

AC 2007-232: COST-EFFECTIVE PROCESS CONTROL LAB SETUP

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Abstract

Many four-year engineering technology programs require or offer course(s) that emphasize examining the transient behavior of systems. The systems can be mechanical, electrical, chemical, or any other engineering discipline. These courses are generally classified as classes covering control system theory. Unfortunately, examining the transient behavior of control systems is very difficult in a lab environment. Frequently, computer software is utilized to model the systems and then monitor their behavior. Since engineering technology programs stress the concept of a “hands-on” approach, efforts are continually made to utilize hardware to fabricate physical systems that can be used to demonstrate class concepts. There are several companies that offer physical systems that can be modeled. Unfortunately, my experience is that these are very expensive.

At the University of Maine, we stress the use of industrial equipment. We have developed a physical system using industrial equipment that students can readily use to validate concepts. The industrial equipment is a combination of inexpensive hardware store items, donated industrial equipment, and industrial equipment purchased at a reduced cost. This paper will describe the system and how it is used in the class to reinforce concepts. Further, it will discuss some of the lessons learned for how to build the system as quickly and as economically as possible.

Keywords

Control System Concepts, Industrial Equipment Used in a Lab Environment

Introduction

Courses that cover control systems material provide the opportunity to develop modeling and analysis skills of physical systems. There are two distinct system types that can be modeled. The servo-mechanism type mainly covers the area of robotics and are exact positioning. The other type is process control consisting of manipulating devices to maintain a medium within an acceptable range. There are many available educational resources that support learning activities within a lab environment with servo-mechanism type systems that are cost effective. However, process control educational resources tend to be more expensive than servo-mechanism lab equipment and available budgets may not support purchasing the equipment. This paper describes the process of developing and fabricating a single loop process control system that can be modeled, analyzed, and controlled by students.

Why Process Control

As previously described, process control type systems consist of manipulating devices to maintain a medium within an acceptable range. Typical graduates of the University of Maine’s Electrical Engineering Technology program obtain positions that involve

working with process control type systems. Some graduates work on servo-mechanism type systems but generally are not involved with the design of the control systems that operate these devices. Servo-mechanism control systems usually consist of state variable controllers with multiple axes requiring multiple variable control. The author's personal experience is that developing more than a basic introduction to state space techniques is beyond the scope of the learning outcomes for a typical four year graduate of an engineering technology program. As a result, control system design for today's servo-mechanism systems is best left for graduate level courses.

Process control systems are frequently designed by engineering technology graduates. In fact, a great deal of application specific knowledge is required to design these systems. For example, a typical process control system for a power plant consists of providing extremely clean water that has most corrosives removed and is maintained at a very specific conductivity level. These systems can be very expensive to build due to the cost of the chemicals used as well as the time required to remove the corrosives. Further, providing sufficient water for the process at most times is also a consideration. The designer of this process must be aware of the end equipment requirements for water conductivity as well as the flow rates required. This type of understanding is generally obtained only after extensive experience in system design.

Process Control System Tuning

Although the design of process control systems is beyond the capability of most recent engineering technology graduates, it is certainly possible for the students to be involved with the tuning of these systems. Tuning consists of the selection of control system parameters to ensure that the medium is maintained within a specified control range. Tuning further consists of the validation that the selected control system parameters are valid. Frequently, tuning consists of providing a step change to the system and then monitoring the system response to determine system time and gain constants. It is possible to develop models of these systems, but occasionally these systems are too complex to allow cost effective model development.

Tuning when a system is provided a step change is frequently referred to as "bump test" tuning. Bump test tuning works well when the system to be controlled is a first order system. A first order system is one in which the process can be modeled by a first order differential equation. If the control systems' course utilizes Laplace techniques than a first order process is one in which the order of the denominator is one greater than the order of the numerator. Fortunately, many physical systems are first order in nature so bump test tuning works exceedingly well.

Selection of Process

The goal of the lab experiment described by this paper is to provide students the opportunity to experience the bump test tuning process. Since students were going to be exposed to the process, the medium had to be benign posing no health risks to the students. Further, the process needed to have a long enough response time so that

students could obtain accurate data. Another consideration is that the process needed to be easily monitored by students to permit time and gain constants. Finally, the system should be self-contained without requiring facility changes.

There were two mediums considered for the process control system. Air and water were considered due to their availability and benign nature. Compressed air systems are frequently found in process control but these systems are generally simple. Further, student monitoring of the compressed air system can be difficult. Process control systems using water as a medium can be easily monitored and are frequently seen in real-world applications. As a result, water was the medium selected for the process control system lab experiment.

The next determination that needed to be made was what item should be controlled. Again, factoring student safety into account resulted in the rejection of controlling pressure within a vessel. Water composition including conductivity, purity, etc. was also considered but rejected due to the cost of the equipment used in maintaining these items. Further, special chemicals are required which can affect student safety. The other control considered was level. Tank or vessel level is benign in that there is very little pressure and no chemicals utilized. Also, the control of vessel level can easily be monitored as the vessel level can be seen. As a result, control of tank or vessel level was selected as the first order process to be tuned by this lab experiment.

Self-Containment

A key item to consider for the lab experiment is to limit the facility modifications required to support the lab experiment. It is also desired to have the lab experiment setup be moved as required. Since the selected lab experiment consisted of maintaining water level in a vessel, it was determined that electrical power should be the only item needed by the lab station. No plumbing supply or drain lines would be allowed since these would limit lab station movement and would require facility modifications.

To address the self-containment concerns, it was determined that a stand alone water supply tank would be utilized for the lab station. This station would provide the water supply and would also act as the load on the process. Since maintaining water level is the process to be controlled, allowing more water to drain from the vessel would provide more loading on the system. Use of a water storage tank would permit significant loading on the system and would also capture the water. This water is then recycled back as the supply for the process. This permits self-containment and results in less waste than if the system was designed with supply and drain lines from the facility.

The supply side of the process is simple to design but requires special equipment. For the water supply storage tank to act as a load on the level control process, it was necessary for the tank to be physically lower than the vessel to allow gravity draining. It was also desired to minimize the equipment located within the water storage tank to permit long term storage of the water without causing equipment to be damaged by corrosion. As a

result, a vacuum pumping system was selected for providing pressurized water to the system.

Industrial Equipment

Another consideration for the lab station was to minimize the devices that are customized for education. The focus was to utilize industrial process control equipment whenever possible. However, industrial process control equipment can be expensive. Also, industrial processes tend to require quantities beyond what would be feasible within a lab environment. As a result, the only viable industrial equipment used within the lab station are the control valves, single loop controllers, and level transmitters.

The control valves used for the lab station are equipped to be supplied a 4 to 20mADC control signal proportional to the desired valve position. That is, the percent open the valve should be. Many process control valves use compressed air to position the valve actuator. The control valve has a built in current to pneumatic converter which takes the 4-20mADC signal and converts it to a corresponding pneumatic signal. The pressure of the air varies from 3 to 15PSI and supplies a force to a bellows to position the valve actuator. An industrial grade control valve was purchased at a significant educational discount.

The level transmitter monitors the vessel level and provides a corresponding 4-20mADC proportional to the level of the vessel. The selected level transmitter uses differential pressure to determine level. As the water level in the tank increases, the weight of the water causes a greater pressure differential. The pressure differential is proportional to the level in the vessel. The selected level transmitter is capable of monitoring a wider pressure than the lab station. To ensure proper operation, the level transmitter must be ranged down to output 20mADC when the vessel level is 100%. As is the case for the control valves, an industrial grade level transmitter was purchased at a significant educational discount.

The signal loop controller is the “brains” of the control system. The device compares the level in the tank to the desired or setpoint level and then develops an output signal to minimize the error between the setpoint and actual level. The controller is a standard proportional, integral, and derivative controller with both automatic and manual control. For most applications, successful tuning is accomplished with only the proportional and integral components. The automatic and manual control modes are essential to permit the bump test. Bump testing requires a small perturbation to the control system. Typically, the bump test consists of manually setting the control valve and then letting the system stabilize. Once the system stabilizes, the setting is changed by 10% and the system is monitored for how long the system takes to stabilize and what percent change in the level occurred. Single loop controllers are being utilized less frequently as the complexity of systems increase. However, they provide a basis for understanding the tuning process.

Lab Station Hardware

The remaining lab station hardware consists of readily available items located at typical large hardware stores. The vacuum pumping system consists of a typical pump and pressurized storage tank utilized for homes with wells. The piping and fittings consist of various ½" copper tubing and copper elbows, tees, and unions necessary to tie the system together. All tubing and fittings were installed using standard pipe soldering techniques. ½" copper tubing was utilized as it was sufficiently large enough to provide adequate flow rates. Tygon tubing was considered but rejected due to the high cost of the tubing and fittings.

The choice of the vessel was made after considering time response of the system. After testing several different vessels, it was determined that small diameter vessels were required to maintain a reasonable time response of the system. Acrylic vessels were considered but were very expensive. In the end, the choice was made to utilize 4" PVC tubing as the vessel. This has a relatively short time constant (around 10 minutes) and is readily available and affordable. The only issue with using PVC tubing is that there is no readily available clear PVC tubing. To allow the students the opportunity to monitor the vessel level, a small section of Tygon tubing was installed in parallel with the tubing. The bottom of the Tygon tubing was connected to the base of the PVC vessel. As the level in the vessel changes, the level in the Tygon tubing changes correspondingly.

Additionally, various valves were employed to provide isolation and drain capability. These valves are standard ball valves or pressure regulating valves. Pressure regulating valves are used to maintain a constant pressure to the control valve to ensure consistency of flow based on valve position.

A small air compressor and manifold was utilized to provide air to the control valves. Newer control valves utilize electric only positioners and obtaining these valve types would preclude the need for the air compressor.

The final element needed for the lab station is power distribution. All of the components can be operated of 120Vac and one power cord is all that is necessary. However, our lab station is configured with a small power distribution panel to provide additional power connections for test equipment. For basic operation of the system, 120Vac is only required.

Overall Configuration

The lab station piping and instrumentation diagram is provided as Appendix A. Further, a bill of material for the lab station is provided in Appendix B.

Lab Station Experience

Student use of the lab station has allowed lab procedures to be refined. The first item was developing an understanding of the system. Initial use was limited to tuning. However, the students didn't get a good feel of the tuning process since they didn't truly understand the system. This was remedied by having the students develop a piping and

instrumentation diagram of the system. The piping and instrumentation diagram development required the students to examine the system and determine what the components were being used for and how the system was operated. This greatly enhanced student learning.

Another item that was identified as an area that required improvement was the initial setup of the system. At first, the instructor had the students enable the system and begin the bump test tuning process. Unfortunately, even with a time constant of approximately 10 minutes, a three hour lab period was insufficient to wait for the system to stabilize and then perform the bump test and again wait for the system to stabilize. As a result, the system is stabilized by the instructor prior to commencing the lab.

The final item learned was to configure the controller to be ready to accept the tuning constants. Today's single loop controllers have many features and proper configuration is time consuming for the students and doesn't enhance student learning. Since there are many different models of controllers and various other types of systems, it was determined that it would be more efficient to have the instructor set the tuning parameters for the students. The students are required to determine the appropriate tuning constants and provide them to the instructor.

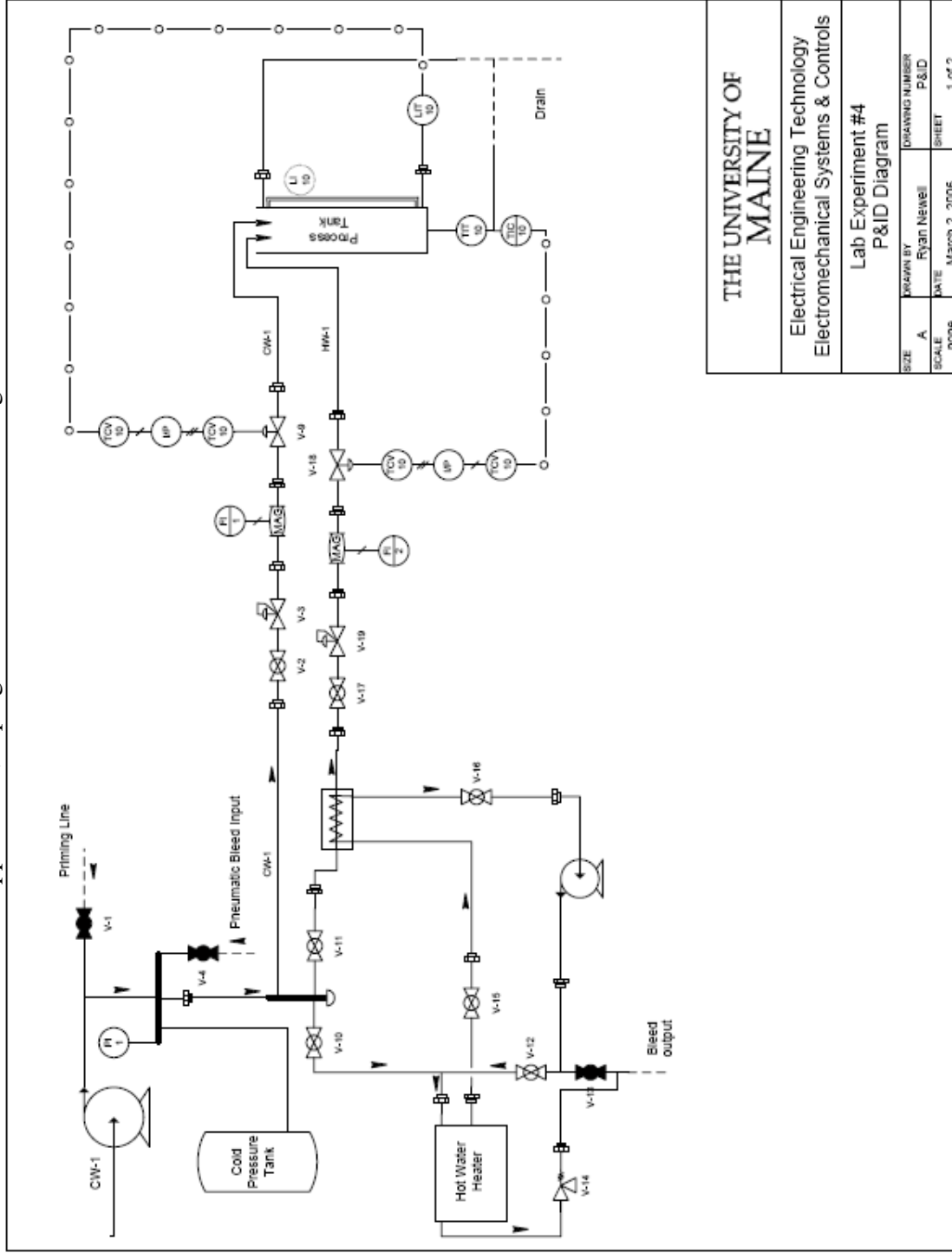
Future Modifications

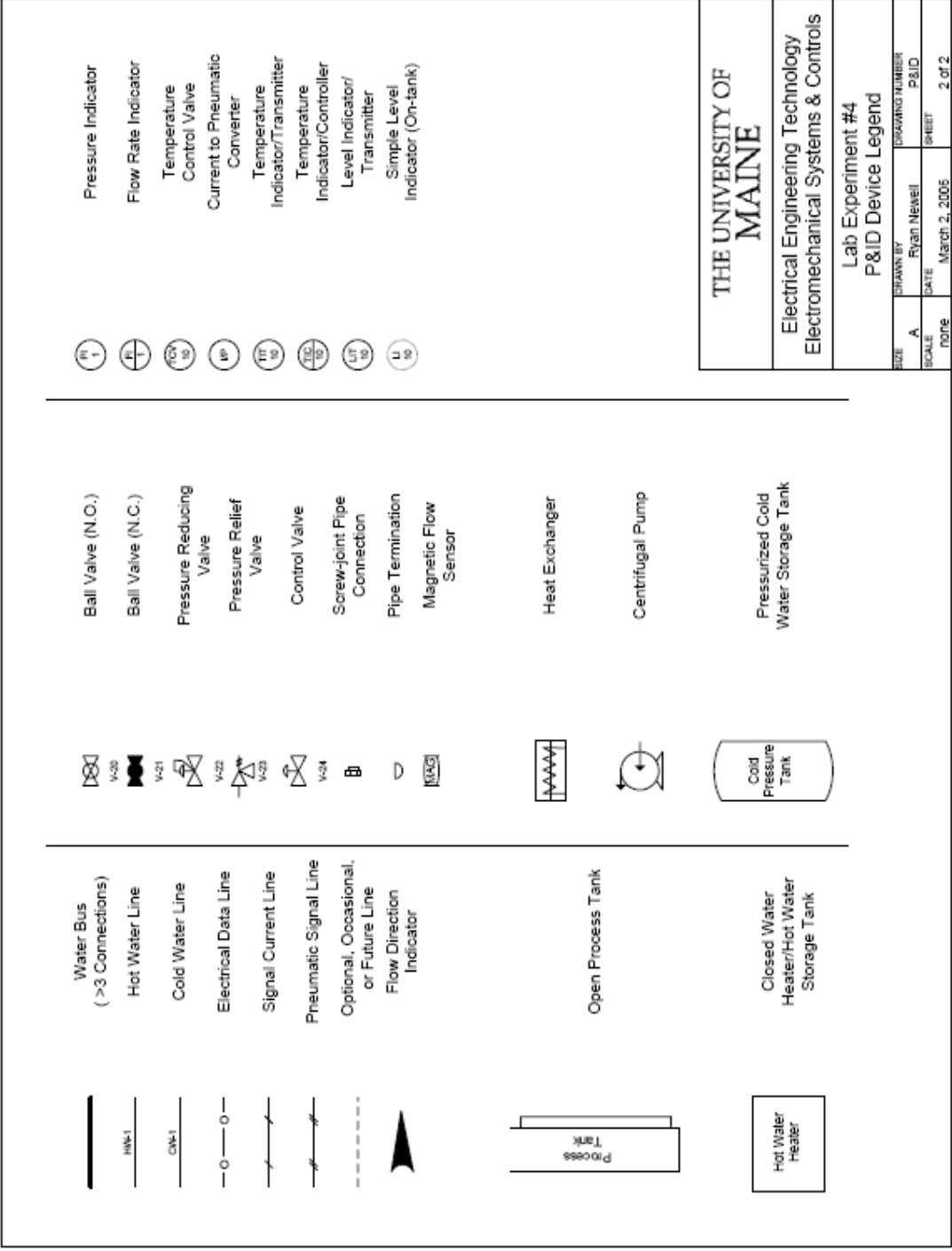
The use of readily available equipment permits further expansion of the project. Several magnetic flow meters have been procured which can be used to perform predictive tuning. Further, the water in the vessel can also be controlled for temperature by providing both a hot water and cold water supply. These items are projected as add-ons to the basic system. Further work to enhance student learning can include detailed modeling of the system using differential equations that describe the behavior of the system. The model can then be simulated in a program to confirm accuracy of the model. Data from the bump test can be used to test the validity of the model

Conclusion

Our experience with the lab station has resulted in a positive learning experience for the students. It is cost effective and highly reliable. It gives the students the opportunity to work with actual industrial equipment and develop familiarity with the tuning process. If sufficient budgets are available, a student project could consist of fabricating an actual lab station and identifying areas for efficiency.

Appendix A, Piping and Instrumentation Diagram





THE UNIVERSITY OF
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Electrical Engineering Technology
Electromechanical Systems & Controls

Lab Experiment #4
P&ID Device Legend

SIZE	DRAWN BY	DRAWING NUMBER
A	RYAN NEWELL	P&ID
SCALE	DATE	SHEET
none	March 2, 2005	2 of 2

Appendix B, Bill of Material

Component Type	Equipment Used	Qty Reqd.
Vessel	4" Schedule 40 PVC Pipe	6 feet
Vessel Support		
-	2" Galvanized Pipe	3 feet
-	2" Support Flange	1
-	6" Pipe Clamps	3
	2" Galvanized Split Rings	5
Shallow Well Jet Pump	Gould J5SH 1/2HP Pump	1
Pressurized Storage Tank	Amtrol WX-202	1
1-1/4" Foot Valve	Harvel LF5000S	1
1-1/4" Tubing	NA	20 Feet
1-1/4" Elbows & Adapters	NA	As Reqd.
1/2" Copper Tubing	NA	30 Feet
1/2" Pressure Regulating Valve	Taco PRV3350	1
12 Circuit Distribution Panel w/ breakers	Square D Q0612L100RB	1
12-2 Outdoor Rated Wire	NA	40 Feet
GFCI Receptacles and Boxes	NA	4
30 Gallon Drain Tank	24x18x18	1
Misc. 1/2 Copper Fittings	NA	As Reqd.
Torch, Solder, & Flux	NA	As Reqd.