed to develop this project is contained in a basic control course like Franklin et al (1994). Then, to include this project in the course is straightforward. In the modeling stage, the students face the uncertainty and the time varying nature of the system. In a basic control course this part of the assignment needs some assistance, but for a high level course is a very good challenge. For example, some identification techniques like LMS and configuration of digital control in a robust approach (Kuo, 1991) may be applied. The controller, in this case, is programmed in a computer with the same software used in the fundamental control course

Finally, in a student survey, all of them expressed the helpfulness of this project to improve the knowledge acquisition of control problems.

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