Low Cost Process Control Trainers

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Abstract

Process control laboratories in most colleges and universities include process trainers for control exercises in temperature, level, flow, and pressure. Schools are usually limited to a single trainer for each process variable because of system size and cost. The use of single systems makes it difficult to use small laboratory teams without reducing the enrollment limit placed on the laboratory section. Ideally, the process laboratory should have multiple trainers in each of the four process variables to learn the basics of process control. Then the students could move to the larger more robust system to study control of a large industrial process. This paper describes the results of a National Science Foundation (NSF) Instructional Laboratory Instrumentation (ILI) grant that supported the design of a low-cost process control trainer for temperature that introduces students to basic control concepts. Construction cost of the system is less than $500, and all of the components are available off-the-shelf from a number of industrial sources. The systems can be controlled by any single-loop process controller, a programmable logic controller, or a microcomputer using a control software product, such as LabView. In addition, the trainers work well in linear electronics laboratories to teach the use of operational amplifiers in instrumentation systems. The systems have been tested at several colleges and universities with excellent results. This paper describes the system design, construction requirements, example laboratory exercises, and test results. A web site that includes a complete set of drawings for the trainer and other supporting information is available. Send e-mail to James Rehg *jar14@psu.edu* for the URL.

Introduction

The cost of process control has dropped as a result of the drop in solid state control devices. Manufacturers interested in improved quality have increased the number of closed loop controls in a broad product area using continuous, repetitive, and line type-production systems. As a result, engineering technology programs at the two- and four-year level have added control courses and laboratories to prepare the graduates for the systems awaiting them in industry. Building a controls laboratory that uses standard industrial control elements is costly and demands allocation of a large laboratory area. Traditionally, process control laboratories in schools used large system trainers to teach the control of material level, flow, temperature, and pressure. While the performance of these systems is satisfactory, problems occur when these large systems are used in introductory control theory laboratories. The problems include:

- The high trainer cost prohibits the purchase of multiple student stations.
- The small number of student stations requires large student teams if standard laboratory section sizes and traditional laboratory scheduling practices are followed.

- The large student teams generate uneven learning among the team members.
- A single large trainer for each control variable (temperature, pressure, flow, and level) dictates that student teams work on different laboratory exercises.
- Students struggle to learn process control basics because of the complex nature of large trainers.
- The combination of long setup time and slow system response makes it difficult to complete a laboratory in a standard two- or three-hour period.

Exposure to industrial level process systems is important in a controls laboratory, but controls exercises should start on smaller process control systems. To satisfy this training need, an NSF ILI grant was used to develop a low cost process control trainer for temperature.

Trainer Design Criteria

The design criteria for the temperature trainer included the ability to reach the desired steady state temperature in a reasonable amount of time; to provide relatively quick response to changes in the set point or system disturbances; to use off-the-shelf industrial components; to interface easily to a variety of control systems; to fit easily on a bench top; and to cost less than $500.

System Components

The heart of the temperature trainer is a heating element from a 37-watt soldering iron. The system block diagram, illustrated in Figure 1, indicates that the temperature is measured with a J-type thermocouple with a thermocouple transmitter used to generate a process variable (PV) that is set by the user, either to a current from 4 to 20 milliamps or to a voltage from 0 to 5 volts.
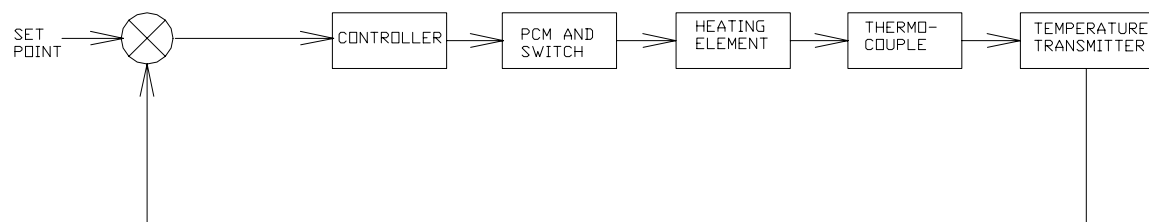

Figure 1

The process variable is compared to the set point value by the controller, and the resulting control variable (CV) is applied to the input of the pulse control module. The pulse control module (PCM) is connected to a solid-state relay with the entire assembly mounted on a heat sink. The pulse control module takes the 4- to 20-milliamp control variable output and produces a pulse width modulated output at the terminals of the solid-state relay. The 120-volt ac power to the soldering iron is varied by the on/off duty cycle of the relay. As a result, the power to the heating

element is changed from near zero to 100 percent by the 4- to 20-milliamp control variable connected to the PCM. The rest of the system components, illustrated in Figure 2, include:

- A section of Hoffman wire-way that houses the heating element and the thermocouple
- A 100-cfm shaded pole blower mounted to the end of the wire-way that removes heat from the system
- A damper attached to the blower to vary the amount of air into the blower
- A small enclosure to isolate the thermocouple from the direct flow of air from the blower
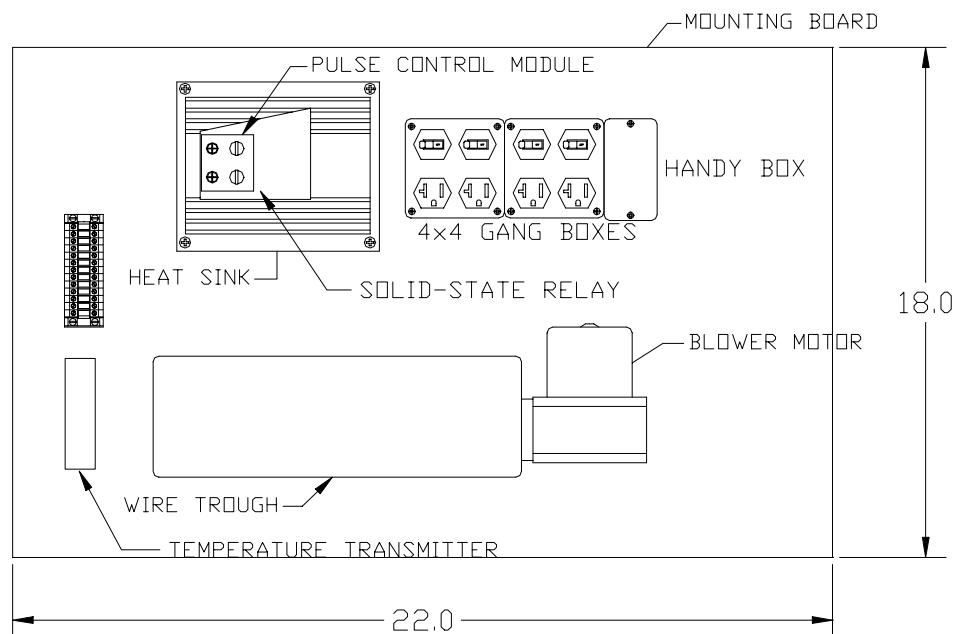

Figure 2

 A detailed view of the soldering iron and thermocouple is provided in Figure 3. Note that the soldering iron handle was discarded, and the heating element, supported by an angle bracket, was mounted in the blower end of the wire-way. Also, the soldering iron tip was replaced with a one-quarter inch treaded steel shaft that has a J-type thermocouple to be mounted next to the heating element and a second thermocouple to be mounted at the tip of the conductor. Both thermocouples have washer-type mounting holes so that they install easily with a pair of nuts. The second thermocouple mounted at the tip is optional. The second thermocouple permits additional measurement in system response and feedforward control applications. The thermocouples and the steel shaft are placed in a small metal switch box that is packed with fiberglass insulation to keep the direct draft from the blower from coming into contact with the thermocouples.

Additional features include two electrical boxes with four combo outlet/switches installed. The electrical circuit for the system, illustrated in Figure 4, indicates that the first outlet is connected to 120-volt ac power through the combo switch, and the second outlet is connected to the

terminal block through the corresponding combo switch. The 120-volt ac switched outlet is used to control power to the blower, and the switched outlet connected to the terminal block permits a varied ac voltage from a variac to be applied to the system for a variety of experiment options. The first switch in the second set of outlets is connected to 120-volt ac power through a series connection of the solid state relay, a diode, and the adjacent combo switch.
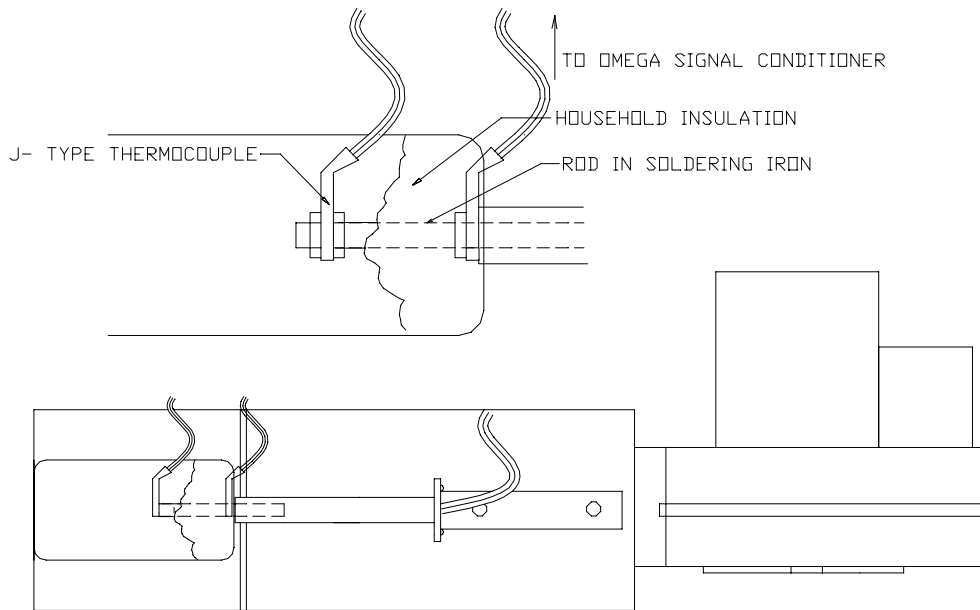

Figure 3

This outlet, called the half power outlet, has two functions: 1) a 25-watt bulb is placed in the socket so that the pulse width modulation from the PCM can be monitored visually; 2) when the soldering iron is placed in this outlet it simulates a dual bank heater system with one bank of heaters not operating. The second outlet in the second set of outlets is connected to 120-volt ac power through a series connection of the solid state relay and the adjacent combo switch. When the heating element is plugged into this outlet, called the full power outlet, the level of heat generated by the element is controlled by the 4- to 20-milliamp output from the PCM. The entire system is mounted on a 22- by 16-inch panel and has a total cost of approximately $450 (one thermocouple only).

Design Considerations

The soldering iron was chosen because its maximum temperature of 800 degrees Fahrenheit worked well with the J-type thermocouple temperature range of 0 to 900 degrees Fahrenheit. Also, the tip of the soldering iron is easily removed to permit insertion of the thermocouple mounting shaft. The one-quarter inch threaded shaft is easy to cut, and the washer-type

thermocouple mounts easily with a pair of quarter-inch nuts on each side. Different materials can be used to vary the thermoconductivity in future experiments.

The washer-mounted J-type thermocouple integrated well with the temperature transmitter. The transmitters provided the necessary cold junction for the thermocouple and amplified the millivolt signal coming from the thermocouple to either a 4-to 20-milliamp or a 0-to-5 volt dc output signal. The temperature transmitter requires a 10-to 32-volt dc supply voltage and has quick release rail-type mounting hardware.
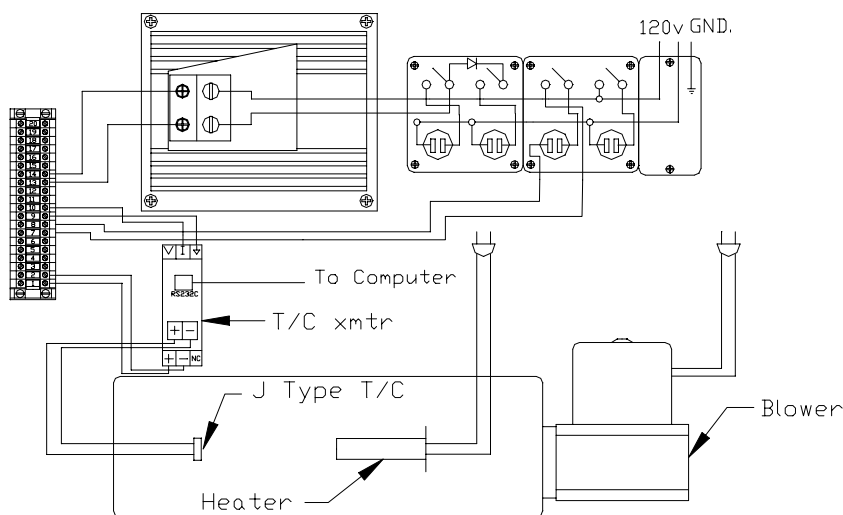

Figure 4 (Illustrated with one thermocouple at the tip)

The transmitter comes with a software package that allows the transmitter to communicate with a microcomputer through the serial port. The software functions include: configuring the transmitter for different types of thermocouples; setting the desired output units (current or voltage) for process variable output; selecting upper and lower temperature limits; selecting upper and lower output values for the process variable; and logging the process variable value for real-time display on the window interface. In additon, the software also provides a graphic display of the last 25 seconds of data from the transmitter.

The air flow into the system is controlled by a restrictor plate mounted to the blower input. The restrictor is used to provide a disturbance to the system so that system response can be evaluated. The system is usually started with the restrictor open and then moved to a full closed position, in order to see how the system responds to a change in the air flow.

System Operation

PID software and hardware modules in programmable logic controllers (PLCs) have been used to control the temperature trainer. In addition, the system has been used with stand-alone single loop controllers and with a microcomputer running LabView software with a-to-d input and d-to-a output boards installed. The system was also used in a linear circuits laboratory to demonstrate on - off control and proportional control using integrated circuit operational amplifiers.

The objectives for five experiments for the trainer are:

Experiment 1
1. Identify all of the control components in the temperature system and describe the function and operation of each.
2. Connect the temperature system to the Allen Bradley SLC 504 programmable logic controller and develop a program for manual control.
3. Adjust the span and scale for all of the control devices and set up the analog input and output module scaling.
4. Use the Visual Basic process monitor software to display process parameters and graph control variables.

Experiment 2
1. Set up a manual control system using the PID command and the base thermocouple sensor.
2. Manually change the control variable (CV) value to achieve steady values of the process variable (PV) at several operating points.
3. Test the system response to set-point and load changes.
4. Set up and test the system for on/off control.
5. Use the Visual Basic process monitor software to display process parameters and graph control variables.

Experiment 3
1. Set up automatic control of the temperature system using the PID command and the base thermocouple.
2. Use the open-loop control method to find the process gain, dead-time, and time constant for the system with the thermocouple at the base.
3. Apply the Ziegler-Nichols closed-loop method to determine the proportional gain (P), integral reset (I), and derivative (D) tuning parameters for the thermocouple located at the base.
4. Test the system response to set-point and load changes with PID control applied.
5. Use the Visual Basic process monitor software to display process parameters and graph control variables.

Experiment 4
1. Set up automatic control of the temperature system using the PID command and the tip thermocouple.

2. Use the open-loop control method to find the process gain, dead-time, and time constant for the system with the thermocouple at the tip.
3. Apply the Ziegler-Nichols closed-loop method to determine the proportional gain (P), integral reset (I), and derivative (D) tuning parameters for the thermocouple located at the tip.
4. Test the system response to set-point and load changes with PID control applied.
5. Use the Visual Basic process monitor software to display process parameters and graph control variables.

Experiment 5
1. Optimize the control characteristics by adding bias and feed forward parameters.
2. Test the response of the optimized system for set-point and load changes.
3. Use the Visual Basic process monitor software to display process parameters and graph control variables.

The transfer function for the system, illustrated in Figure 5, shows the relationship between the output of the transmitter in milliamps and the input to the pulse control module in milliamps. The transfer function for the heating element is 0.4075 volts rms per degree Fahrenheit.
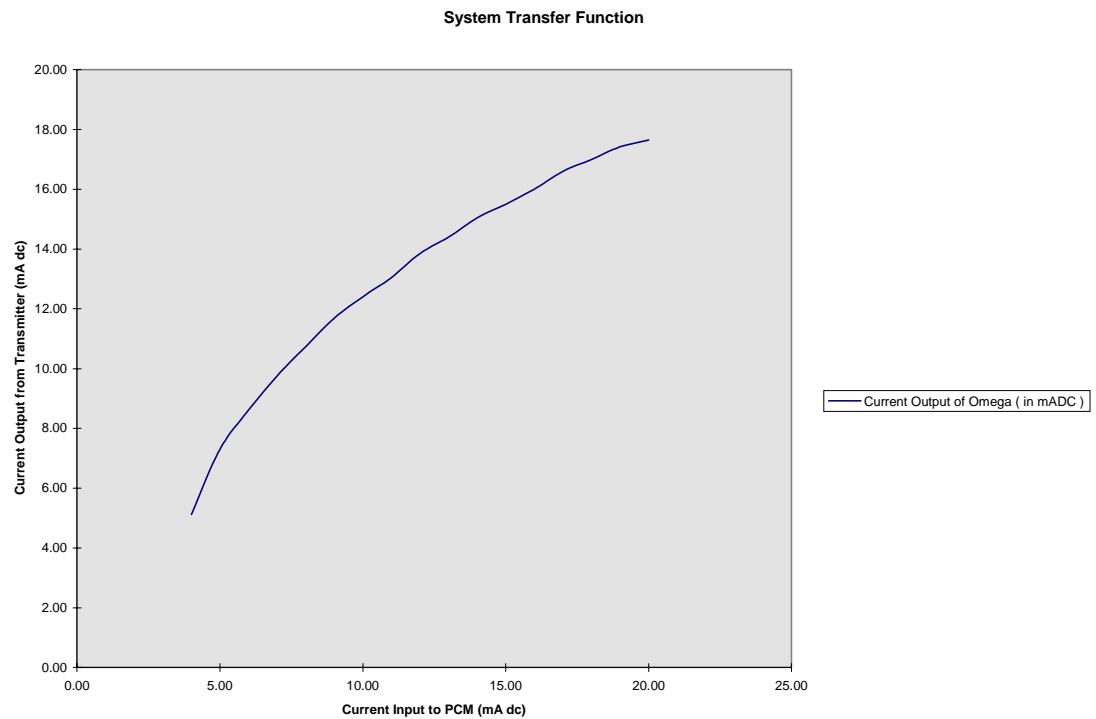
System Transfer Function

Figure 5

Conclusions

The process control temperature system was built and used at a number of colleges with a variety of controllers. In one laboratory implementation eight student teams with two students per team worked through the laboratory exercises to learn how to tune a PID controller. The students found the control problem presented by the smaller trainer easy to understand. The size and complexity of the smaller systems were not intimidating, and the level of understanding of process control techniques exceeded the level previously attained when students started on the larger system trainers. A web site that includes a complete set of drawings for the trainer and other supporting information is available. Send e-mail to James Rehg *jar14@psu.edu* for the URL.
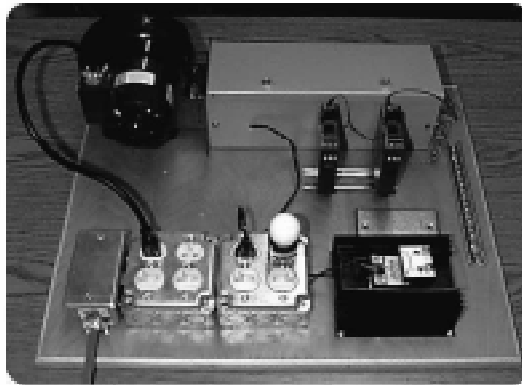

Figure 6 Picture of the finished system

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Biography

JAMES A. REHG – James Rehg received B. S. and M. S. degrees in Electrical Engineering from St. Louis University and has completed additional graduate work at the University of South Carolina and Clemson University. Since August 1995 Jim has been working as an assistant professor of engineering and the Program Coordinator of

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