Introduction to Programmable Logic Controllers in a Mechanical Engineering Instrumentation Course

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Introduction and Background

Many mechanical engineering curricula include both instrumentation and controls courses. The instrumentation courses typically focus on transducers and experimental data collection, while the controls courses are often theoretical. The traditional linkage between instrumentation and control, which is still recognized and practiced in industry [1], is often overlooked in these courses.

Large numbers of University of Alabama (UA) mechanical engineering graduates enter process industries and manufacturing facilities where programmable logic controllers (PLCs) have become ubiquitous. A PLC is typically combined with a variety of instrumentation inputs from proximity sensors and other transducers. Outputs include electric motors, pneumatic solenoid valves, signal lights, warning horns, etc. Low-cost PLCs with inexpensive PC-based programming packages have become available in recent years. Several manufacturers [2,3,4,5] have excellent websites describing their hardware and software in detail. A generic tutorial on PLC programming is available on the web [6], as well as a manufacturer-specific tutorial [7].

A five week module that introduces mechanical engineering students to PLCs is described in this paper. This module is an updated version of the material presented in an earlier paper [8]. Examples of the lab setup, student exercises, and follow-on senior design projects are provided. A website is available that contains these items with additional supplemental materials [9]. Key aspects of the instrumentation course that contains this PLC module are described next.

Course Organization

The topics covered in the first instrumentation course, ME 360 – Instrumentation and Control Components, are listed in Table 1. A detailed listing of course objectives can be found on the UA mechanical engineering department's website (www.me.ua.edu). This course has existed in this form for the past three years. At that time the existing instrumentation course was split into ME 360 and ME 460 – Thermal Systems Instrumentation, which focuses on temperature, pressure and flow instrumentation and larger scale experiments [10].

Most of the early part of ME 360 covers material from a fairly traditional instrumentation course. Experimental procedures (including formal report writing), signal conditioning, mechanical system transducers, and data acquisition are emphasized. Coverage of electric motors, proximity sensors, and pneumatic system components is necessary to prepare students for the PLC material. As shown in Table 1, the programmable logic portion of the class takes about five weeks, including two or three major lab exercises. These lab exercises are conducted with the custom PLC test stands.

Table 1. Topics Covered in ME 360.

Topic	Lecture	Lab
Introduction, general characteristics of measurement	2 hrs	3 hrs
Statistics and uncertainty analysis	2 hrs	3 hrs
Electrical signal conditioning, op-amps	4 hrs	6 hrs
Strain gages, force and torque measurement	3 hrs	3 hrs
Position, velocity, and acceleration sensors	2 hrs	3 hrs
Data acquisition	2 hrs	3 hrs
DC and AC motors	4 hrs	6 hrs
Proximity sensors, electrical control components	2 hrs	3 hrs
Industrial fluid power (pneumatic) components	2 hrs	-
Relay ladder logic and programmable logic controllers	10 hrs	6 hrs

PLC Test Stand Hardware

The ME department was very fortunate to obtain a large quantity of industrial grade pneumatic system components from a local manufacturer a few years ago. They were scrapping one of their manufacturing lines and donated the parts to us. Several sets of pneumatic cylinders, solenoid valves, proximity sensors, pressure regulators, DC power supplies, etc. were obtained from this donated equipment. Enough equipment was provided to build four identical test stands as shown in Figure 1. A ¼ inch pegboard back plate gives a very stiff mounting surface, while the large number of pre-drilled holes provides an essentially unlimited number of mounting options. Aluminum brackets were made to hold each of the three cylinders. Each cylinder is equipped with magnetic proximity sensors that indicate the extreme positions of the stroke. In addition to the pneumatic components, a low-cost pushbutton/signal light operator panel (shown at the top of Figure 1) was purchased. This device provides nine normally open momentary contact pushbuttons and six warning lights in a convenient, compact package. A 24 VDC fan small was also added to provide an additional output device.

Several older PLCs were included in this set of donated equipment. These were not used for two reasons. First, the hand-held device used for programming was not user-friendly. Secondly, the documentation was almost entirely written in a foreign language. Instead, several low-cost, modern PLCs were purchased [2]. A modular design with a powered base plate and a variety of snap-in modules for inputs and outputs was selected. The following components (in addition to the CPU module) are used in the test stands: a four slot base with 110/220 VAC power supply; a 16 point, 24 VDC digital input module; an 8 point, 12-24 VDC current sinking digital output module; and a 4 pt relay output module.

The total cost for this PLC configuration was relatively modest. A site license for the inexpensive Windows-based programming software was also purchased. All of the programming is done on a personal computer, then downloaded to the PLC. This process greatly simplifies programming and debugging. Students are very familiar with the Windows interface and are able to quickly enter and modify their PLC programs.

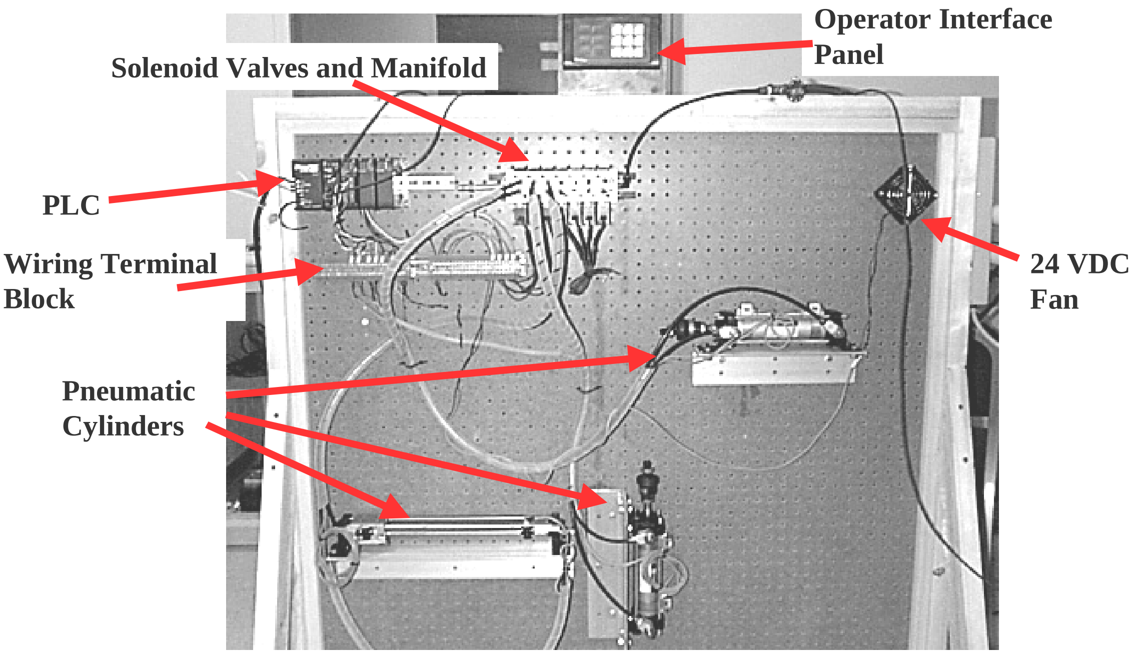

Figure 1 – PLC Test Stand

Basic pneumatic system components are introduced just before students begin the section on programmable logic controllers. These components include

- actuators (cylinders, motors, rotary actuators),
- pressure control valves (pressure relief, pressure regulator)
- flow control valves,
- directional control valves (check, manual, two/three/four way), and
- miscellaneous (filter, lubricator, pressure switch).

These components form the building blocks for many of the industrial control exercises that are studied in PLC programming. Students are required to learn a basic set of pneumatic system schematic symbols, as well as some application requirements. Figure 2 is a detailed pneumatic system schematic of the PLC test stand and is representative of what students are expected to be able to both produce and describe.

Relay Ladder Logic Programming

Students are introduced to programmable logic controllers after a brief (1 hour) discussion of relay ladder logic. Relay ladder logic uses electro-mechanical relays and is introduced first because it is conceptually simple and is still found in many situations where simple logic is used to control one or two output devices. A sample pneumatic system schematic diagram and associated relay ladder logic diagram is shown in Figure 3. This circuit implements what is commonly called a "one shot." A single press of the normally open pushbutton PB-1 causes the cylinder to fully extend then immediately retract a single time.

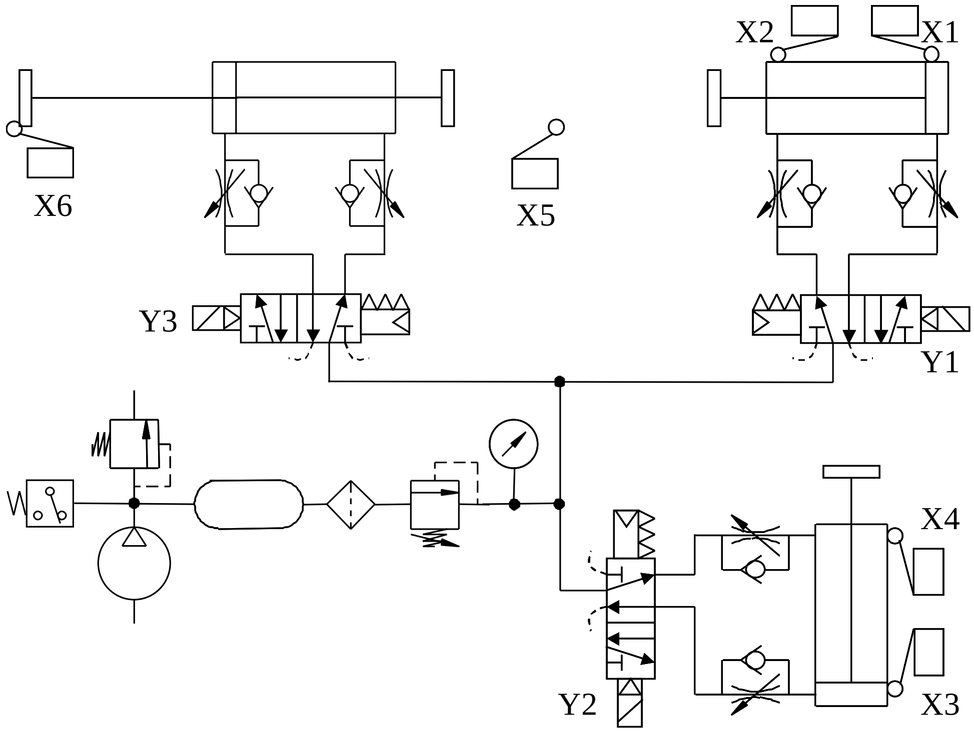

Figure 2 – PLC Test Stand Pneumatic System Schematic

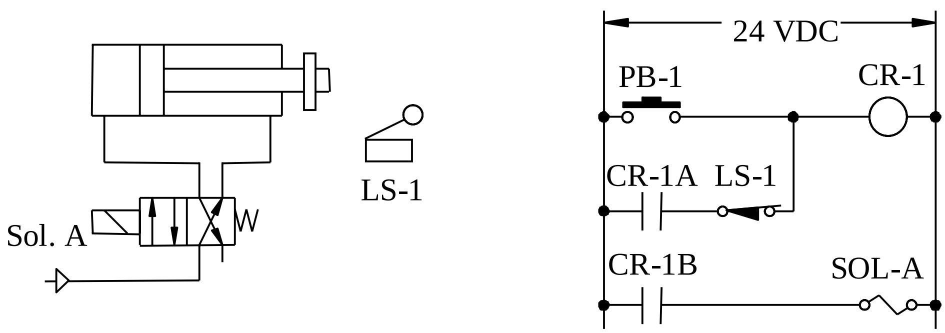

Figure 3 – Relay Ladder Logic Example

Examples of PLC Programming

After relay ladder logic is introduced, students are introduced to the more modern PLC programming through a series of in-class exercises. Three different types of exercises with progressively more difficult material are used,

- analysis of correct programs,
- de-bugging of incorrect programs, and
- design of new programs to meet desired specifications.

After each of these skills are introduced and practiced in class, follow-up lab exercises with the test stand are used to strengthen the student's understanding. An example of each type of PLC programming exercise is given for illustration.

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The first example shows a common clamp and work cycle operation in Figure 4. A PLC wiring diagram is required in addition to the pneumatic system schematic and the PLC program. Students are expected to give a line-by-line analysis of the operation of circuits at this level of complexity.

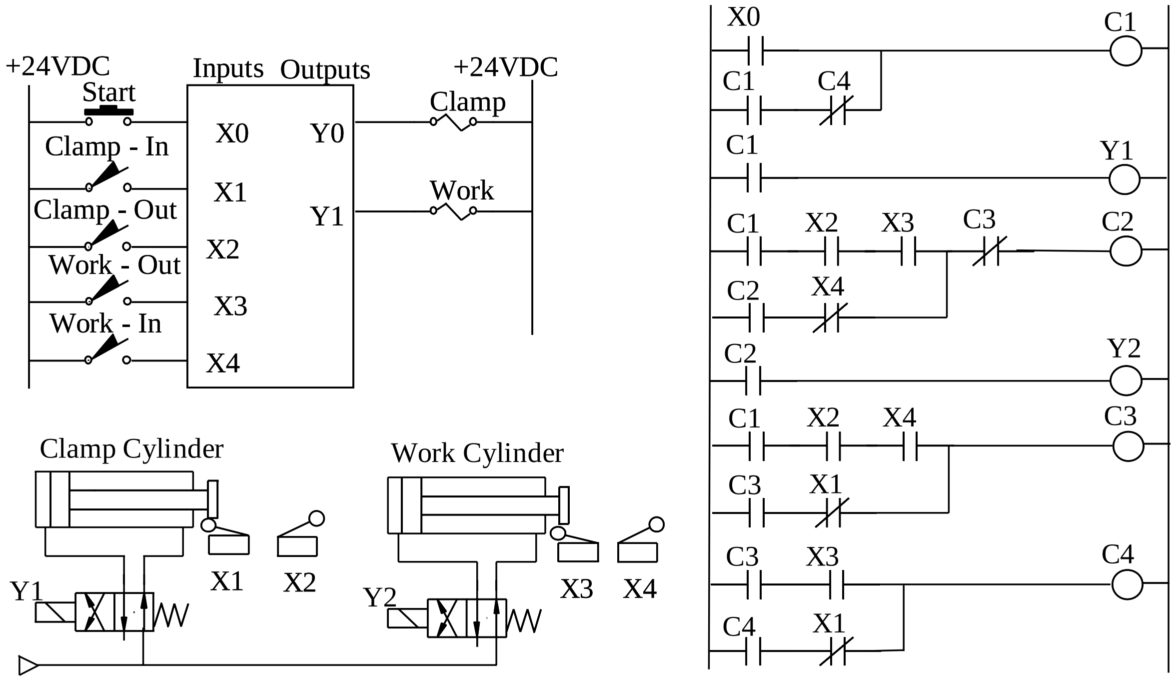

Figure 4 – PLC Program - Analysis

After learning to analyze correctly operating circuits, students are asked to de-bug PLC circuits with one or more errors. Students are given a description of what the system is designed to accomplish. For the system shown in Figure 5, the intended goal is

- operator presses normally open Start pushbutton
- the double-acting, double ended cylinder extends fully (and activates LS-2),
- a 3.5 second delay occurs,
- the cylinder retracts (and activates LS-1), then
- the cycle stops (until Start is pressed again).

This problem is a modified version of the "one shot" shown in Figure 3. The PLC diagram shown in Figure 5 has three major errors:

1. The timer input is turned on (rung #3) as soon as the Start button is pressed, not when the cylinder fully extends.
2. A permanent "hold" circuit is formed on rung #4a when contact C2 is activated by the timer TM3 and the limit switch connected to X2.
3. Contact C3 is indicated in rung #5, but C3 never appears as an output on the ladder logic diagram.

During an in-class period, students are placed into small groups (usually their lab groups of 2 or 3) and given 5 minutes to identify these errors. They are also asked to modify the given ladder logic diagram such that the system operates properly.

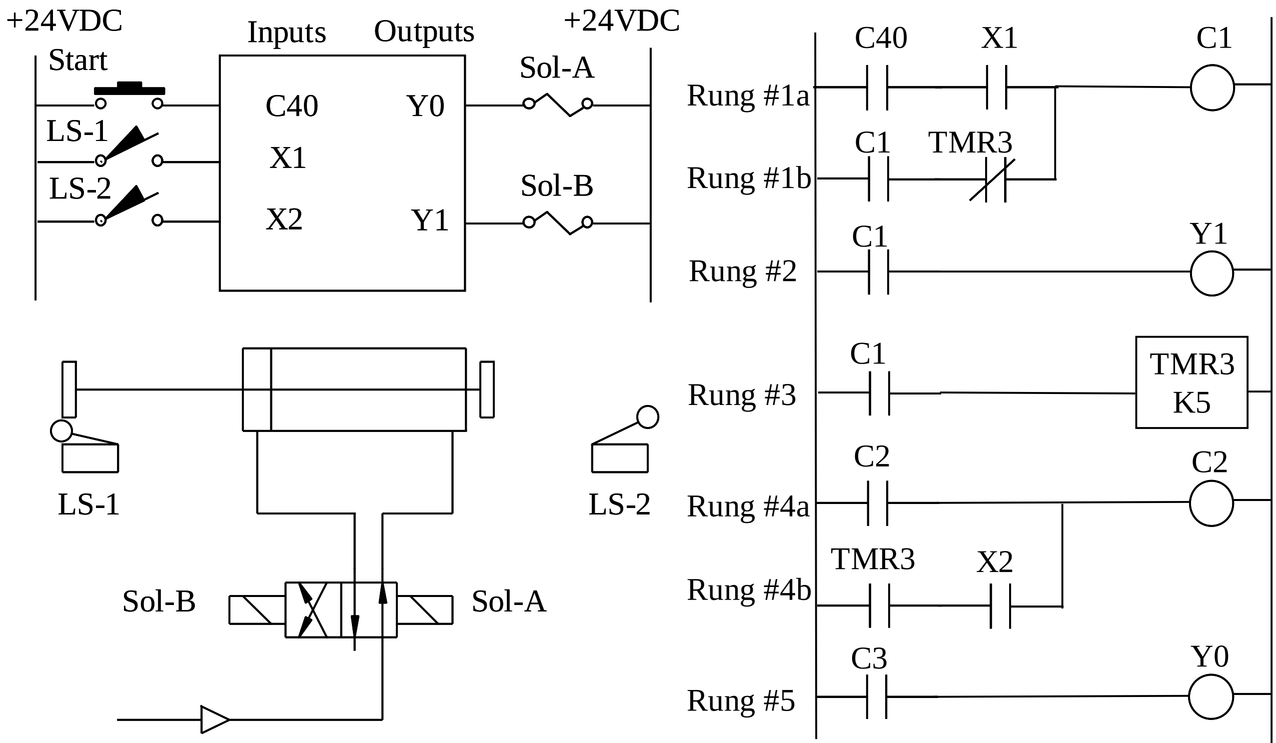

Figure 5 – PLC Program – De-bugging

The last set of exercises in PLC programming requires the students to solve several design problems. The design problems use the PLC test stand described in Figures 1 and 2, along with requirements for timing, counting, sequencing, etc. Example design problems can be found on the course website [9]. Students are required to sketch the PLC wiring diagram (connection of limit switches, pushbuttons, solenoids, etc. to the PLC), the pneumatic system diagram, and the ladder logic diagram for their solution. A group of 2 or 3 students would normally take about 2 to 3 hours to write and fully de-bug their PLC program.

Examples of Student Projects

Several of the mechanical engineering students at the University of Alabama have used progammable logic controllers in their designs in their senior capstone courses. Figure 7 shows a page turning device controlled by a small PLC. This student group “cannibalized” an old dot-matrix printer for many of their components. The PLC uses inputs from photoelectric position sensors to control the up/down position of the solenoid-controlled “finger” which contacts the page.

Another senior design project solution is shown in Figure 8. This device was design to enable a wheelchair-bound individual to fish with a rod and reel. The goal was to have a completely hands-off operation of both casting and reeling with only “sip and puff” input devices. Many of the requirements for this design were taken from the American Society of Mechanical Engineers Year 2001 Student Design Contest [11]. These rules were modified somewhat to allow students to use PLCs for control and to have a wider variety of actuators to choose from. The device shown in Figure 8 uses another small, inexpensive PLC to control all aspects of the operation – casting the rod, releasing the reel button, and reeling.

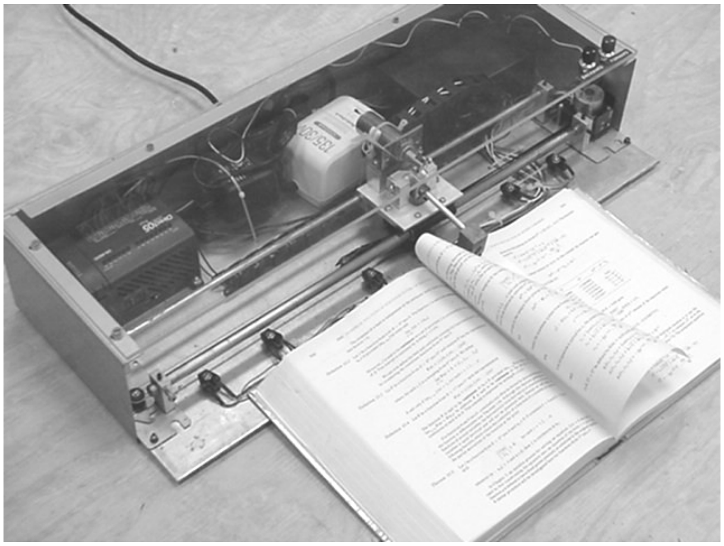

Figure 7 – Assistive Technology: Page Turning Device

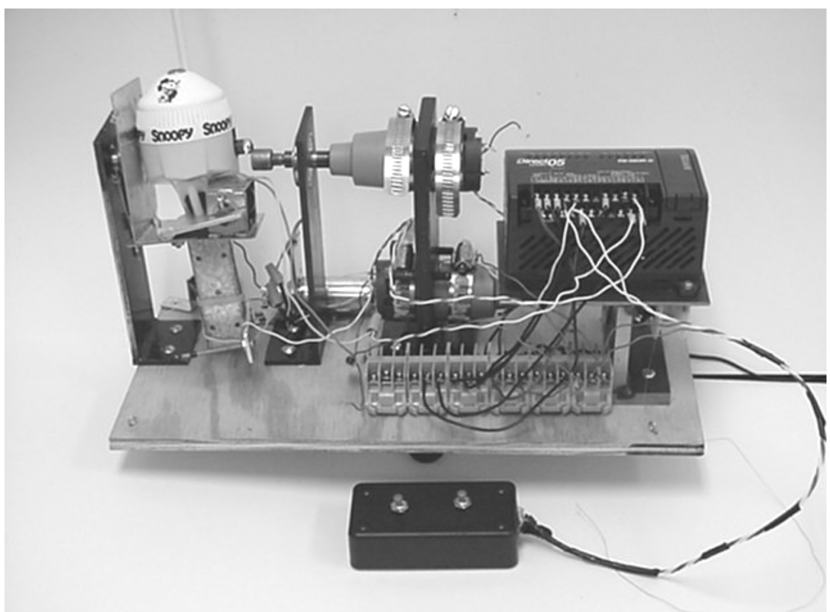

Figure 8 – Assistive Technology: Fishing Device

Conclusion

A six week module covering programmable logic controllers in a mechanical engineering instrumentation course has been developed. A test stand with several pneumatic cylinders, solenoid valves, pushbutton inputs, and other function is used for laboratory exercises in PLC programming. Specific examples of PLC program analysis, de-bugging, and program design have been presented. Senior design projects that use PLCs for control have also been described.

Student response to this material has been uniformly positive, primarily due to their recognition that this is useful, "real world" knowledge that many of them will use in their engineering careers.

References

1. URL: http://read-out.net/signpost/oid.html; Education and Research in the area of Measurement, Control and Automation.
2. URL: http://www.automationdirect.com; AutomationDirect (Koyo) Controllers.
3. URL: http://www.allen-bradley.com/plclogic/; Allen-Bradley Controllers.
4. URL: http://public.modicon.com/; Schneider Automation Programmable Logic Controllers.
5. URL: http://www.keyence.com/plc/plclibraryhome12.shtml; KEYENCE Corporation of America: PLC Library.
6. URL: http://www.plcs.net; Your Personal PLC Tutor Site - The BEST Place to Learn PLC Programming.
7. URL: http://www.sea.siemens.com/training/step2000/courses/plcbasics/intro.asp; STEP 2000: Basics of PLCs.
8. Midkiff, C., J. Parker and S. Bell, Mechanical Engineering Curriculum Reform at The University of Alabama, Proceedings of the 1997 ASEE Southeastern Section Conference, pp. 150-156, Marietta, GA, March, 1997.
9. URL: http://www.me.ua.edu/ME360/plc; ME 360 - Programmable Logic Controller Module.
10. Parker, J. and D. Schinstock, Introduction to Hydraulic and Logic Systems in a Controls Course, 1996 ASEE Annual Conference Proceedings, CD-ROM, Paper 3266, Washington, DC, June, 1996.
11. URL: http://www.asme.org/students/design_contest/Y2001index.html; 2001 ASME Student Design Contest.

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Joey K. Parker is currently an Associate Professor of Mechanical Engineering at The University of Alabama, where his teaching responsibilities include control systems, instrumentation, and both freshmen and senior capstone design. He has been involved with the Foundation Coalition effort at Alabama since 1993, and recently served as the freshman TIDE (Teaming, Integration, and Design in Engineering) program coordinator. He received his B.S.M.E. degree from Tennessee Technological University in 1978, and his Master's and Ph.D. in Mechanical Engineering from Clemson University in 1981 and 1985, respectively. His research interests include electro-mechanical actuators, microcomputer applications, and industrial automation.