A Thermal Process Control Laboratory

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Abstract **- Thermal systems are an important segment of engineering design, but practical, realistic laboratory models are not plentiful. There are some educational oriented systems models, but these are expensive and typically the design details of the machine are not furnished with the purchase of the equipment, making deviation from the original intent of the equipment difficult.**

This paper describes the development of a small, portable, and inexpensive system that allows students a wide range of educational experiences. Students may study the overall design and construction of the system, selection and cost of components, and the effect of different control schemes.

The laboratory apparatus is built around an industry standard, low cost PLC. The control scheme may be changed from a simple OFF-ON control to a PID loop by a software routine on the PLC. Heating and sensing devices are those used typically in plastics manufacturing equipment and the controlled device may be varied to simulate the effect of process conditions and raw material on the thermal control system. Data logging is available to allow students to record and observe the system effect of process changes.

The apparatus may be fabricated at a low cost (under $500), is small in size and portable, and may be powered from available single phase AC voltage. This has important implications in programs where lab space or funding is an issue, and also may be integrated into distance education programs. Examples of integration into courses are addressed.

Index Terms — *Controls, Machine Design, Project, Heat Transfer*

INTRODUCTION

Thermal processes are a key part of machine design. This is particularly true in the area of manufacturing process and machinery design. Here the control of temperature and heat transfer becomes an integral part of the design. There has been work done to devise cost effective means for demonstrating some of the basic concepts in heat transfer and there has been work in cost effective means of illustrating analog controls, but the two concepts are seldom married together. The goal of this work was to produce a laboratory apparatus that could be used in the study of heat transfer and of control systems.

In the educational area it is also important that the laboratory apparatus be cost effective. Cost effectiveness has several components. First is the capital cost of purchasing the components and any construction costs incurred in the construction.

Second is the cost of operating and maintaining the apparatus. Expendables such as plastic pellets for thermoplastic processes are sometimes available through donation, but that limits the type of material available. Frequently donated material does not come with complete documentation which makes it hard to close the gap between published values and empirical results.

Documentation plays a part in the cost of maintenance also. Often an apparatus that is purchased does not come with complete documentation, forcing the user to rely on the vendor for parts and support. That is usually a more expensive solution than purchasing common parts and using internal resource for maintenance.

Third is the cost of space. This is a very important consideration in most schools as it is very difficult to find funding for new facilities, thus highlighting the importance of effective use of existing facilities. Efficient use of space not only implies that the apparatus have a small "footprint" but also that it be portable. Portability allows equipment to be stored when it is not in use and also allows movement to where the demonstration is most effective, allowing a "just in time" approach to teaching. Power requirements also impact portability, so the input voltage and current requirements should be such that the apparatus may be used in different locations. Other utilities such as compressed air and cooling water must also be considered.

Last, the concept of cost effectiveness incorporates the usefulness of the apparatus. An apparatus that may be used over several classes is more efficient than one which is used only in one class. There is another benefit that derives from using one apparatus to teach several subjects and that is the familiarity that students gain for the process incorporated into the apparatus. This reduces the amount of training necessary in operation of the apparatus and also may be used to help students understand the interaction of all the pieces to form a process. This holistic understanding of processes has been identified as a gap, or deficiency, in newly graduated manufacturing engineers [1].

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APPARATUS

The experimental apparatus may be divided into 2 sections. The first section consists of the input device (thermocouple) and the controller. The controller accepts input (process variable) from the input device, applies process variable to an algorithm, and turns on an output. The second section is the device which receives the output, typically a heater in the case of thermal processes.

Controller

The appearance of low cost, high performance, expandable PLC's in the market has opened some new opportunities for educational laboratories [2]. Several manufacturers offer low cost PLC's and there are advantages to each manufacturer. Often the selection of a brand is driven by the predominance of one brand in the school's service area, or the school may have support from the manufacturer or vendor of a particular brand.

The components used in the systems described in this paper are marketed by AutomationDirect [3]. The Direct Logic line of PLC's offered by AutomationDirect is inexpensive, flexible, and offers a wide range of options. Moreover AutomationDirect is an internet based business and has their price lists, application data, and user manuals available at no cost at their web site. This provides an opportunity for students to find information valuable in design, analysis, and project management oriented classes [4].

The basic model of PLC available from AutomationDirect is the DL05 (Figure 1). This model has 8 discrete inputs and 6 discrete outputs as well as an expansion slot. The expansion slot is the key to this PLC's usefulness in thermal control circuits that normally have an analog circuit component as well as discrete, or "off / on" components. There are many communication and input / output (I/O) modules available for this PLC. Among the I/O modules available are thermocouple and RTD inputs.

A very basic thermal control demonstration system may be constructed by assembling a DL05 PLC with a thermocouple input module and a commercially available thermocouple designed for injection molding machines.

This entire system may be built for approximately $250 (approximately $125 for the PLC, $100 for programming software, $15 for the thermocouple, and $10 for power cord). To use the system the student inserts or attaches the thermocouple to a known (ice water) or unknown (heater grille) and observes the indicator light on the output terminal selected as the control output.

The program in this case is typically an off / on control sequence programmed into the ladder logic of the PLC.

The DL05 PLC also has 4 Proportional Integral Derivative (PID) loops built in. These loops are set up to read an analog value corresponding to the value of the process variable (temperature in this case) compare to a set point value (enter by the operator) and yield an output analog value of the control output. Unfortunately the DL05 only has one expansion module slot so that although the value of the control output is calculated, there is no device to provide a physical output.

FIGURE 1
DL05 PROGRAMMABLE LOGIC CONTROLLER

Another shortcoming of this system is that it does not allow the operator to change variables without modifying and then reloading the PLC program. This is time consuming and requires some programming knowledge on the part of the operator. This may not be desirable in some academic settings. AutomationDirect sells operator interfaces that allow the student to monitor process variables and to change set points. These operator interfaces are similar to the device shown in Figure 1 and have 2 to 4 lines of text on an LCD display. They may also be used, in conjunction with a PLC program, to select menu items. The operator interfaces, with software and cabling, start at around $220.

The low cost of this basic system offers some opportunities for distance education.

Table 1 illustrates the cost for the basic demonstration system.

DESCRIPTION	PRICE	QUANT.	TOTAL
DIRECT LOGIC PLC, MODEL DL-05	$85.00	1	$85.00
PROGRAMMING SOFTWARE	85.00	1	$85.00
DIRECT LOGIC 4 CHANNEL	169.15	1	$169.15
THERMOCOUPLE INPUT MODULE			
PPS THERMOCOUPLE, J TYPE	15.00	1	$15.00
		TOTAL	$354.15
OPERATOR INTERFACE	225.00	1	$225.00
		TOTAL	$579.15

TABLE 1
BASIC CONTROLLER SYSTEM COSTS

In order to accommodate the analog output capabilities of the PLC you need another expansion slot. AutomationDirect markets an upgraded version of the DL05 named the DL06. The DL06 has the same basic features as the DL05, but with an increased number of fixed discrete inputs (20) and discrete outputs (16), and with 4 expansion module slots.

The increased number of slots allows for a thermocouple module and an analog output module to be run at the same time.

Description	**Price**	**Quant.**	**Total**
Direct Logic PLC, Model DL-06	$208.25	1	$208.25
Programming Software	126.65	1	$126.65
Direct Logic 4 channel	169.15	1	$169.15
Thermocouple Input Module			
PPS Thermocouple, J type	15.00	1	$15.00
Direct Logic 4 channel	126.65	1	$126.65
Analog I/O Module			
		Total	$645.70

TABLE 2
CONTROLLER COST WITH ANALOG OUTPUT

Although the increase in cost for the DL06 system is significant (approximately $300) there is a significant increase in flexibility and capability.

There are 4 PID loops built into the processor of the DL06, there are 4 thermocouple inputs in the first expansion module, there are 2 analog outputs in the second expansion module, and there are 16 discrete outputs in the frame. This allows one to operate as many as 4 control schemes side by side for comparison.

For example, one might have 2 thermocouples measuring process variables at the same physical location in 2 similar target processes. One of the thermocouples might be accessed by a portion of the controller program which compares it to a set point and turns on or off a discrete output. This models a thermostat and the operator may experiment with the variables associated with that process.

Another thermocouple might be accessed by one of the PID loops in the control program and used to control one of the analog outputs in the expansion module. This capability allows the student to observe and compare the performance of both types of systems.

In addition to the above advantages of the DL06 system, it also has 2 additional expansion slots. One of these might be used for an Ethernet connection to allow data capture of the process variable on a time basis. This data may be used in a spreadsheet to compare the thermostat process (off / on control) to the PID loop analog control, or to examine the effect on the process of changing variables in the PID control.

Outputs

The ultimate output for most thermal processes is a resistive heating element. Between this element and the PLC, however are some components to allow for functionality.

Discrete PLC outputs are essentially small switches and are typically limited in their ability to conduct large currents. Typically they are limited to a maximum of around 2 amps of current. This limits the size of the heating element to below 200 watts for a 115 volt device.

Many thermal processes, such as the melting of plastic pellets in an injection molder, require a higher power input. In this case the output of the PLC is used to energize a relay with a larger current capacity, which in turn switches power to the heater. A ten amp electromechanical relay, with a socket, may be obtained from AutomationDirect for approximately $10.

Analog outputs require a different output scheme. The analog output from the controller may be either current (4 to 20 ma) or voltage, typically 0 to 10 volts. Both of these schemes offer low power handling capability. To transfer power to the heater an SCR power controller is normally used. The input signal is used to verify to power supplied to the heater. A 16 amp rectifier (SCR) controller for a 115 volt power source will cost around $105 from Plastics Process Equipment [5].

Heaters are also available from Plastics Process Equipment. These are industrial style heaters normally used in thermoplastic processes. They can be in the form of band heaters, which wrap around a cylindrical form, or as cartridges, which are cylindrical.

Figure 2 illustrates a typical example of a cylindrical output device. A band heater is wrapped around the cylindrical barrel of an injection molder barrel. To simplify the construction a thermocouple with a flat “spade” end is inserted between the band heater and the barrel. A band heater for this application would have a power rating of approximately 350 watts and cost $10 from Plastic Process Equipment.

Cartridge heaters are priced similarly. Typically they are embedded into a metal part in the process. They might be used with aluminum or steel plates to study conduction or convection processes.

CONCLUSIONS

The author has used this system to illustrate the principles of heat transfer and the implementation of the thermal processes. Response from students has been positive as this allows them to vary system parameters easily and observe the effect.

The basic system can be purchased relatively cheaply and if used over several courses, might be cost effective for students to purchase in a distance learning environment.

The systems are small and compact, and used in conjunction with a laptop PC for programming, offer great portability. The author has used the system in the class room for demonstrations.

The system may be used over a wide range of classes, including PLC programming and manufacturing process analysis and automation,

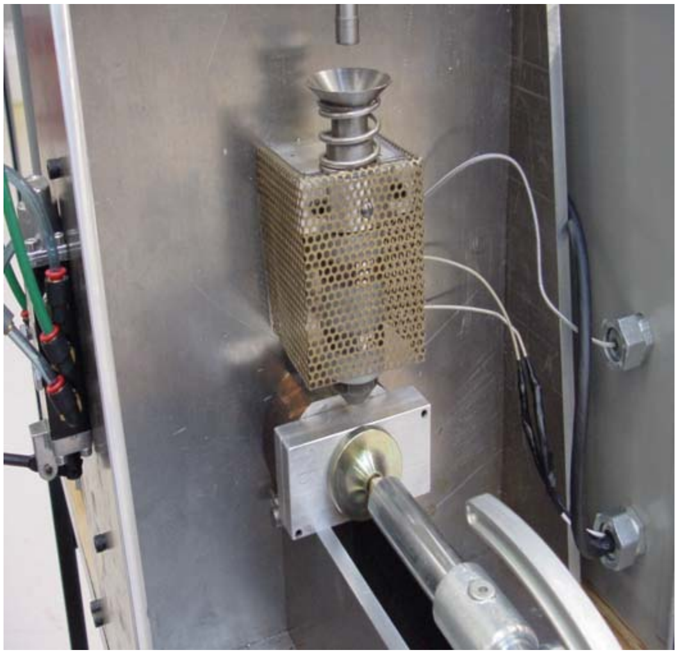

FIGURE 2
INJECTION MOLDER BARREL

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