DESIGN OF

TEMPERATURE CONTROLLERS

USING LABVIEW

A Thesis Submitted for Partial Fulfillment
Of the Requirement for the Award of the Degree of
Bachelor of Technology
In
Electronics and Instrumentation Engineering
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CERTIFICATE

This is to certify that the project report titled **"DESIGN OF ON/OFF,PROPORTIONAL AND PID TEMPERATURE CONTROLLERS USING LABVIEW"** submitted by **Abhilash Mishra** (109ei0329) and **Pinaki Mishra** (109ei0330) in the partial fulfillment of the requirements for the award of Bachelor of Technology Degree in the Electronics and Instrumentation Engineering during Session 2012-2013 at National Institute of Technology, Rourkela (Deemed University) and is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any Degree or Diploma.

Date: 13/05/2013

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Dedicated
To
My Parents

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This project is by far the most significant accomplishment in our life and it would be impossible without people who supported us and believed in us.

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ABSTRACT

This work describes a framework of ON/OFF, proportional and PID temperature controller systems. The design and implementation of this process is done using LABVIEW software. The project involves includes data acquisition, data processing and the display of data.

A ON/OFF controller is designed to measure temperature and the LABVIEW virtual instrument is used to control the temperature and ensure that the temperature does not go beyond a certain set point.

Feedback control is used in industry to improve and regulate response and result of a number of processes and systems. This project gives us an idea about the development and design of a feedback control system that keeps the temperature of the process at a predefined set point. The system contains data acquisition unit that gives input and output interfaces in between the PC, the sensor circuit and hardware. A proportional, integral, and derivative controller is implemented using LabVIEW. The project provides details about the data acquisition unit, the implementation of the controller and also presents test results.

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Chapter 4

LIST OF FIGURES

LIST OF ACRONYMS

P   Proportional

PI   Proportional Integral

PD   Proportional Derivative

PID   Proportional Integral Derivative

LabVIEW   Laboratory Virtual Instrumentation Engineering Workbench

VIs   Virtual Instruments

IEEE   Institute of Electrical and Electronics Engineers

DAQ   Data Acquisition

CHAPTER 1

INTRODUCTION

In this chapter, the overview of the different controllers are described. Literature survey of the work has been discussed. The objective of the thesis is explained. At the end organization of thesis has been presented.

1.1 INTRODUCTION TO LABVIEW

LabVIEW TM (Laboratory Virtual Instrument Engineering Workbench), a product of National InstrumentsTM, is a powerful software system that accommodates data acquisition, instrument control, data processing and data presentation. LabVIEW which can run on PC under Windows, Sun SPARstations as well as on Apple Macintosh computers, uses graphical programming language (G language) departing from the traditional high level languages such as the C language, Pascal or Basic.

All LabVIEW graphical programs, called Virtual Instruments or simply VIs, contains a Front Panel and a Block Diagram. Front Panel has various controls and indicators while the Block Diagram consists of a variety of functions. The functions (icons) are wired inside the Block Diagram where the wires represent the flow of data. The execution of a VI is data dependant which means that a node inside the Block Diagram will execute only if the data is available at each input terminal of that node. By contrast, the execution of programs such as the C language program, follow the order in which the instructions are written.

LabVIEW manages data acquisition, analysis and presentation into one system. For acquiring data and controlling instruments, LabVIEW supports IEEE-488 (GPIB) and RS-232 protocols as well as other D/A and A/D and digital I/O interface boards. The Analysis Library offers the user a comprehensive array of resources for signal processing, statistical analysis ,filtering, linear algebra and many others. LabVIEW also supports the TCP/IP protocol for exchanging data between the server and the client. LabVIEW v.5 also supports Active X Control allowing the user to control a Web Browser object.

The version used for our project is LabVIEW 2010

1.2 DATA ACQUSITION USING LABVIEW

Data acquisition (DAQ) is the process of acquiring an electrical or physical phenomenon such as voltage,current, temperature, sounds or pressure with a computer. A DAQ system consists of a DAQ card or sensor, hardware from which data is to be acquired and a computer with associated software. A DAQ card has various features which can be designed for different purposes. For data involving very high accuracy the sampling rate of the card should be high enough to reconstruct the signal that appears in the computer. NI USB-6363 DAQ can be used to get data related to impulse voltage which require very high accuracy. Sampling rate of this card is 2MS/s (megasamples per second). This DAQ can be used in variety of platform like Microsoft windows, MAC, and Linux etc. For acquiring data from high voltage system, first the system parameters should be scaled down to values supported by the DAQ card. So the high voltage system should be connected to instrument transformer to scale down the voltage as well as

current. For remote control of a system (stand alone mode), CompactRIO can be used which provides embedded control as well as data acquisition system. The Compact RIO system's tough hardware configuration includes a reconfigurable field-programmable gate array (FPGA) chassis, Input/Output modules, and an embedded controller. Additional feature of Compact RIO is, it can be programmed with NI LabVIEW virtual instrument and can be interfaced.

1.3 ORGANIZATION OF THESIS

Besides the first chapter which gives us an introduction to the thesis, the thesis consists of three other chapters. The second chapter deals with ON/OFF temperature controllers. The third chapter describes the operation of proportional and PID temperature controllers. It also gives an idea about how they are controlled using LABVIEW. The final chapter quantifies all the results and conclusions are drawn based on the observations.

CHAPTER 2

ON/OFF TEMPERATURE CONTROLLER

This chapter describes the functioning of a simple ON/OFF temperature controller.

2.1 SYSTEM OVERVIEW

A control system consists of components and circuits that work together to maintain the process at a desired operating point. Every home or an industrial plant has a temperature control that maintains the temperature at the thermostat setting. In industry, a control system may be used to regulate some aspect of production of parts or to maintain the speed of a motor at a desired level.

Although a control system can be of open loop type, it is more common to use negative feedback. The block diagram shown in Fig. 2.1a illustrates the basic structure of a typical closed loop control system. The Process represents any physical characteristic that must be maintained at the desired operating point. In this paper, it is the temperature that is to be maintained at the desired value.

The purpose of feedback is to provide the actual or the current value of process variable. In this application a solid state temperature sensor is used to monitor the temperature. It outputs a voltage that is too small for practical purpose, typically in the millivolt range. The signal conditioning block that follows amplifies this signal to a useful level. The signal conditioning block may also be used for calibration purposes by scaling the voltage from the sensor to the corresponding temperature. The output from the signal conditioning block is designated in Fig 2.1(a) as V_{PV}, the current value of the Process variable.

The Set Point, designated as VSP, represents the user input. It is the desired value of the Process Variable, temperature in this application. The two signals, VPV and VSP are applied to the difference amplifier whose output is the Error signal VE = VSP – VPV.

The Controller block in Fig.2.1 a is the heart of a control system. It accepts the Error signal VE and produces an appropriate output. In practice a control may be one of several types: ON/OFF, Proportional, Proportional plus Integral or Proportional plus Integral plus Derivative (PID). These controllers differ in the manner in which they operate or process the Error signal.
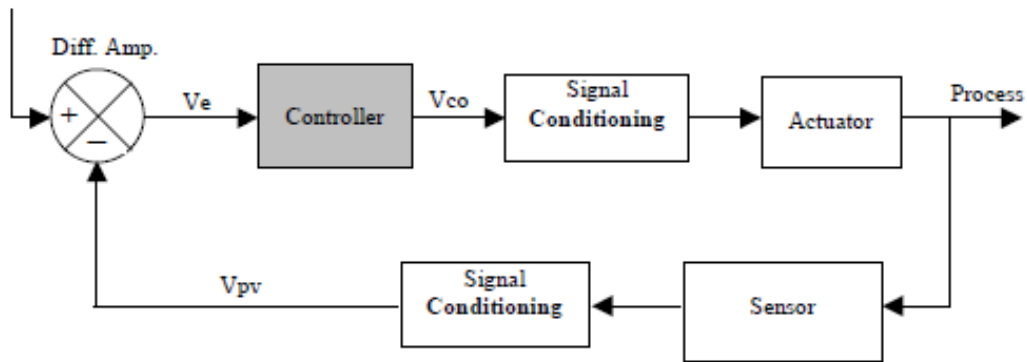
(a)
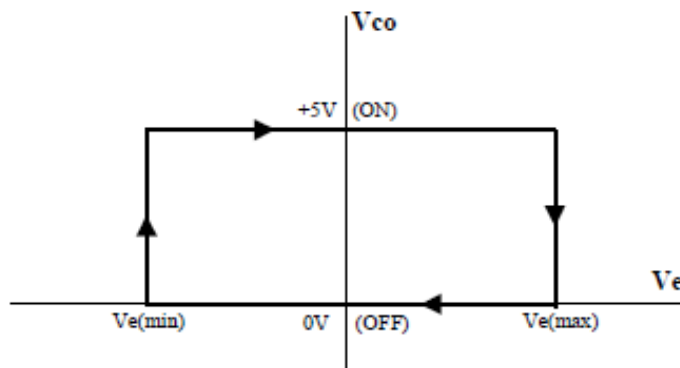
(b)

Fig 2.1(a) Closed Loop Control System
(b) Hysterisis Loop

The use of negative feedback is the key to the proper operation of a control system. Consider the operation of the ON/OFF control system depicted in Fig. 1b. The object of the temperature control system described in this paper is to provide air condition (cooling) control. Suppose that the Controller is OFF (VCO = 0V), providing no cooling. The operating point is now on the bottom part of the hysteresis curve in Fig 2.1b. This results in increasing temperature and also in increasing VPV. The Error signal VE = VSP -VPV is decreasing since VSP does not change. VE continues to decrease until VE =VE (MIN). At this point the controller switches ON (VCO = +5V) and drives the actuator (fan) in this experiment) which provides cooling. The Error signal now begins to increase because VPV is dropping. It continues to increase until VE = VE(MAX). At this point the Controller switches OFF, shutting OFF the fan and the cycle repeats. The difference VE (MAX) - VE (MIN) is called the dead band. It is the range of the Error signal in which the controller is either ON or OFF. No regulation of the Process Variable occurs inside this range. The dead band is necessary because without it the system will oscillate constantly between ON and OFF operating states.

2.2 SYSTEM HARDWARE

The data acquisition board (DAQ board) serves as the interface between the computer and the real world as shown by a block diagram in Fig. 2.2. It is installed in the PC that operates under Windows. In this application MIO-16E -10 board was used. Channel. 0, one of the analog input channels, is wired to the external temperature sensor. Channel.1 is wired to the D/A Ch.0, one of the DAC output ports, and also to the fan. Thus the current temperature data is coming into computer via analog input Channel. 0 and the control signal that controls the operation of the fan

comes from the computer via D/A output Ch.0. In addition, analog input Channel.1 monitors the

operation of the fan as it receives the same signal from the computer as does the fan.
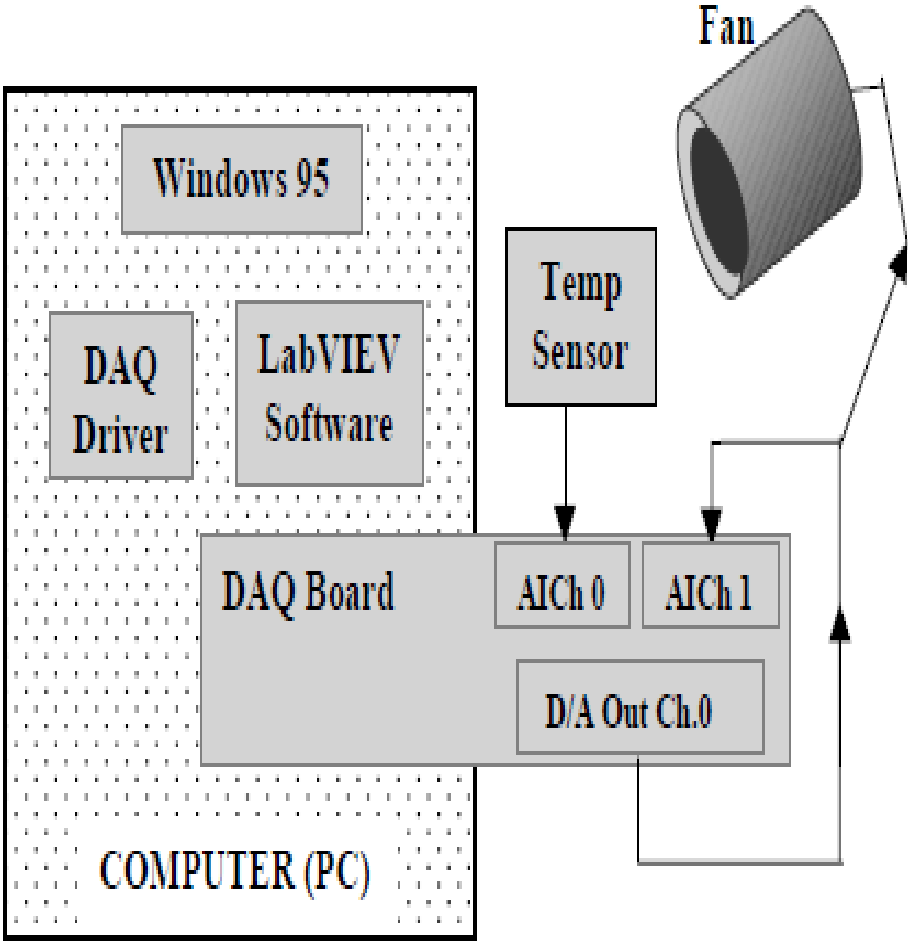

Fig 2.2 System Hardware Block Diagram of ON/OFF control

2.3 SYSTEM SOFTWARE

Analog input data acquisition options include: *immediate single point input and waveform input*. In using the immediate single point input option, data is acquired one point at a time. Software time delay to time the acquisition of the data points, which is typically used with this option, makes this process somewhat slow.

Waveform input data acquisition is *buffered and hardware timed.* The timing is provided by the hardware clock that is activated to guide the acquired data points quickly and accurately. The acquired data is stored temporarily in the memory buffer until it is retrieved by the data acquiring VI.

The temperature control application described in this article uses two Easy VIs. The AI Sample Channel.vi is used to acquire data from Analog Input Channels 0 and 1 while AO Update Channel.vi outputs 0 V or +5 V to D/A channel 0 to control the operation of the fan.

2.3.1 FRONT PANEL

All programs which are written inside the LabVIEW environment are called VIs. Each VI consists of a Front Panel and a Block Diagram. The Front Panel includes various controls and indicators while the Block Diagram contains various functions and other VIs, that are interwired among themselves. Shown in Fig 2.3 is the Front Panel of the temperature control VI.

As shown, the Front Panel includes two Waveform Charts and other objects. The top Waveform Chart displays the error signal (the difference between the set point and the process variable), and the bottom chart displays VCO, the Controller status.

Other objects inside the Front Panel includes the recessed box with two digital controls. They are used by the operator to input the Set Point (VSP) value of and the scaling factor (T Calibrate) which converts the temperature sensor output from millivolts to degrees F. The thermometer indicator measures the current temperature and the Cooling indicator displays the Controller state (ON or OFF). The last object in the Front Panel is the Run/Stop switch which is used to initiate and terminate the VI execution.
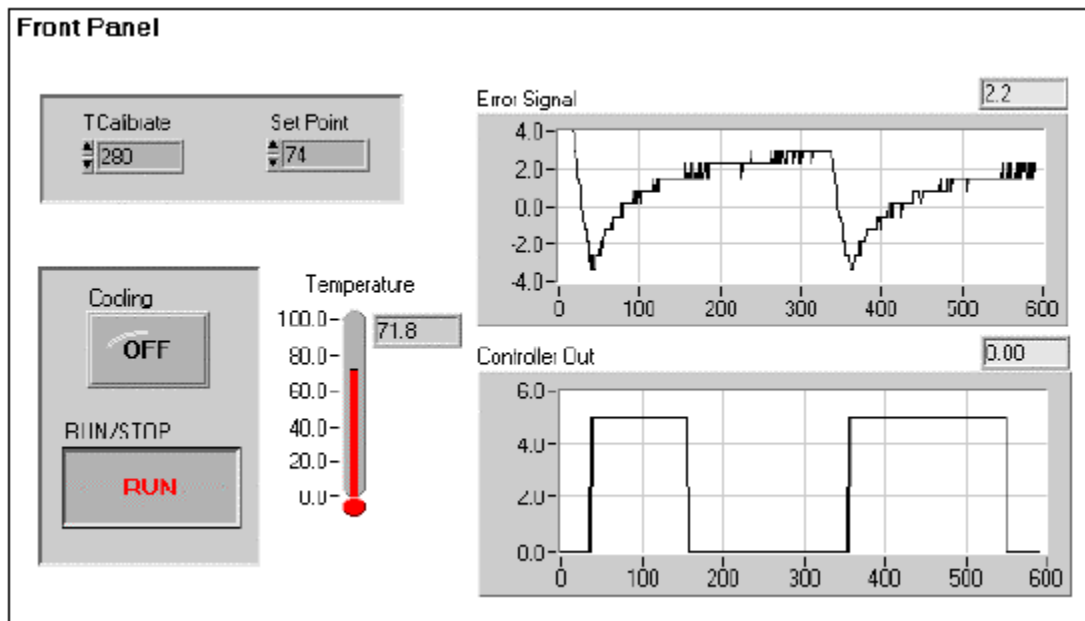

Fig 2.3 Front Panel of ON/OFF Control

2.3.2 BLOCK DIAGRAM

The Block Diagram is the graphical program that shows the data flow of the temperature control operation. Unlike a high level language program, like the C language where instructions are executed in the order that they are written, the execution of a LabVIEW VI depends solely upon the flow of data: a particular object inside the Block Diagram will execute only if data is available or present at all its input terminals. The execution continues at each node that has the data.

Fig 2.5 shows the details of the Block Diagram which can be used to describe the operation of the ON/OFF controller while Fig 2.4 shows the hysteresis of the ON/FF Controller operation as the Error signal varies between -2°F and $+2^{o}$F.

The operation begins with a check on whether the Controller is ON or OFF. This is accomplished with VI 2 (AI Sample Channel.vi) and the comparator C1. The output of C1 is either TRUE or FALSE. If TRUE, then the Controller is OFF, and if FALSE then the Controller is ON. VI 2 takes its input from Channel 1 of Device 1 (DAQ Board number). As described earlier, analog input Channel 1 is physically wired to DAC output Ch. 0 which controls the operation of the fan. Thus by testing the DAC output Ch. 0, we can determine whether the Controller is ON or OFF.

This will place the Controller operating point either on the lower segment or the upper segment of the hysteresis loop.
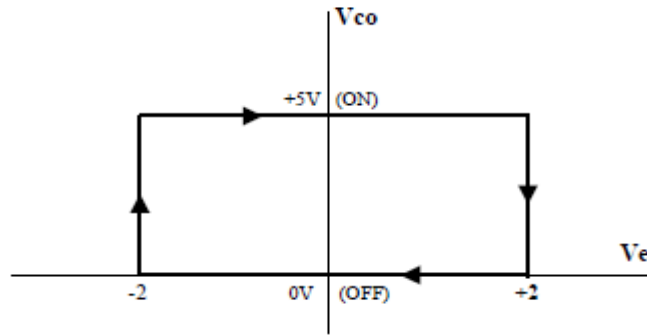
Fig 2.4 Hysterisis Loop of ON/OFF control
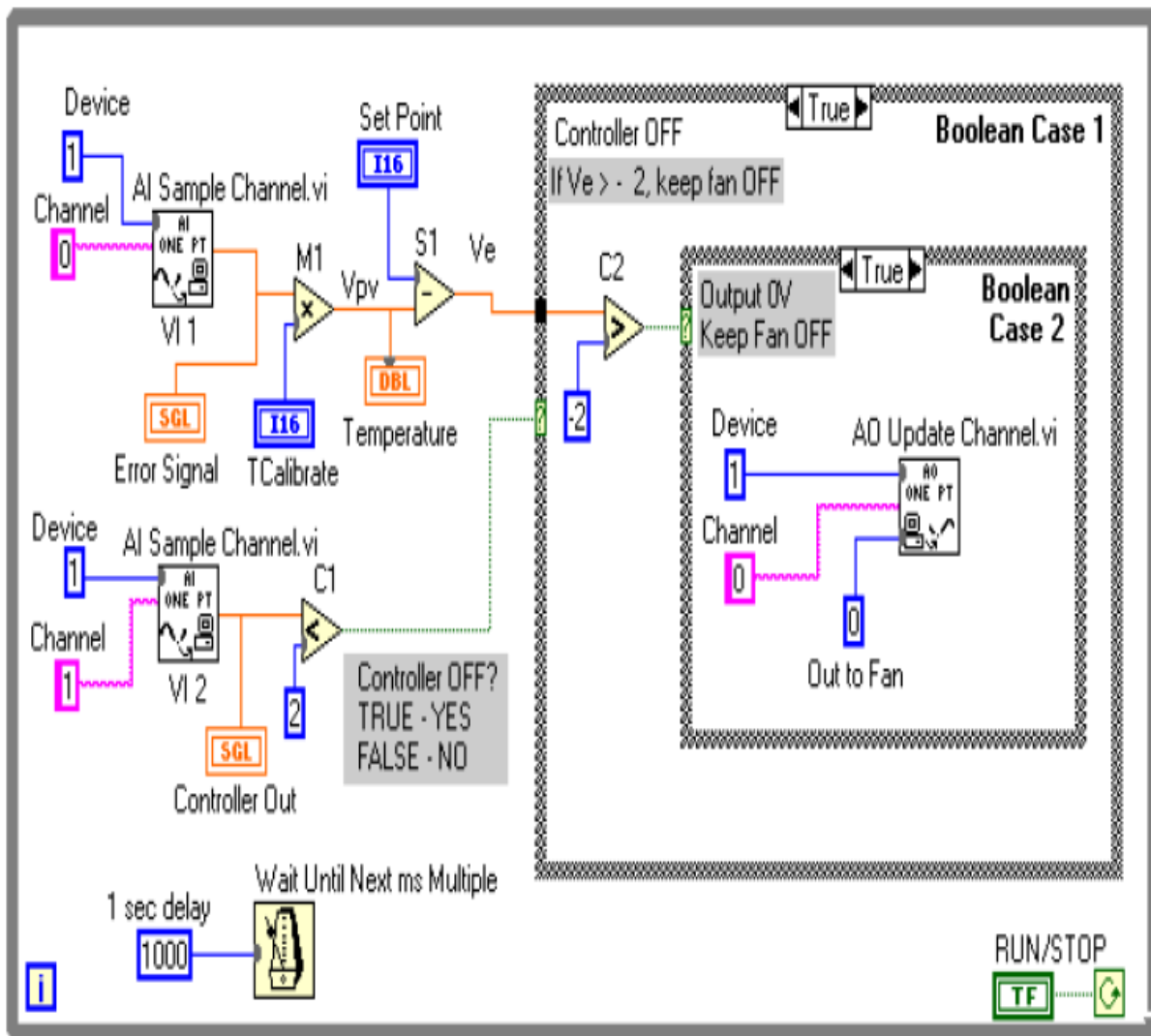
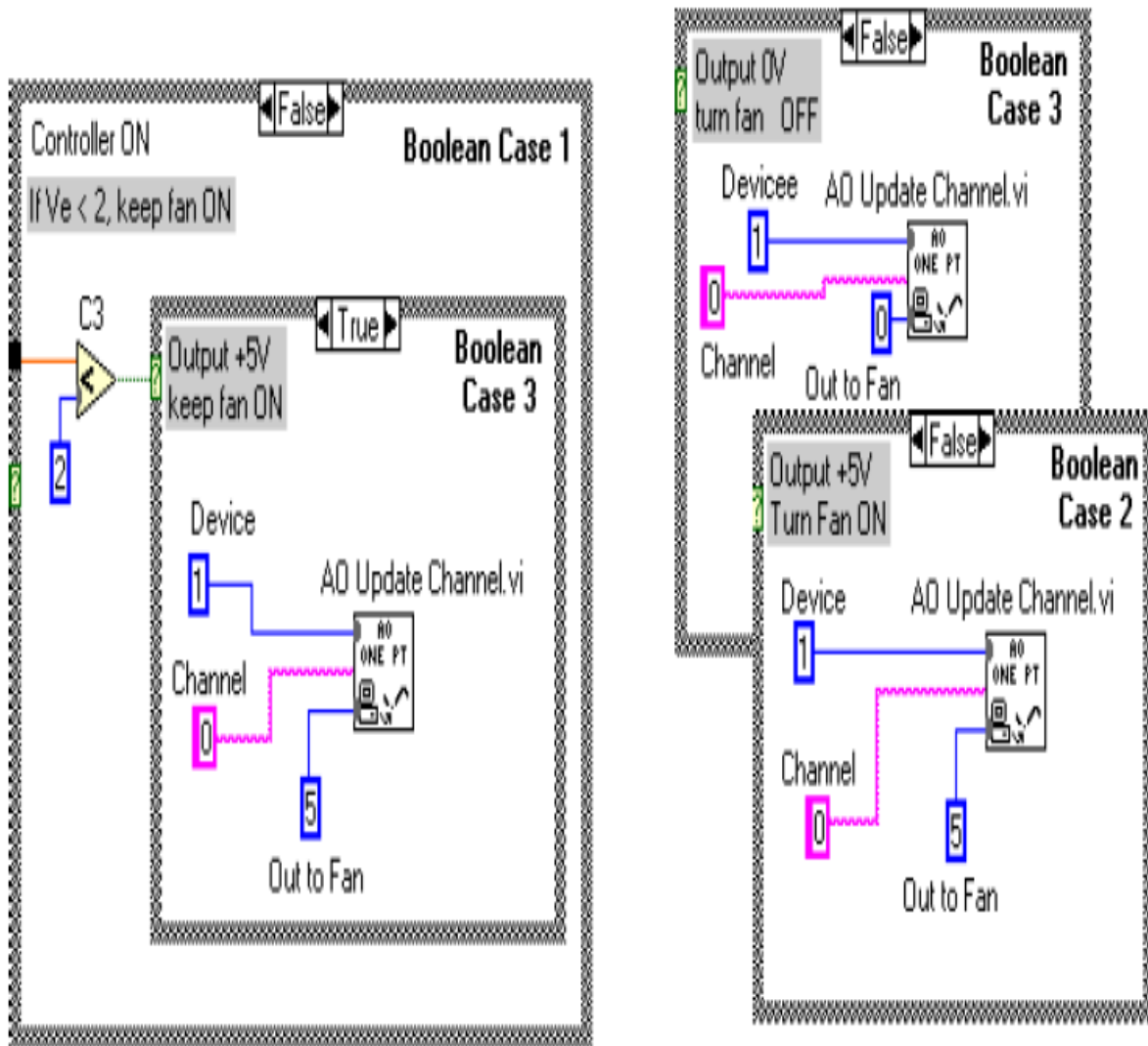Fig 2.5 Overview of the Block Diagram for ON/OFF control

At this time V1, M1 and S1 determine the value of the Error signal (VE). V1 takes the temperature sample from the analog input Ch. 0 to which the temperature sensor is wired. M1 multiplies the temperature sample by the scaling factor (T Calibrate) and S1 subtracts this value from the Front Panel digital control Set Point (VSP) . The result is the Error signal.

The Controller has to make a decision whether to turn the fan ON or OFF. This decision making process is implemented with nested Boolean Case structures. The reader should follow the hysteresis loop in Fig 2.4 and the code in Boolean Cases 1, 2 and 3.

If the output from Comparator C1 is TRUE, then the True frame of Boolean Case 1 will be executed. The Controller must be OFF and its operating point is on the lower segment of the hysteresis loop in Fig. 4. We must check next if the Error signal is greater than -2^oF. This is done inside the True frame of Boolean Case 1. If the Error signal is greater than -2^oF, then the True frame of Boolean Case 2 outputs 0V, keeping the fan OFF. But if the error signal is equal to or less than -2^oF, then the False frame of Boolean Case 2 outputs +5v to turn the fan ON.

If C1 output is FALSE, the Controller must be ON. Comparator C3 inside the False frame of Boolean Case 1 checks the Error signal if it is less than $+2^oF$. If TRUE, the True frame of Boolean Case 3 outputs +5 V to keep the fan ON. And if FALSE then the False frame of Boolean Case 3 outputs 0v thus switching the fan OFF.

This operation is inside the While Loop which is enabled by the RUN/STOP switch in the Front Panel. As long as the switch is in the RUN position, its terminal counterpart in the Block Diagram outputs a TRUE to the condition terminal keeping the While Loop enabled; a FALSE disables the While Loop. As long the While Loop is enabled, the code inside the loop is repeatedly executed. This results in acquiring a temperature sample once a second. To stop the operation, the user must click on the RUN/STOP switch.

The two Waveform Charts in the Front Panel show the error signal and the Controller Output . The Wait Until Next ms Multiple function provides 1 s time delay between the data points.

2.4 CONCLUSION

The system described in this article is a prototype that mimics the operation of a large air conditioning system. Within the constraints of the design and the limits of the physical configuration, the system performed within the design limits. The dead band was set to $\pm$ 2°F which makes the Controller switch at +2°F at the upper end, and -2°F at the lower end.

The rate of cooling achieved by this application was estimated to be approximately 1 minute to cool the air around the temperature sensor from 76 to 72°F. Its accurate determination was not done because it depends on many factors such as the volume to be cooled, enclosure and its insulating properties and other factors.

CHAPTER 3

PROPORTIONAL AND PID TEMPERATURE CONTROLLER

This chapter describes the functioning and operation of proportional and PID temperature controllers.

3.1 SYSTEM OVERVIEW

To observe the working of the system a heating element which gives off constant heat was used. The surface temperature of the heating element is controlled by varying the amount of cooling received. A small electric fan is positioned directly in line with the heating element in such a way that cool air is forced over it. The amount of heat transferred from the heating element is directly proportional to the rate of air flowing over it. We monitor the surface temperature of the element and control it by changing the speed of the cooling fan.

3.1.1 DAQ SYSTEM

The system uses a data acquisition system (DAQ) which is connected to a PC in the lab. It gains input from the process and gives out output signals to the control element. A control algorithm is implemented on the PC which is connected to the DAQ system. LabVIEW software from National Instruments is used to design the custom data acquisition and control program. The program measures the temperature from the process, compares it to a predefined set point, and

issues the desired control signal to the final control element. The signal controls the rotation speed of the fan used. The fan rotation speed decides the air flow rate over the heating element.
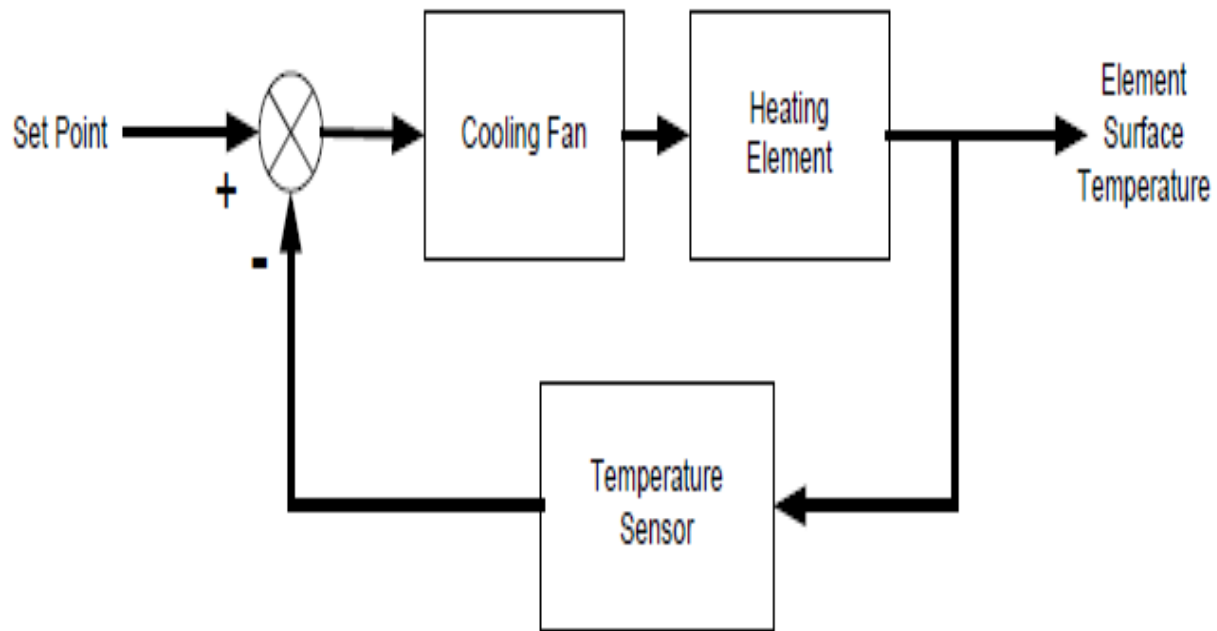

Fig 3.1 System Block Diagram for PID control

The DAQ device joins together the SCXI chassis and modules to the PC. It performs the A to D and D to A conversion required for interfacing the I/O signals to the PC. The card used is a NI 6040E PCI card. It has 16 analog inputs, two 24-bit counter/timers, 2 analog outputs and 8 digital I/O lines.

3.1.2 SYSTEM CHASIS

The SCXI-1000 is a 4-slot chassis which can power and control up to four modules. It is expandable and can allow more than one chassis to be chained as single system. The chassis gives power to the modules and a communication bus which is connected to the PC.

3.1.3 ANALOG INPUT

The analog input is a SCXI-1102C 32-Channel Input Module. It is very convenient for measuring small current and voltage inputs, and consists of a Cold Junction Compensation circuit which is used with thermocouple sensors. Connected to the front of the SCXI-1102C is a terminal block. This block provides the wiring terminals to which external signals are connected.

3.1.4 ANALOG OUTPUT

For analog output, a SCXI-1124 6-Channel Analog Output Module is used. It can provide up to six channels of slowly changing DC voltage or current signals. The output voltage range is selected using software with the maximum swing in between ±10 volts.

3.2 SYSTEM HARDWARE

3.2.1 SYSTEM POWER

To provide power to the electronics and fan, a 12-volt DC supply is used. A voltage regulator IC can be used to provide the positive 12-volt supply that runs the fan and op-amp circuits. As a

result, only one external power connection is required. A connection to a 15-volt power supply is what is needed to supply a regulated 12-volt supply to the entire circuit.

3.2.2 HEAT CIRCUIT

A resistance heater circuit is used as the system heating element. It is made by wiring two 270Ω resistors in parallel. These resistors are connected directly to the 12-volt DC power supply. When the resistors heat up, they dissipate 1.2 Watts of power. Almost all of this is given up as heat . It is a simple way to model a heat dissipating source that can reach 160° F.

3.2.3 TEMPERATURE SENSOR

A temperature sensor is connected to the surface of the heating element. This sensor provides feedback to the control system. The temperature sensor used is a J-type thermocouple sensor which is commonly used in industry. It can sense temperatures ranging from 32-90 degrees Fahrenheit. It is suitably designed for use with the SCXI system as the signal conditioning system can take care of the cold junction compensation and the scaling which is required to get an accurate temperature measurement in degrees Fahrenheit.

3.2.4 FAN INTERFACE CIRCUIT

A custom interface circuit is required to control the DC fan. The easiest way would be to join the fan directly to the SCXI-1124 output module. Unfortunately, this is not possible for a variety of reasons. First, the module is not designed to hande the amount of current required for the fan to operate. The fan is designed to function at 12 volts DC and around 60mA of current. When it is used as a voltage source, the module can give at most 5mA of current. So, an interface circuit is required for the fan to work properly. The circuit should be able to provide the power required by the fan. Even if the module is able to deliver the current needed, the module's voltage range is different from that of the fan
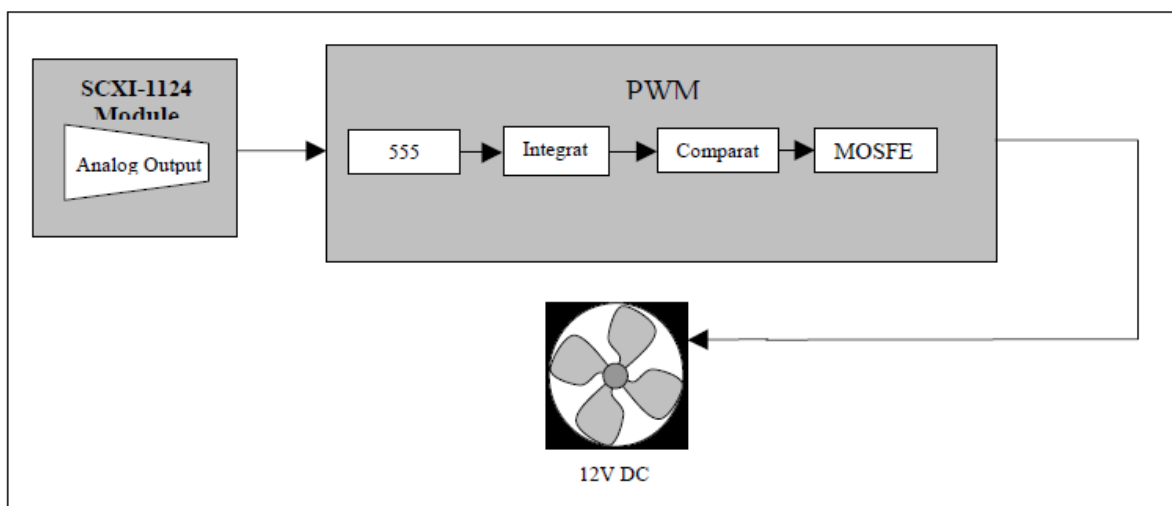

Fig 3.2 Interface circuit for DC fan

The simplest method is to vary the input voltage provided to the fan in between its maximum and minimum values. This means varying the voltage between 0-12 volts. The easiest method is to use an adjustable voltage regulator. A typical regulator provides up to 1 Amp of current which is enough to power the fan. But the problem associated with this method is that a large amount of

power is misspent in the form of heat dissipated by the regulator. The fan is also designed to operate under its full supply of 12 volts. Running the fan at voltages below this shortens the life of the DC motor.

3.3 SYSTEM SOFTWARE

The software integrates easily with the data acquisition software and measurement products from NI. When used with the SCXI system, it results in very quick development of powerful control applications.

Perhaps the biggest advantage of the LabVIEW system is that it contains hundreds of VI's which are ready to use in a custom program. In the designof this project we took full advantage of these ready-made VI's for acquistion, control, and analysis.

3.3.1 FRONT PANEL

The front panel allows us to control and monitor the process. It consists of software controls and indicators that resemble physical controls such as LEDs, sliders, buttons, and charts. Shown below as Figure 3.3 is a screenshot of the front panel of our project.
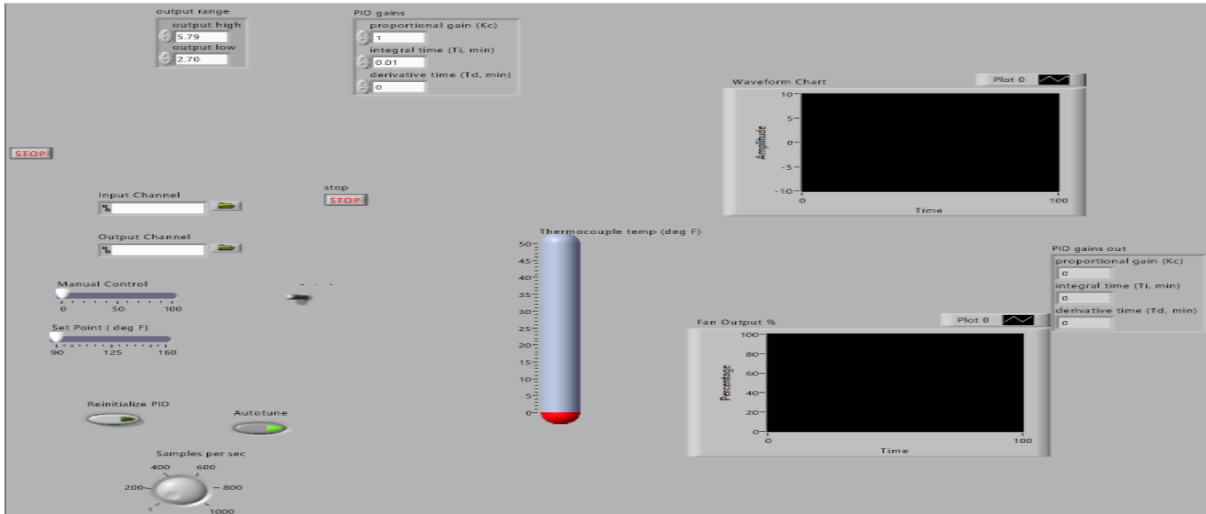
Fig 3.3 Front Panel for PID control

The temperature of the process is shown in a thermometer-style indicator. It is also recorded on a strip chart. The strip chart also consists of the set point value. By displaying both measured values and set point on the strip chart, one can easily visualize how the system responds to any change in the set point. This is very helpful when determining the correct PID constants. It also has a slider for manually adjusting the fan speed and one to control the temperature set point required for automatic control. A toggle switch is used to switch between automatic and manual control. There is a dial control which sets the sampling rate. It controls the speed of the software loop. The PID values can be inputted in a numerical control box. Below the PID control boxes are two push button switches. The one marked Autotune begins an automatic tuning routine. The routine tries to find the most optimum values for P, I, and D by using the Zeigler-Nichols ultimate gain method. After this, the new PID values are then automatically entered into the control box.
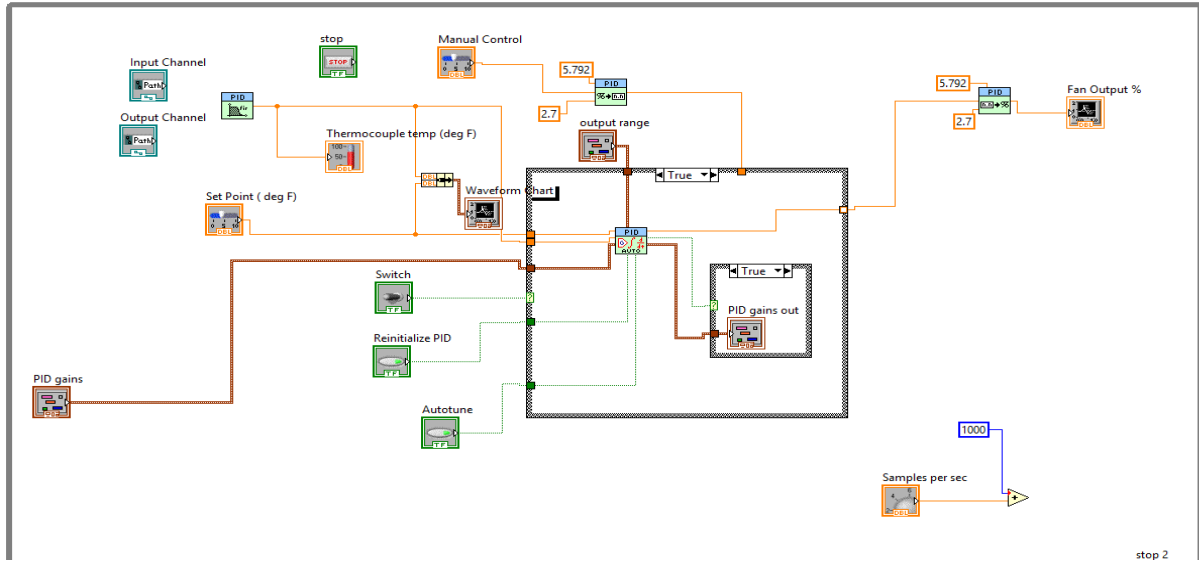
3.3.2 BLOCK DIAGRAM

Fig 3.4 Block Diagram for PID control

The block diagram shown above is a graphical representation of the software program.

It has several icons that show typical programming elements which include constants,

variables, subroutines, and loops.

3.4 BUILDING THE SYSTEM

3.4.1 BREADBOARD CIRCUIT

Fig 3.5 Heating and Fan Interface Circuit

3.4.2 WRITING AND DEBUGGING THE SOFTWARE

Since the LabVIEW environment is graphical programming language, it is very simple to write and debug the software. One doesn't have to memorize codes because every code element and structure can be selected from a menu and dragged into the program. The program can be run and debugged in a single window. As a result troubleshooting is very quick. There is an

"Execution Highlighting" option which acts as a debugger by gradually stepping through the program. This action allows us to see how the code is behaving.

3.5 SETUP REQUIREMENTS

The system requires a proper power supply to operate the breadboard circuit and fan, a connection to the correct SCXI input and output modules, and the LabVIEW VI. The controlling PC does not need to be physically connected to the hardware circuit. If the hardware is connected to a PC via the SCXI system, the entire process can be controlled and monitored from any PC that runs the VI and communicates over the network. For example, we were able to do some of our software testing on a PC located at some distance from the real SCXI system and process circuit.

3.6 OPERATION

To provide power to the process circuit, a 15-volt power supply is required. It is able to provide positive and negative 15-volts to the circuit. The system is very easy to operate. Once the circuit is connected and power is provided, the VI is started. The operator can measure the current temperature of the circuit and manually control the speed of the fan. Once the system has settled, control can be handed over from manual to automatic. The PID algorithm now provides instructions to the controller. The PID algorithm ensures a bump less transfer from manual to automatic. It also consists of an auto-tuning function. The auto tune button is pressed to begin the self-tuning process. Once the tuning process is completed, the new constants are entered into the

control box. The chart scale and setpoints can be adjusted even when the program is running. To stop the program click on the stop button anytime.

3.7 RESULTS

The system worked well given the constraints on construction and design. The fan cools the heated element to a temperature of 110° F while running at is maximum speed. The operator, using manual control, can vary the fan speed from zero to almost full speed very easily. The system keeps the temperature near the desired set point using automatic control. This is true even without setting the loop for optimal control. For example ,when it was set as proportional only control, the temperature was kept constant with an offset of about five degrees from the setpoint. Shown as Figure 3.5 below is a screenshot displaying a graph of the set point and measured values.
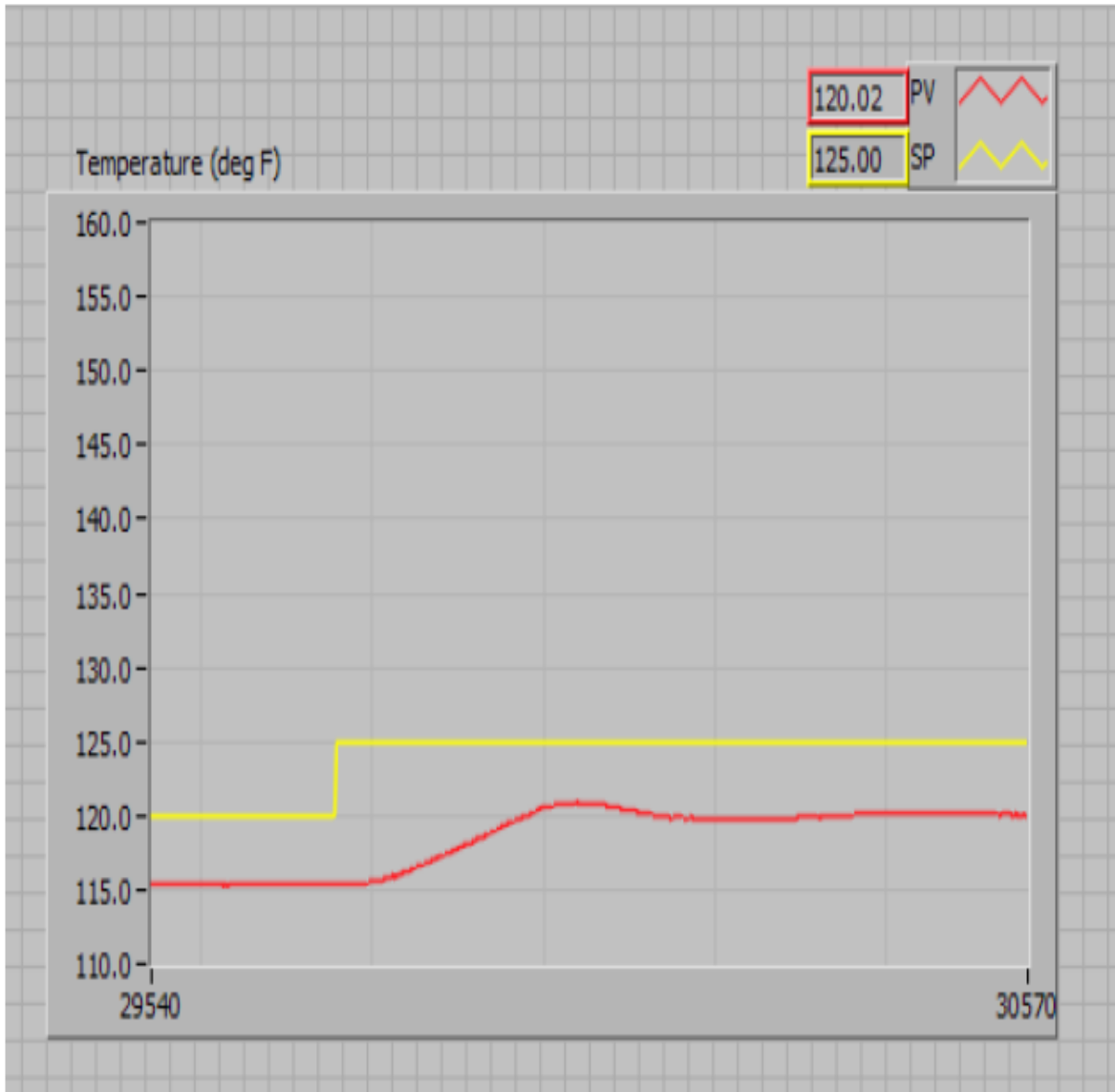
Fig 3.6 Gain for proportional controller

The figure above dispalys the response of the system to a set point step change of

about 5 degrees. The temperature arrives at a steady state, but with 5 degree offset.

The offset reduces with increase in the proportional gain. As the proportional gain is

increased, the offset is reduced, however, oscillation is introduced into the system. This
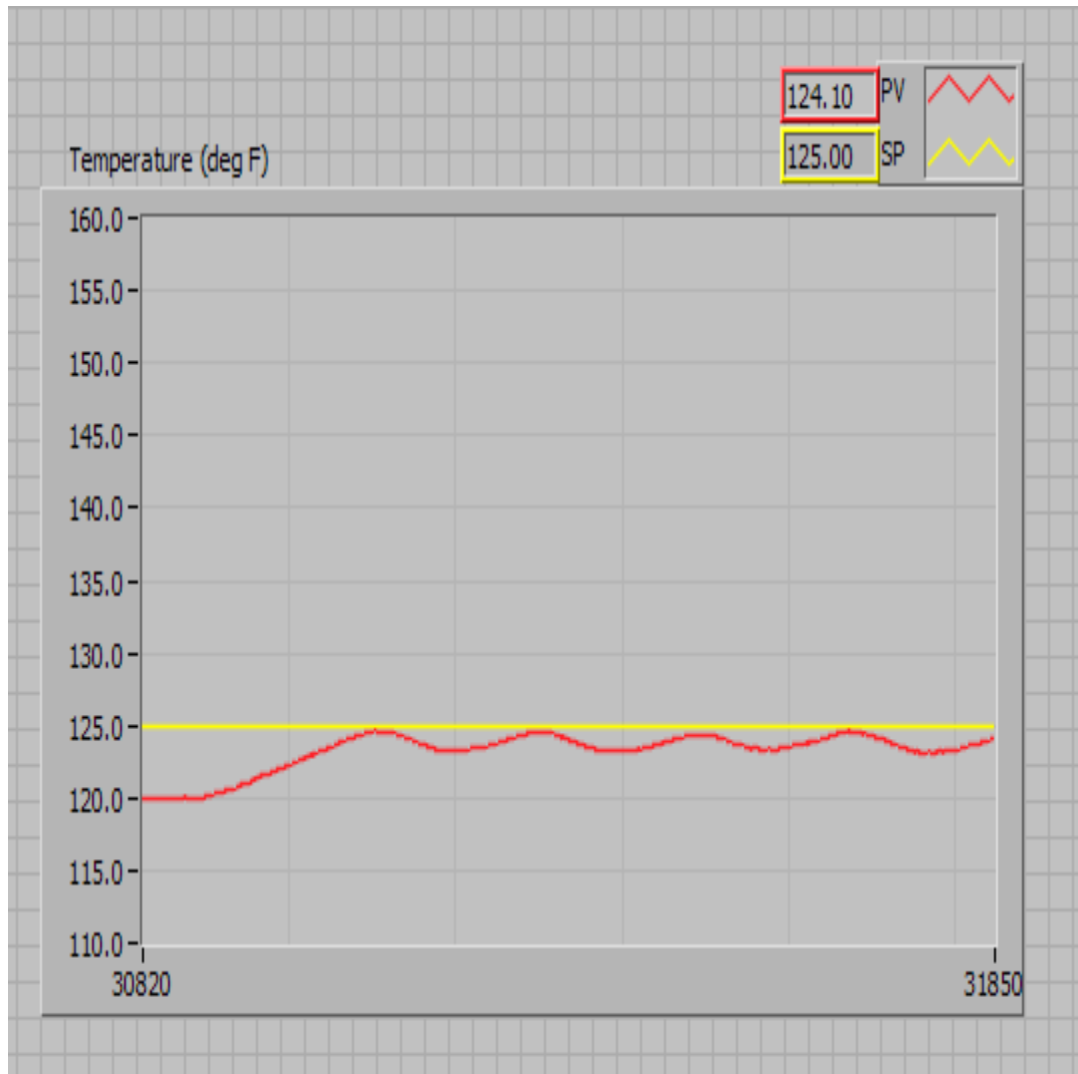
is shown as Figure 3.7.

Fig 3.7 Minimal offset with oscillation

The PID VI that was used includes an auto tuning function. With the loop tuned, the

controller was able to keep the process temperature within ±½ degree of the set point.

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3.8 CONCLUSION

The system described in this chapter gives an idea about the development and design

of a feedback control system that uses a proportional, integral, and derivative controller

which is implemented using LabVIEW. The system also provides a very good learning

tool for implementing PID control.

CHAPTER 4

CONCLUSION

CONCLUSION

In this thesis, temperature control system is designed with different controller by using *Circuit Design and Simulation* tool in LabVIEW. Different controllers used are On/Off, Proportional (P), Proportional Integral Derivative (PID) to design the controller for boiler. Comparison between the performances of different controllers is studied and as a result the response of PID controller is more accurate than other controllers. So, this controller is selected for the temperature control system.

Also all types of controllers are designed in LabVIEW. There may be other softwares used for designing control system but LabVIEW is the simplest of them all. It is because it uses the drag and drop principle, it doesn't need any code to run the software since it follows graphical coding. e.g for a while loop we simply make a box inside which the contents of the are taken.

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