Using a DC Solenoid in a Closed-loop Position Control System to Teach Control Technology

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ABSTRACT

A DC solenoid that is normally operated in two positions, is used to implement a closed-loop, position control system. The laboratory work supports and reinforces material presented in the classroom. This laboratory activity takes place in a cooperative learning environment, each group being populated by students from the Electronic & Computer Technology, the Manufacturing Technology and the Aeronautical Technology Department. Students are initially given a general positioning problem with few restrictions. Then, by adding constraints and making suggestions, they determine that a DC solenoid is a viable solution. As the students evaluate the system, they recognize that without the mathematical tools that they are acquiring in class, their task is very difficult or impossible. The series of experiments enable students to learn more about: (a) modeling, (b) block diagram representation, (c) instrumentation and data acquisition, (d) component characterization, (e) frequency response testing (f) analysis, (g) computer simulation using MATLAB/SIMULINK, (h) controller design, (i) implementation of the controller using op-amps, and finally (j) complete system performance verification. As a result, students develop a good connection between the theory and application, and recognize the importance of team work and collaboration. They are amazed at their ability to transform a two-position device, jokingly referred by them as bang-bang, into a gentle-moving system that goes to any intermediate position.

INTRODUCTION

Regardless of the specified field the engineering technology graduate eventually pursues, an understanding of dynamic modeling and analog feedback control is essential. These disciplines bring together many previously unconnected ideas. The laboratory component is extremely important and helps students make a connection between the concepts and the application. The laboratory experience allows the student to develop familiarity with hardware, specially if they use the same hardware throughout the semester. To optimize the experience, the instruction must continually aim at making a connection between the theory and the application. Otherwise, the student is overwhelmed by the excessive mathematics and its complexity.

This paper focuses on the laboratory component of a Control Technology course (EET406) at Arizona State University. It is a required course for the students in the Department of Electronics and Computer Technology who have chosen Electronic Systems as their area of emphasis. In addition, students from other disciplines (Aeronautical, Manufacturing, and Mechanical Technology) are also enrolled. A parallel graduate course is also offered. In the undergraduate course the laboratory is mandatory. For the graduate class, the laboratory is optional, but encouraged. Textbooks [1,2,5,6] normally used in engineering curricula, together with handouts have been used.

The laboratory experience takes place in a collaborative environment setting. Students from the various disciplines mentioned above make up the teams. Early experiments attempt to create a common starting point. They also allow the student to recognize the many similarities and analogies between the different technologies (electrical, mechanical, etc.). These early experiments are followed by a set of focused experiments, whose aim is to teach and reinforce control systems tools and techniques, while designing and building a closed-loop position control system using a solenoid. Gradually, the students experience the transformation of a solenoid, from a two-position device in open-loop, to a modulated positioning device, in closed-loop mode.

WHY TEACH CONTROLS IN ENGINEERING TECHNOLOGY?

Many classes in an engineering/engineering technology program address components, their characteristics, and subsystems using them. A controls course, on the other hand, provides a systems approach to problem solving. Exposure and training using a systems approach, offers the graduates skills that are likely to be useful no matter what field they will pursue [4]. In addition, it helps the individual develop a generalist attitude that is a trademark of the engineering technology graduate.

In depth interaction with a particular control system alerts the students to issues associated with correlation: how changes in one parameter affect other variables. It also allows the students to appreciate the many advantages of a closed-loop system.

A controls class with a complimentary laboratory allows the students to develop an appreciation for transfer functions and their characteristics. Students learn how effective these concepts are in describing the static and dynamic characteristics of a component or a subsystem. They become believers, for instance, that a low-pass RC filter and a lag (or low-pass filter transfer function) are really equivalent. Most important, they learn a language that allows them to communicate with control engineers from other disciplines.

Another side benefit of a control laboratory is student exposure to, and practice with, laboratory instrumentation. Though effective labs have output variables that are visible, there is always a need for instrumentation to evaluate the system.

Further, as students see the functional similarities between the different technologies (electrical, mechanical, etc.), and recognize analogous variables, they feel more confident in working with a system that is outside their particular area of training.

Fortunately, due to the computing power and user-friendliness of present computer programs, the mathematical rigor, derivations and excessive hand calculations of the past are no longer a barrier. Modern computer programs are particularly beneficial to the engineering technology graduate who has an applied orientation rather than a theoretical one.

Finally, an analog feedback control class offers an excellent preparation for those who will take a class in digital control.

CONTROL TECHNOLOGY CLASS OFFERED AT ASU

The one semester course consists of three 50-minute lectures, and a weekly, 2-hour lab. We take advantage of the diversity of backgrounds found in students from the previously defined departments, and form cooperative learning teams. Each team has members from each of the four programs. This approach is valuable in dealing with systems that integrate various technologies. For instance, Electronic & Computer Technology students can explain how an operational amplifier works to their fellow Manufacturing Technology team members, while the later does the same for the earlier in dealing with fluid problems. If the guidelines for good cooperative learning are followed (team building, individual accountability, etc.), interaction and depth of learning are excellent. Not only do the students develop their skills in communications and team dynamics, but they also become more prepared for what they will encounter in industry.

The initial preliminary four labs allow the students to reach a common level of understanding. They also motivate the students to brush up on basic concepts. This preparatory phase is reinforced with quizzes and close teacher-student interactions. All subsequent labs focus on control issues associated with the solenoid. The four preliminary labs are:

Lab 1: Fundamentals: Review of Laplace Transform and exposure to MATLAB/SIMULINK
Lab 2: Electrical System: RC Circuit
Lab 3: Fluid System: Discharge of a water column through a fluid restriction at the bottom.
Lab 4: Mechanical System: A mass-damper-spring system

These labs allow the student to get a taste for modeling dynamic systems. This author believes that for a student to learn modeling well, more time than a few weeks is necessary. He suggests a class totally dedicated to modeling prior to taking controls.

In the lab, the students work directly with hardware, which is motivating [3] to most students. In addition, the also perform simulations using MATLAB/SIMULINK. The graphical environment of SIMULINK eases learning, and allows them to build complicated systems. Once they have accepted the transfer function concept, they are comfortable using MATLAB alone. Subsequent labs focus on other topics of feedback control, using a solenoid position control system.

A DC SOLENOID AS A VEHICLE FOR TEACHING FEEDBACK CONTROL

After the student completes the first four labs, the lab format changes. Subsequent labs are more of a interactive/exploratory nature, rather than primarily consisting of calculations and computer simulations. These labs focus on making a closed-loop, position control system using the solenoid. The lab handout is distributed early in the week, and it has questions/exercises that are due at the beginning of the lab. This motivates the students to do some preparatory/reflective work before they come to the lab. Often, they do not have all the answers. This approach serves several purposes. Students develop an appreciation for the many components necessary for a closed-loop control; they also recognize that closing a loop is not as easy as they may have thought. Often students need to recognize that they do not know all of the factors that affect the current problem. Many questions are open-ended.

The first lab in this second category is presented as a problem given to a controls engineer: an animation/special effects company wants a drive system that will move the jaw of a plastic figure proportionally to an electrical command signal. The head is connected to a plastic-tube-rod mechanism that goes to the system that the controls engineer (the student) will design (See Figure 1). After this introduction, the students are asked to come up with possible implementations to accomplish the stated task. No restrictions are placed on what particular technology or method they must use. They are instructed to do this individually and later, to share and explain their ideas with the rest of the group. A tremendous variation in what the students produce at this time has been observed.

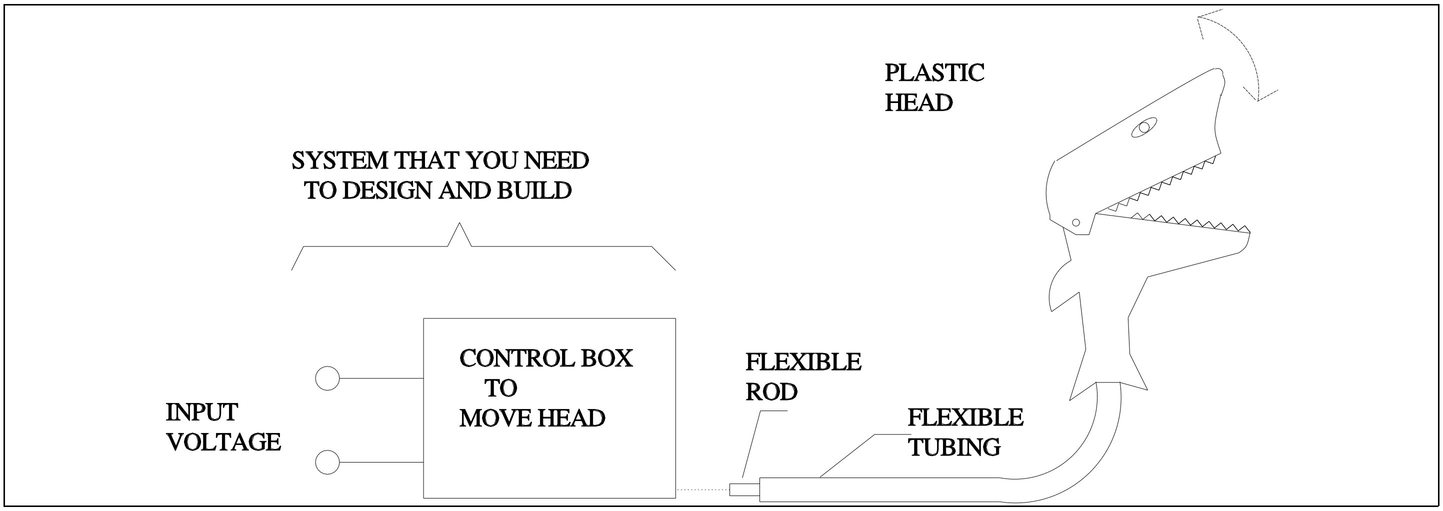

Figure 1: Plastic figure that need to be activated.

Next, the instructor, taking the role of the chief engineer, makes a suggestion. He tells the class that a DC solenoid, with some enhancements, will accomplish the job. Further, he just happens to have a solenoid/spring arrangement (Figure 2a), which he wants the students to evaluate. By means of the lab handout, the student is asked to apply a variable DC voltage to the solenoid-spring arrangement while measuring current and plunger position. As the plunger moves in, the same current creates a much larger force, which makes the plunger quickly move in all the way. Thus, only two positions are possible, and students fail to obtain intermediate positions. The instructor then explains to them the reason for the two states of the spring/solenoid, using Figure 2b. He also explains to them that with feedback this difficulty can be overcome. This is for some a review of electromagnetics, while for others it is a first-time experience. It is important to review basic electromagnetics, to maximize their understanding.

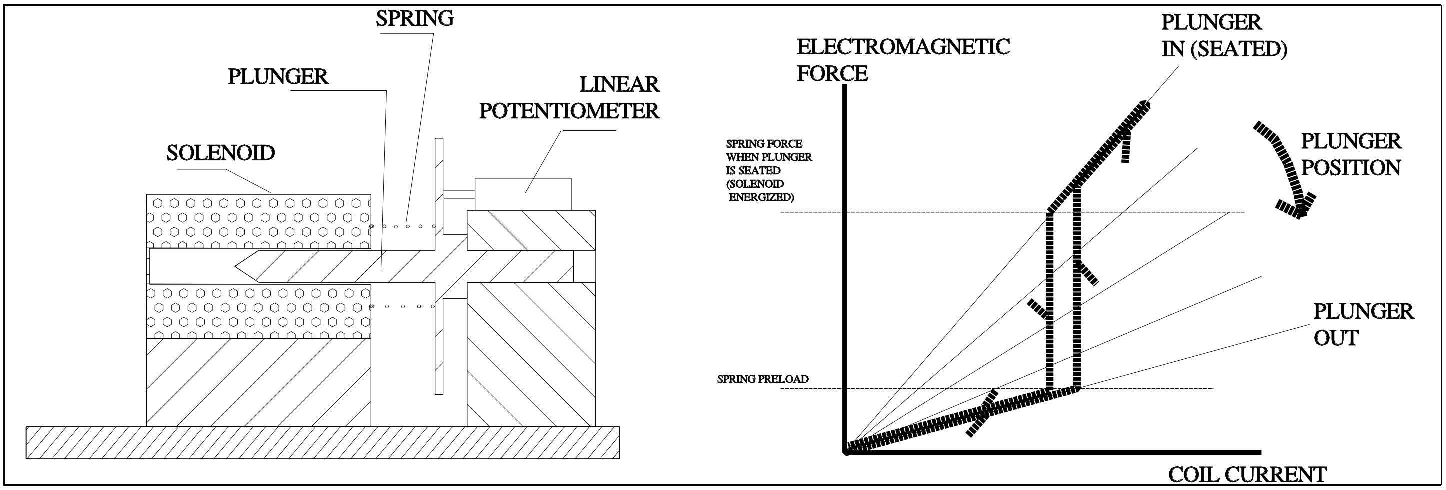

Figure 2: Schematic of solenoid set-up and its current-force characteristics.

Prior to working with the solenoid problem, the students are given simple homework problems that can be solved by hand. After they completed it, they are asked to solve the same or similar problem with the computer (MATLAB/SIMULINK). This approach is used to reinforce the topics presented in the lecture, such as transient response, frequency response, root locus, etc. After this homework is turned in, they are asked to perform the procedure for the solenoid problem. In this manner, the student is guided through a series of exercises that mimic the tasks and reasoning processes that a controls engineer will perform.

The student is told that the control implementation, shown in Figure 3, is a good starting point. Then, the students are asked to model the system and produce a block diagram representation (Figure 4). students are amazed at the large quantity of information that is embedded in such a diagram. They also realize that many of the blocks in the diagram represent a linearizations about an operating point. The student is guided to perform additional measurements (mass, spring constant, etc.) the same way that a controls engineer would do. The method of parameter estimation via frequency response testing is presented. The system is excited with a very low frequency sinusoidal input, while recording the input and the error (VD) with a storage oscilloscope. This information is the used to calculate the open-loop gain.

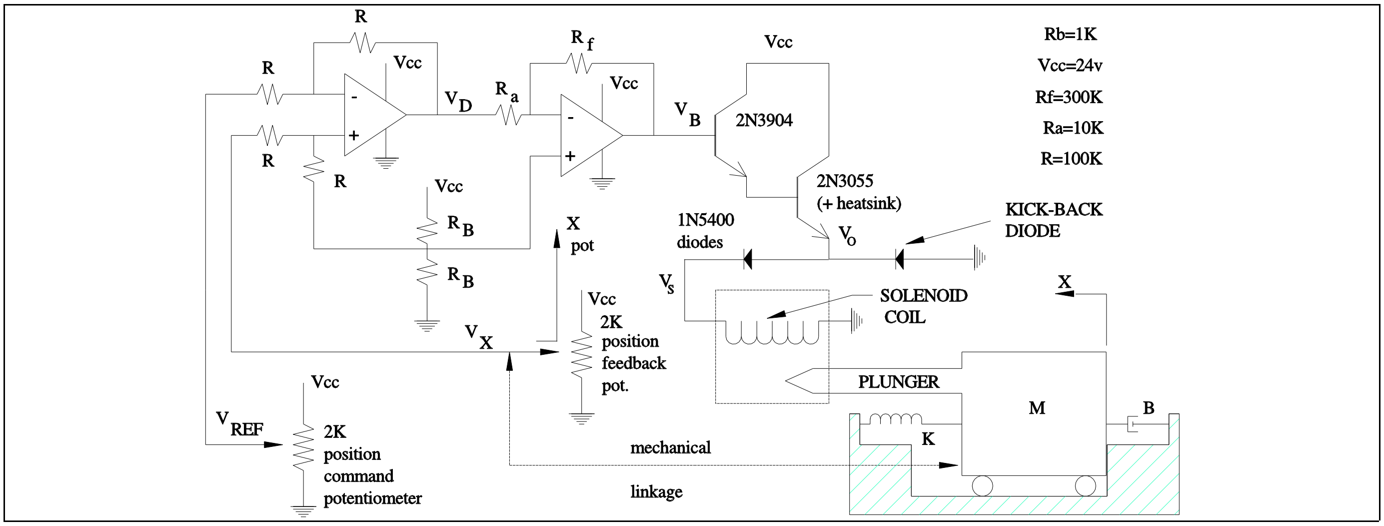

Figure 3: Hardware implementation for closed-loop solenoid position control system.

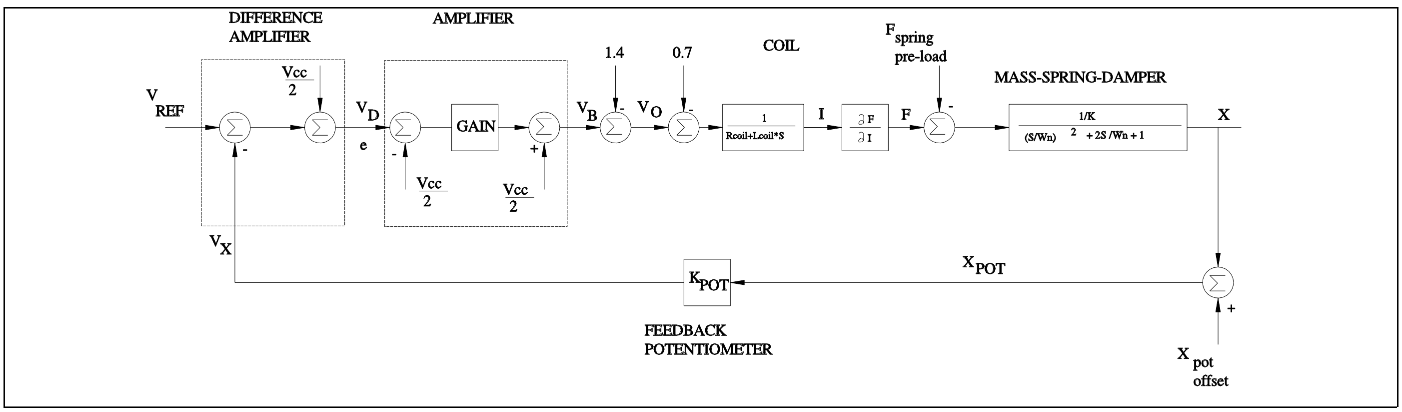

Figure 4: Block diagram for solenoid control system.

By this time in the semester, the student has become very familiar with the dynamics associated with the solenoid and the various computer tools. Then, they are asked to improve the transient response, by decreasing overshoot. They design a lead compensator and implement it in the circuit.

Through this series of labs, the student has been led to model, design, build, compensate and test a closed-loop position control system by the end of the semester. By working on this specific problem, they have applied most of the ideas presented in class. Most students at this point are excited about the material that they learned.

CONCLUSIONS

The experience presented has been a positive one for most students. They recognize the power and usefulness of control systems. Since they have worked with the same system for several weeks, they have developed a close intimacy with the hardware (DC solenoid, op-amp, potentiometers, etc.) This gives them confidence to use the same components in other applications.

To make this type of laboratory productive, coordination between the lab and lecture is essential. An open-lab environment where the student could come anytime and work with the hardware is beneficial.

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