A Project in PID Temperature Control and Loop Tuning

Michael Oelschlegel and Rafic Bachnak
Texas A&M University-Corpus Christi
Corpus Christi, TX 78412

Abstract

Automatic temperature control can be accomplished in different ways with varying degrees of accuracy. One method, PID control, normally requires a tuning process after the system is installed. This paper describes how a kiln with manual temperature control was modified to automate the process by utilizing a microprocessor-based PID controller. The controller accepts input from a “K” type thermocouple to switch the heater on and off with a solid state relay. The process variable is transmitted through a data acquisition system to a PC for storage and further analysis. This project provides valuable hands-on experience in control loop tuning and produces reasonably accurate results. The paper shows the design schematic and presents results.

Introduction

PID control allows a system to accurately adjust for load or setpoint changes. Implementing a PID controller, however, requires that it be ‘tuned” or adjusted for the system for which it is installed [1, 2]. This tuning process requires the user to understand the type of algorithm utilized by the controller.

The Mechanical Engineering Technology (MET) curriculum at Texas A&M-Corpus Christi includes a class in strength of material. In this class, students perform tests on various metals before and after the samples are heated. One apparatus for heating the samples is an electric kiln. This kiln is powered by 120 VAC and draws 16 amps. It is capable of producing temperature of 2000 degrees F. The kiln is fitted with an infinite heat switch. The switch acts as a duty cycle switch. The higher the setting the longer the heater is on and the less time it is off. Visual feedback of the temperature is provided to the operator via an analog temperature meter. As the temperature approaches the desired amount, the operator must use his judgment to adjust the rheostat. If the temperature is rising at a fast rate, it will probably overshoot the desired setpoint and the operator must turn down the setting.

This project involves retrofitting the kiln with an automatic control using a small microprocessor based PID controller. The controller accepts a “K” type thermocouple and switches the heater on and off through a solid state relay. The process variable is acquired by a data logger and transmitted to a computer for storage, processing, and analysis.

The new system gives control systems students the opportunity to gain valuable hands-on experience in control loop tuning and provides MET students with a kiln with automatic temperature control.

Methods of Control

Automatic control of a kiln could be accomplished in one of several ways. The simplest is the ON/OFF control. This is accomplished with a temperature switch, usually with an adjustable dead band. As the falling temperature crosses the low edge of the dead band, the switch turns on the heater. The heater remains on until the temperature rises and crosses the upper edge of the dead band. This method is used where precise control is not required.

Another method of control is TIME PROPORTIONAL. This type of controller is designed to eliminate the temperature cycling associated with ON/OFF control. A proportional controller decreases the average power being supplied to the heater as the temperature approaches setpoint. This has the effect of slowing down the heater, so that the temperature does not overshoot. It will approach the setpoint and become stable. This proportioning can be accomplished by turning the output on and off for short intervals. The proportional action occurs within a proportional band around the setpoint. Outside the band the controller behaves like an OFF/ON controller. As the temperature rises into the band, the output starts switching off and on. How far into the band the temperature is determines the on/off ratio. At setpoint, the on/off ratio is 1:1 or 50% duty cycle. At 25% into the band (from the bottom) the ratio is 1:3 or in other words it is off 3 times as long as it is on. The output (duty cycle) only changes when the difference between the setpoint and actual temperature is changing. The system will probably balance at some point other than setpoint. This requires the operator to reset the setpoint so the controller will change its output and bring the temperature up to the desired setting. The resulting difference between setpoint and temperature is known as offset.

A third type of control is PID. PID is proportional with integral and derivative control. The integral portion of the controller integrates the deviation signal with respect to time. This integral is summed with the deviation signal to shift the proportional band. The output is thus automatically increased or decreased to shift the proportional band to bring the temperature back to setpoint [3]. The derivative function provides the controller a means of shifting the proportional band to compensate for rapidly changing temperature. The output of the PID control can be a duty cycle relay control as described earlier or an analog signal. The analog signals are usually fed to a power controller. These can either be zero crossover SCR controller or a phase angle SCR controller. Both types control the average power applied to the heater. These are used on higher current applications.

System Design

The controller chosen for this project accepts the kiln's existing K type thermocouple. The controller has a duty cycle output to control the heater and an analog output for the data logger. The duty cycle output is a pulsed dc voltage that controls a solid state relay capable of switching the 16 amps required by the heater. A third output was added to the basic unit to send a signal representing the process variable (temperature) to the data logger. This eliminated the need for a second thermocouple. Since the kiln may be operated upward to 2000^{O}F and the controller has an ambient limit of 130 ^{O}F, a fan that draws cool air was added to prevent overheating the controller or solid state relay. Figure 1 shows the schematic of the new system.

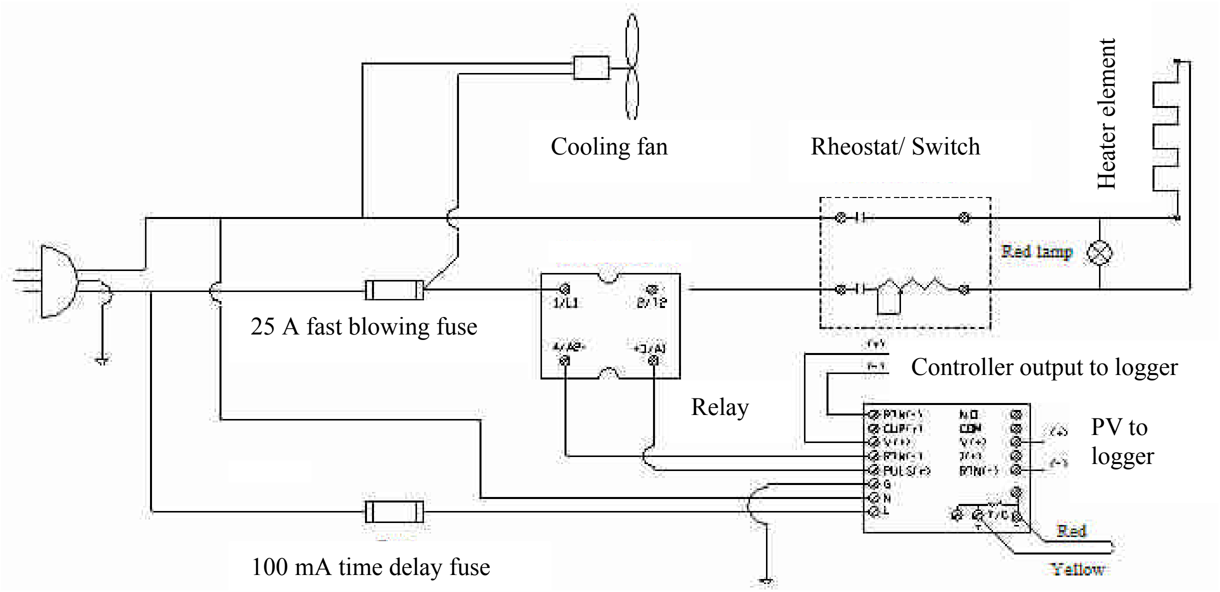


Fig. 1 Automatic controller circuit with a fan

Description of System Components

Table 1 shows a parts list for the project and Figure 2 shows the kiln with the controller installed. Total cost of all parts is around $390. The following paragraphs give short descriptions of all parts.

Table 1. Parts list

Item	Description	Model No.	Vendor	Price
1	Temperature Controller	CN77554-PV	Omega Engineering	$304.00
2	Trim Plate	TP4	Omega Engineering	$19.00
3	Solid State Relay	SSRL240DC25	Omega Engineering	$26.00
4	Heat Sink	FHS-2	Omega Engineering	$17.00
5	Fuse	KAX-25	Omega Engineering	$11.00
6	Fuse Block	FB-1	Omega Engineering	$13.00
7	Fans	4715FS-12T-B50	NMB Technologies	$0.00
	Total			$390.00

Temperature Controller: A small controller in 1/16 DIN package capable of handling thermocouple, RTD, voltage, or current inputs. The controller is capable of ON/OFF, Ramp & Soak, PID with manual or auto tuning, anti-reset windup, and open loop protection. The controller has one output that is a pulsed 10 VDC used to drive an external relay, and another that is a voltage or ma signal proportional to the output. An option was added to provide an analog output of the process variable.

Trim Plate: Used to mount the 1/16 Din in the 2-3/4" hole left by the old analog meter. Solid state relay: Rated for 25 amps with a nominal voltage of 24-280 VAC. Since the heater pulls 16 amps there is a 50% safety margin.

Heat sink: – 1.2 ^{O}C/W used with solid state relay. With a load of 16 amps this heat sink will allow operation in an ambient of approximately 175 ^{O}F.

Fuse: Fast acting I^2T fuse to protect the load circuit.

Fuse Block: required for fuse in item 5.

Fan: 115 VAC/60HZ/0.19AMPS

Fig. 2 Kiln with controller installed

Tuning the Controller

The controller is capable of automatically tuning itself. Self-tuning can be generally accomplished in several ways. The controller can follow a set of "corrective rules" or have a model of the process built in. Some automatic tuners can be configured for different control objectives such as minimum overshoot or minimum settling time. Self-tuning controllers also differ in their data collection techniques. Some apply a series of artificial disturbances to the process and observe how it behaves. Others make due with data collected during normal loop operations [4]. While the controller is capable of automatically tuning itself, it also allows manual tuning. This was of prime importance since one of the goals of the project is to gain a feel for doing actual tuning of a closed loop. There are several different algorithms used in PID controllers. According to Dave Harold, senior editor for *Control Engineering*, there are essentially three types in use: ideal, series and parallel [5]. Since the proportional, integral, and derivative components interact with each other differently, their tuning must be approached differently.

In 1942, John G. Ziegler and Nathaniel B. Nichols of Taylor instruments published two techniques for setting the proportional, integral and rate of controllers [6]. Although their algorithms were different for the pneumatic control of their day, they are still the basis of many methods. The discussion of this article used the ISA standard form of the PID algorithm. The first technique is the 'open loop' response method. The system is allowed to stabilize at some point. The controller is then switched to manual and a small step change is introduced into the output. The resulting reaction curve of the process variable is then analyzed. From this chart the process gain, the dead time, and the process time constant are obtained. These values are then plugged into equations to yield the PID parameters. The other method Ziegler and Nichols used was a 'closed loop method.' In this method the integral and derivative portion is disabled. The proportional band is decreased (gain increased) until the pv just starts oscillating. This is known as the ultimate gain. The period of the oscillation is the ultimate period. These values are again plugged into a different set of equations to get the tuning parameters.

Closed Loop Tuning Procedure

The following steps are followed to tune the controller:

1. Set proportional band at 5%, Cycle time to 5 seconds, Reset and Rate both to 0.
2. Set SETPOINT to 450^{o} F and turn on kiln.
3. Once temperature has stabilized with a steady state offset, note if there are any oscillations in the process variable (oscillation may be as long as 30 minutes).
4. If there are no oscillations, divide the proportional band by 2. This will make it more sensitive. Repeat this process until the process just starts to oscillate. This is the ultimate gain. Measure the time period of the oscillation.
5. Increase the proportional band until the offset increases to 65%.
6. Take the reciprocal of the oscillation time and multiply it by 8/5. This is the RESET.
7. Take the oscillation time and divide by 10. This is the RATE.
8. Should the control overshoot, reduce the RESET value and the RATE. The RATE should be 1/(6 x RESET).
9. When finished increase cycle time as long as possible without causing oscillations.
10. Check response to set point change in automatic.

Experimental Results

The results of the tuning process follow:

Chart 1 - The Proportion is set to 2 with the Integral and Derivative set to zero. The chart shows that the system response fluctuates around the desired value but never settles down. The system is unstable due to the narrow Proportional Band (high Gain).

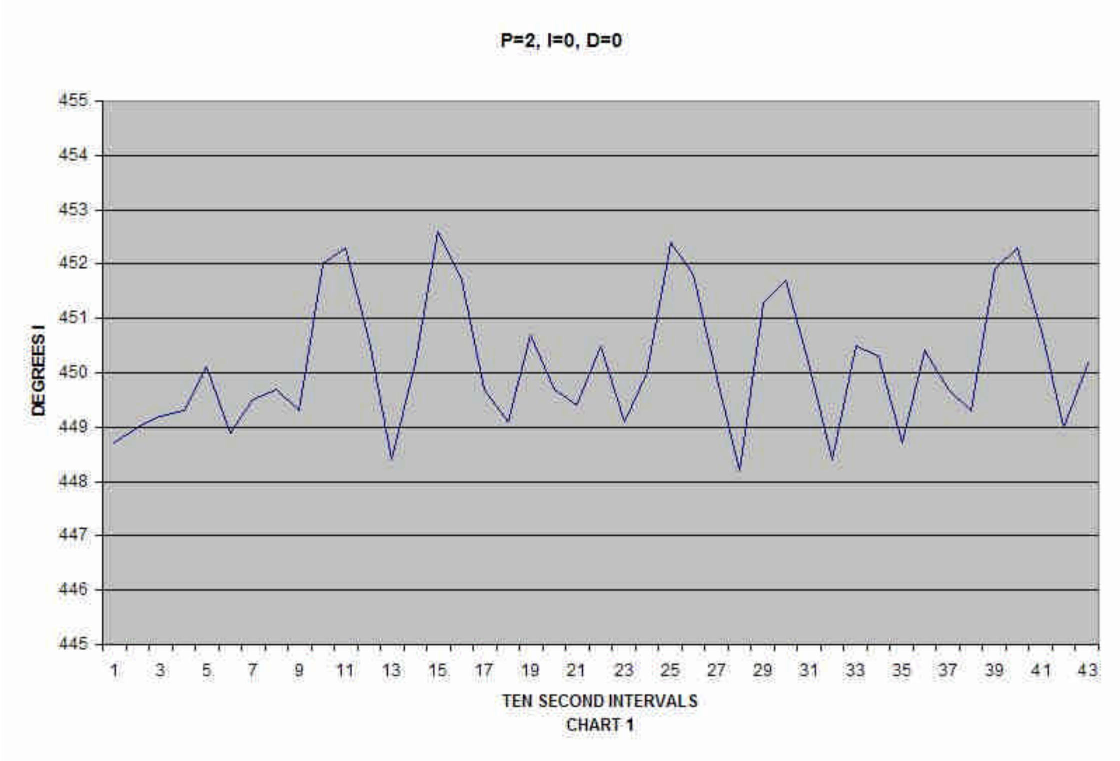


Chart 2 - The proportional band is adjusted to several settings. The Ultimate Gain is found when the Proportional Band is set to 5. The Ultimate period is measured to be about 60 seconds. Using this number, the Integral term is 96 seconds and the derivative term is 4 seconds.

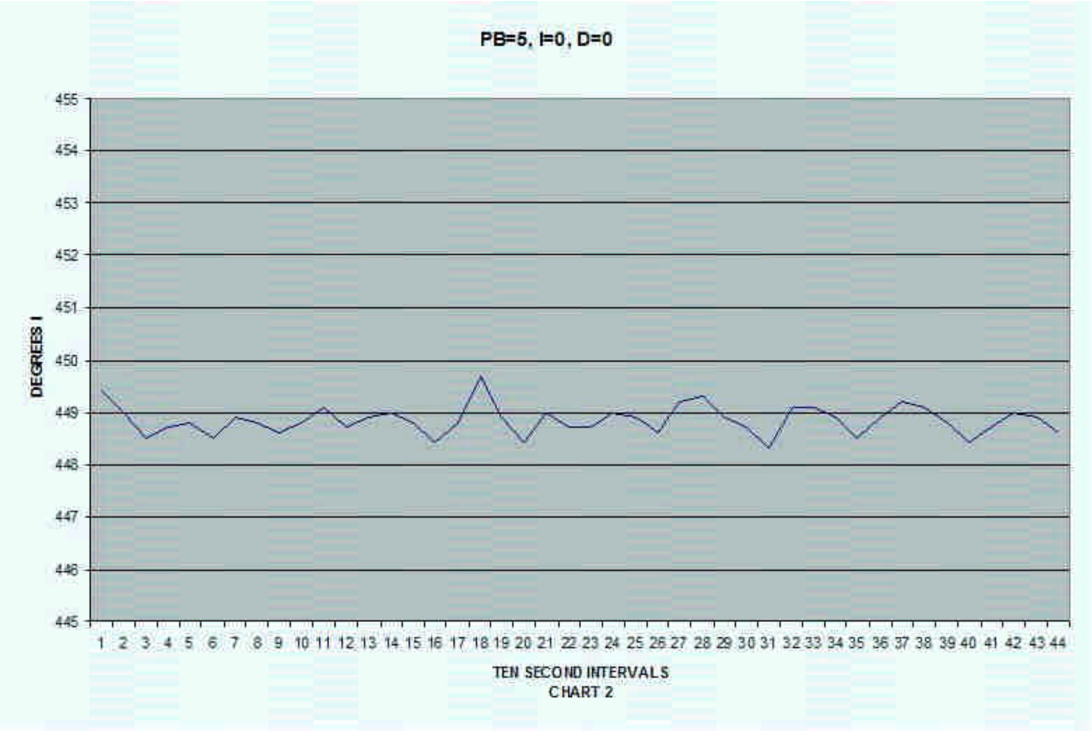


Chart 3 - This chart shows the steady state operation with the PID settings at 20, 96, and 4. As can be seen, the temperature became very erratic. When the temperature signal is noisy the D term reacts to the noise and cause havoc.

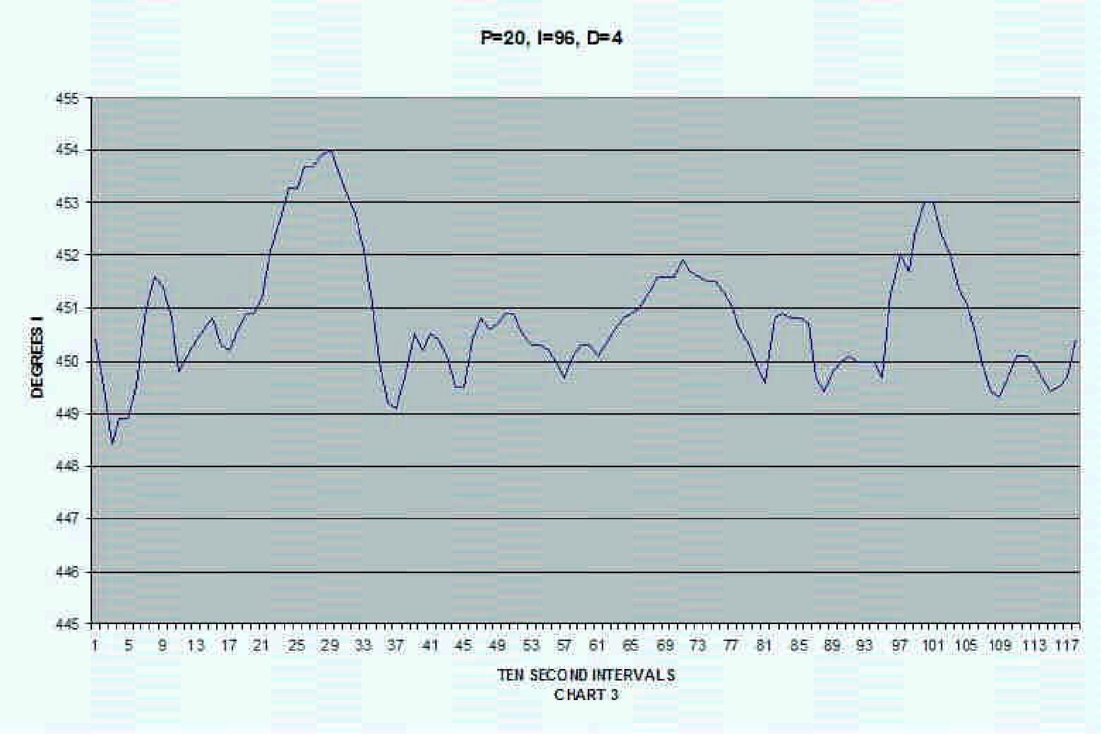


Chart 4 - The derivative term is completely removed here. As can be seen from the chart, the response of the system is much more controlled.

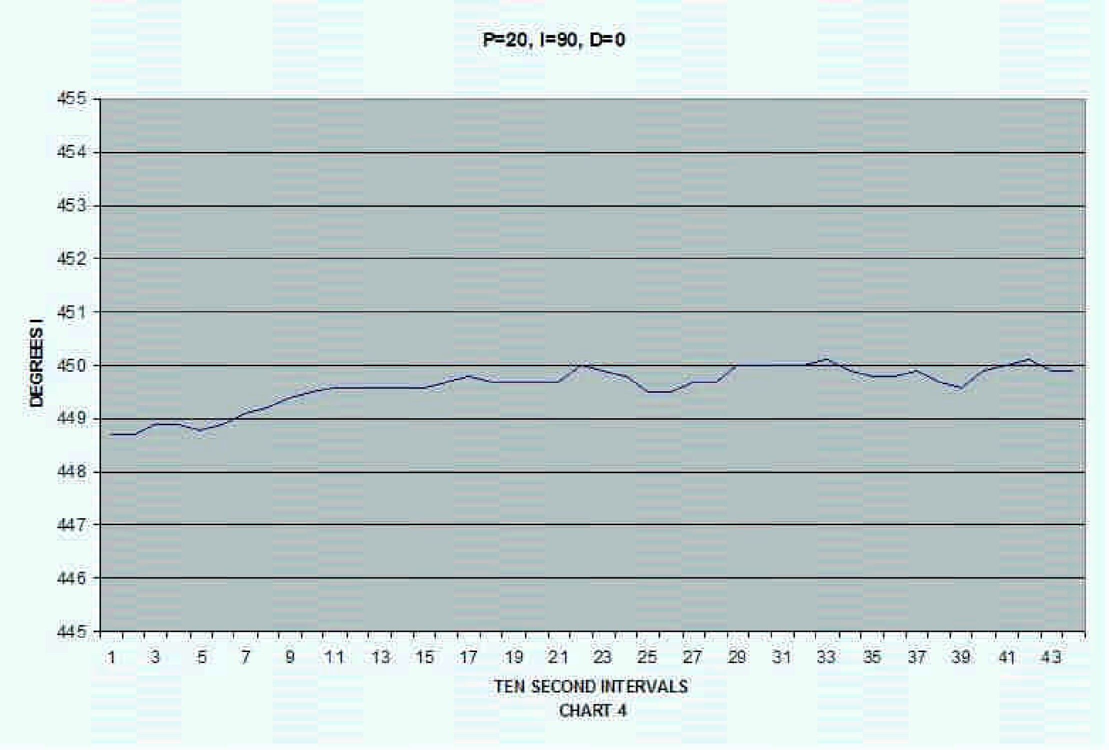


Chart 5 - With the PID settings changed to 20, 90, and 0, the set point is changed from 450 to 500 degrees F. After the temperature settles, the setpoint is returned to 450 degrees F. It is noted that the offset is removed slowly until the temperature settles at the set point.

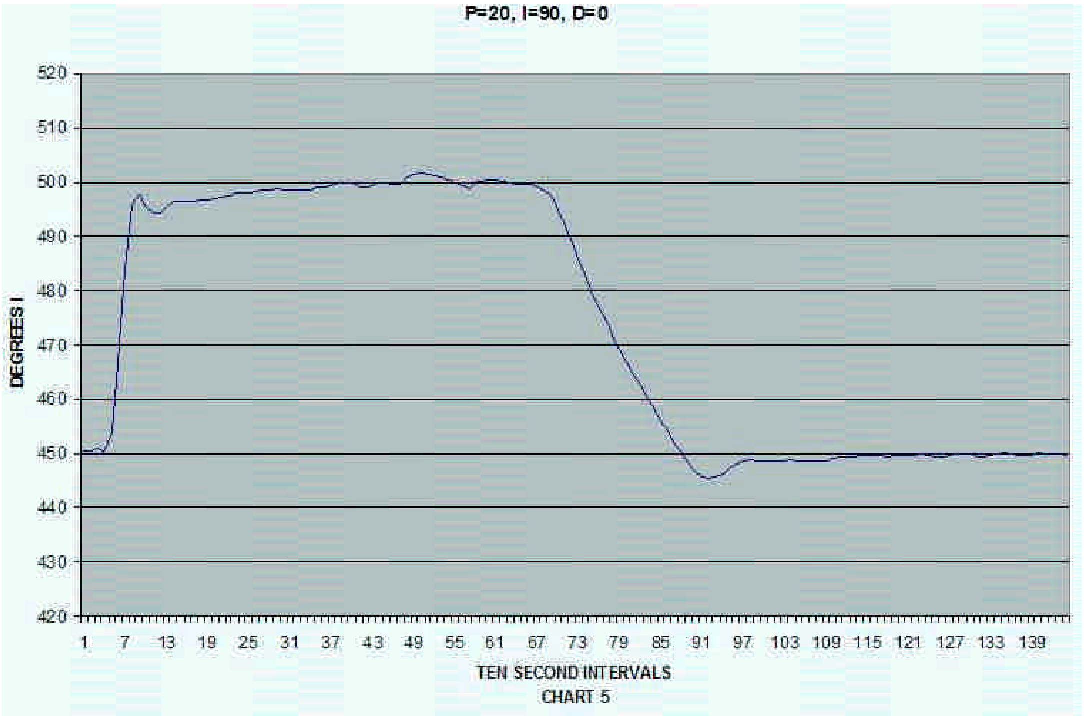


Chart 6 – Here, the Integral setting is reduced by half (increasing the affect of the integral action). It is noted that the temperature settles out sooner. The temperature does seem to wander about the setpoint a bit.

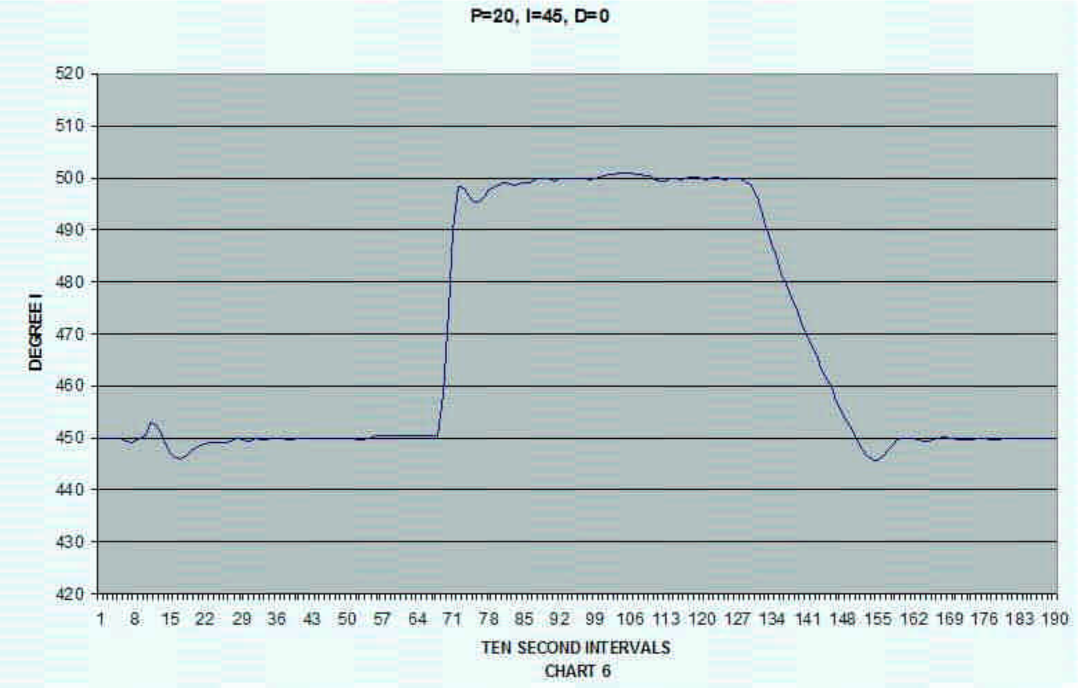


Chart 7 - Here, the integral time is increased slightly to smooth out the temperature wandering. There is a trade off between settling time and temperature stability.

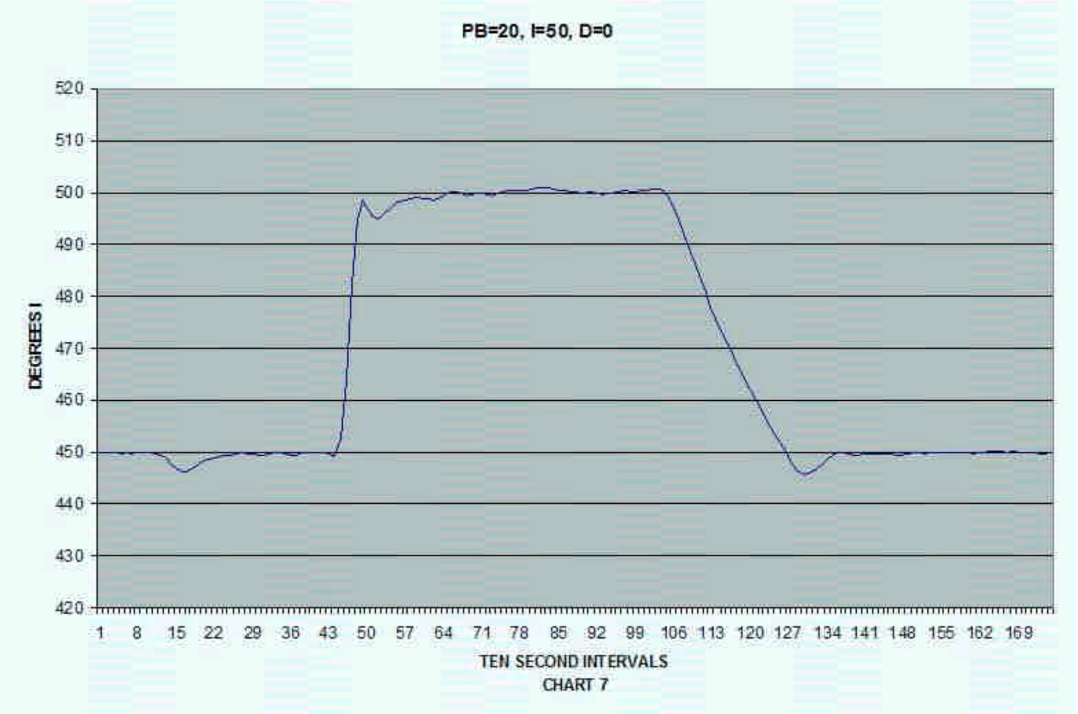
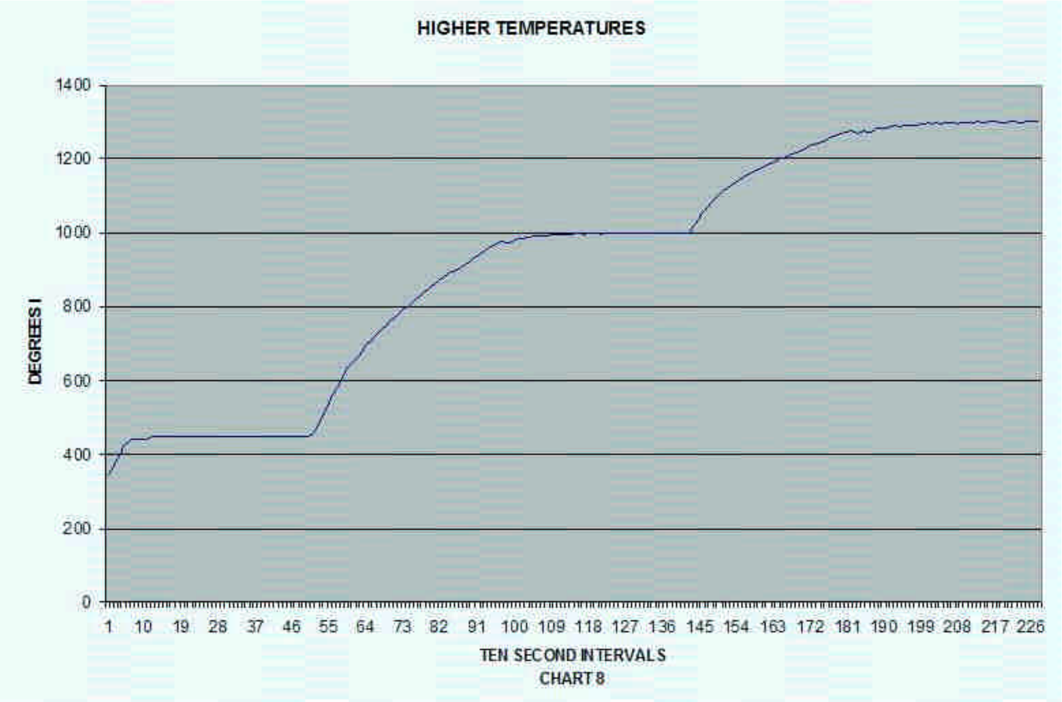


Chart 8 - The set point is increased up to1000 ^{o}F and then to1300 ^{o}F. In both cases the temperature rose to the setpoint with little overshoot. There was about a 1 degree fluctuation of the temperature at 1000 ^{o}F and about 2 degrees at 1300 ^{o}F.



With a temperature range of 2200 ^{o}F a 2 degree fluctuation would be less than 0.1 % of the process range. Each run required about 30 minutes. Ten minutes were allowed for the temperature to stabilize with the new setting before a setpoint change was introduced. Ten minutes were allowed for the temperature to settle down at the new set point.

Conclusion

Automatic temperature control can be accomplished in many ways such as on/off control, time proportional, and PID. PID control delivers the greatest accuracy because it corrects the offset inherent in the proportional mode. Since the P, I, and D terms vary in their interaction depending of the algorithm used, the tuning process must be approached accordingly. This project costs about $400 but yields a system that provides a valuable experience in tuning control loops.

Bibliography

1. R. Ramachandran, R. Ordonez, S. Farrell, Z. Gephardt, and H. Zhang, "Multidisciplinary control experiments based on the proportional-integral-derivative (PID) concept," 2001 ASEE Annual Conference Proceedings, Session 1526, 17 pages.

2. A. Eydgahi and M. Fotouhi, "A fuzzy knowledge-based controller to tune PID parameters," 1999 ASEE Annual Conference Proceedings, Session 2520, 11 pages.

3. Vance J. VanDoren, "Understanding PID Control," Control Engineering, June 1, 2000.

4. Vance J. VanDoren, "Self-Tuning Controllers Auto-Select P, I, D Values," Control Engineering, September 1, 1997.

5. Dave Harrold, "Process Controller Tuning Guidelines," Control Engineering, August 1, 1999.

6. Vance J. VanDoren, "Ziegler-Nichols Methods Facilitate Loop Tuning," Control Engineering,

Biography

MICHAEL OELSCHLEGEL
Michael Oelschlegel is a senior in the Control Systems Engineering Technology program at Texas A&M University-Corpus Christi, expecting to graduate in May 2003. He received an AAS Degree in Electrical Engineering Technology in 1978 and in Electronic Engineering Technology in 1985, both from Del Mar College in Corpus Christi. Mr. Oelschlegel is presently employed as a power distribution specialist with Equistar Chemicals.

RAFIC BACHNAK
Rafic (Ray) Bachnak is an Associate Professor of Engineering Technology at Texas A&M University-Corpus Christi. He received his B.S., M.S., and Ph.D. degrees in Electrical and Computer Engineering from Ohio University in 1983, 1984, and 1989, respectively. Dr. Bachnak was previously on the faculty of Franklin University and Northwestern State University.