Department of Electronics and Telecommunication Engineering
University of Moratuwa

Hot Plate Controller using PID

Submitted in partial fulfillment of the requirements
for the module

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Group 19

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Contents

Abstract

This project is done to implement a Hot Plate Temperature Controller using PID controlling unit. The whole circuit system is designed using analog electronic-based concepts. PID controlling unit is designed to maintain the temperature of the hot plate at a desired level. This hot plate temperature controller can control the temperature up to 200°C. The term PID refers to the means of Proportional (P), Integral (I) and Derivative (D) terms. Mainly it provides the sum of error changes processed by these three sub-units. The error signal will be calculated using the difference between user input temperature and sensed temperature. Based on the output from PID unit, the average power that is fed to the hot plate by main circuit will be controlled to obtain desired temperature. The overall project mainly consists with designing and testing the circuit, calibration of sensor readings, calibration of PID controlling unit and PCB and enclosure designing.

1 Introduction

Hot Plate Temperature Controller project is mainly based on analog-electronic based concepts. The main concept behind this project is to control the temperature of a hot plate using analog PID controlling unit. The main circuitry is powered by 230V, 50Hz domestic power supply and its output was designed to control 2kW load by controlling the average power which is supplied to it. The load can be heated up to 200°C temperature value.

To achieve the overall performance, the main circuit is divided into four consecutive parts which are power regulation unit, sensor interfacing unit, PID controlling unit and firing angle controlling unit. The desired temperature value will be entered to the sensor input unit through a sensor input terminal. The current temperature value will be sensed through a RTD sensor. The difference between these two values will be calculated and fed to the PID controlling unit. After processes the error in PID controlling unit, the processed error will be fed to the firing angle controlling unit, which will generate a PWM (Pulse Width Modulated) signal that is changing its width based on this processed error value. Finally, the generated PWM signal will be fed to opto-isolator followed by a triac. Based on the output from triac firing angle unit, the average power supplied to the hot plate will be changed and the power dissipation of the load will be controlled accordingly.

2 Basic System Architecture

The current temperature sensed from the sensor and the set point temperature will be the inputs to the system. Based on the difference between those values, system will control the average power which is fed to the hot plate.

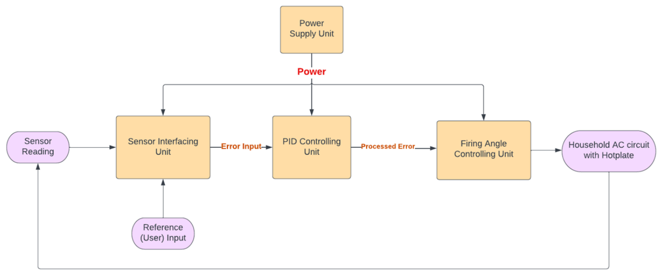


Figure 1: Block Diagram

3 Power Supply Unit

Even though the hot plate is operated under the national domestic power supply standards (230V, 50Hz AC power supply), the circuit components such as op-amps, sensors and other sensitive components are operated under the small power standards (op-amps will require 12V and -12V voltages and other sensitive components require 5V to operate according to the main circuit design). In power regulation unit, a 15V - 300mA center tapped transformer will be used to step down the domestic power supply. To produce the desired DC voltages, a rectifier bridge followed by three different voltage regulators is added to the circuit.

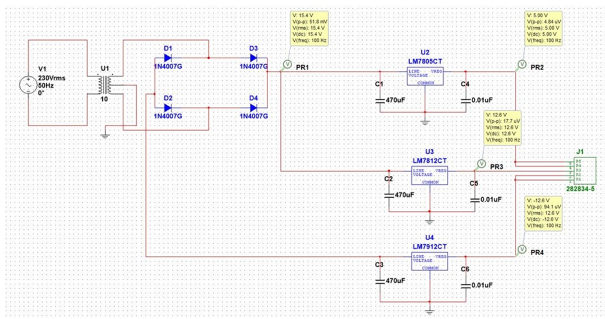


Figure 2: Power Regulation Circuit

For the operation of the sensor and other sensitive components (voltage dividers), 5V will be produced by using LM7805CT IC. LM7812CT and LM7912CT ICs will produce 12V and -12V DC voltages respectively to power up op-amp ICs in other three circuitries. Also, the AC voltages stepped down by the transformer will be used in firing angle control unit to generate ramp signal which is used in generating PWM signal to control the AC waveform supplied to the hot plate.

4 PID Controlling Unit

PID controlling unit, which consists with negative feedback mechanisms in three sub-units named Proportional (P), Integral (I) and Derivative (D) units, is used to control the current temperature value at a desired level[1].

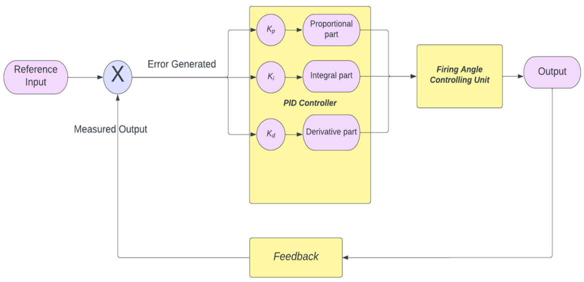


Figure 3: PID Block Diagram

The major functionality of a PID controlling unit is continuous values of a parameter (temperature) can be processed. The input for the system will be the difference (the error) between current temperature value and the set temperature value, which is processed by the sensor interfacing unit. The error value will be processed through above three sub units separately and summed up to make the final processed error value. The overall system operation done by the PID controlling unit can be defined as,

$$E_{processed} = K_p.E + K_D.\frac{\mathrm{d}E}{\mathrm{d}t} + K_I.\int E\,dt$$

$$E_{processed} = \text{Processed Error Value}$$

$$E = \text{Error Value}$$

The terms K_p ,K_D, K_I refer to the weighted parameters that decides the contribution from each sub unit to the final output (processed error value). The circuit is designed in such a way that those parameters can be controlled as the user preference to gain optimum control operation from the overall circuit. Each sub-unit is designed by using UA741 general purpose op-amp ICs and each sub-unit has its own component placements to perform multiplication, integration, and differentiation operations. Then the outputs from these three sub-units will be added using a summing amplifier circuit. After summing up these three outputs, the processed error value will be fed to the firing angle controlling unit.

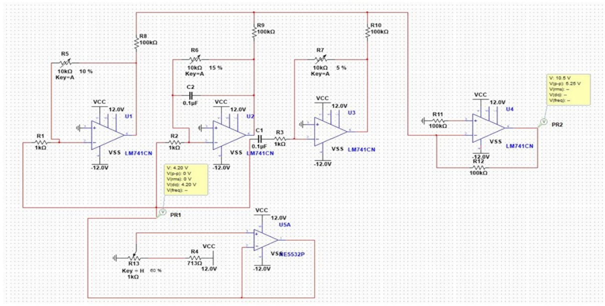


Figure 4: PID Controlling Circuit

Before feeding the error value to the PID control unit, it will be gone through a unity gain amplifier (buffer circuit) made by using NE555325 op-amp IC in order to avoid interferences between two adjacent circuitries. In the proportional (P) unit, output will be proportional to the input error value which provides a major contribution when deciding the heating rate of the hot plate to the set temperature value. It works as a multiplication operation by a constant which can be altered using a potentiometer. Integrator(I) unit will provide a smooth temperature change when the current temperature reaches to the set point value. It keeps track on the past values so that we can manage the temperature changes near the set point value. The differentiator(D) unit will avoid the overshooting effects of the temperature variation. But the major drawback of this unit is it amplifies signal variations due to noise and circuit interferences and have an effect on the final output in a destructive way. After the above three operations the output from those units will be gone through an equally weighted summing amplifier.

5 Sensor Interfacing Unit

5.1 Sensor

Figure 5: pt100 RTD sensor

To regulate the temperature of a coil, it is necessary to have a method for determining its present temperature. This is accomplished through the use of a temperature sensor, and in this case, four sensor types have been evaluated: Thermocouples, RTDs (Resistance Temperature Detectors), Thermistors, and Semiconductor-based ICs. While thermocouples are the most commonly utilized type of temperature sensor, they require a fixed temperature at one end and produce a minimal output voltage, necessitating precise amplification.
[5]
After careful consideration, we concluded that the thermocouple is not the optimal selection for our hotplate project. Additionally, we assessed the use of a thermistor, but it did not satisfy our precision requirements and also it is not linear along with the temperature. As a result, we opted for the PT100 sensor, which is an RTD type temperature sensor. The primary factor in our decision was its capacity to measure a broad range of temperatures, and for shorter temperature ranges (such as 0-200C), the sensor output is almost linear, allowing us to eliminate additional circuitry needed for linearization.

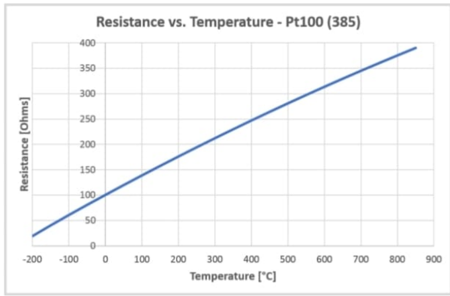


Figure 6: Sensor behaviour

5.2 Error signal generation

PT100 sensors are the most prevalent type of platinum resistance thermometer. The designation "PT" signifies that the sensor is composed of platinum and "100" indicates that its resistance at 0C is 100 ohms. The sensor utilizes resistance to measure temperature and comprises an element that operates using this principle. If a voltage source is utilized to supply the sensor, there may be significant currents flowing through the sensor, leading to self-heating of the sensor, which can impact the precision of the measurement. As a result, we adhered to the conventional practice of operating the PT100 sensor at the lowest possible current to counteract the effects of self-heating, and employed a constant current source to supply the sensor.[6]

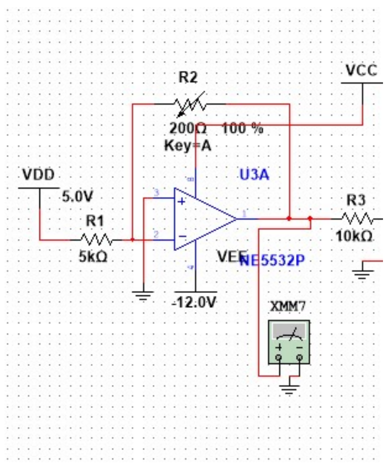


Figure 7: Constant Current Source

Since the source is a constant current, the voltage difference between two terminals is proportional to the resistance. However, the resistance of the sensor is proportional to the temperature, resulting in a voltage output from the sensor that is proportional to the temperature. Nonetheless, at this stage, the voltage output was not within a usable range. Thus, we had to eliminate the offset and amplify the signal so that it could be effortlessly handled by an op-amp. To accomplish this, the sensor voltage was directed to an amplifier with a gain of 6 and then subtracted from a fixed value to eliminate the offset. This subtraction process also resulted in amplification. The resultant mapped values were then sent to the final subtractor, which generates the error signal. The error signal was created by subtracting the sensor voltage from the set voltage, and it was delivered to the PID controller via a buffer.

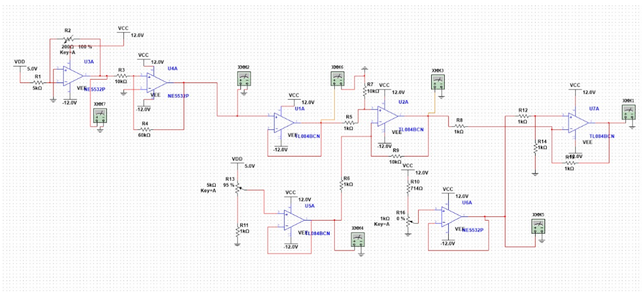


Figure 8: Sensor interfacing circuit

6 Firing Angle Controlling Unit

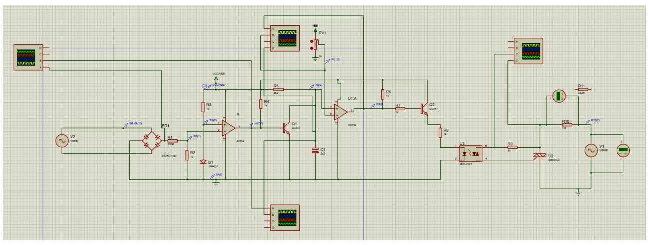
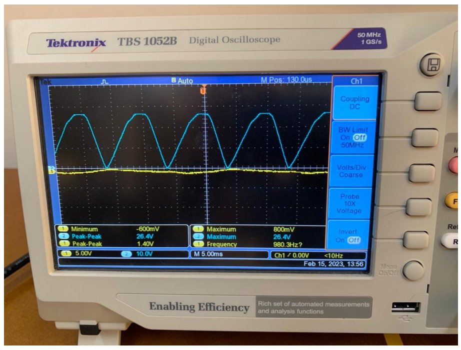


Figure 9: firing angle controlling circuit

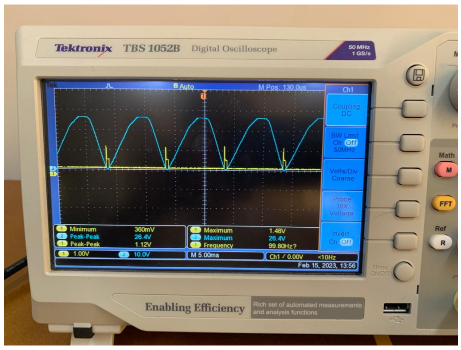
The firing angle controlling unit is mainly used to control the average ac power supplied to the hotplate according to the process error value from the PID unit. This system consists of four operational stages. They are,

- Zero crossing detection
- Ramp Generation
- PWM signal generation
- TRIAC controlling unit

Initially the AC 15V voltage obtained from the transformer will be fully rectified through a full wave rectifier which will be supplied to the inverting terminal of LM339 voltage comparator.



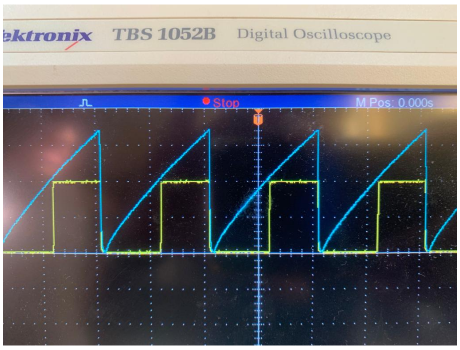
The non-inverting terminal will be supplied with a constant 0.7V voltage drop by a 1N4007 diode. Then the rectified waveform will be compared with the 0.7V constant voltage and generate pulse indications at zero crossing points.



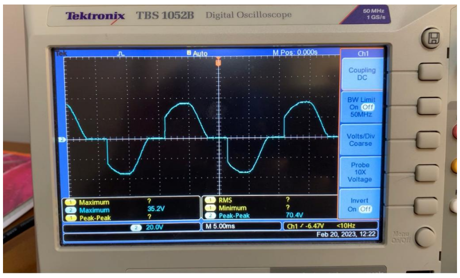
This output will be fed to the base of a BC547 transistor which is followed by a capacitor.[3]

When the output of the zero crossing detection circuit is less than 0.7V the transistor goes to the cut off region and the capacitor gets charged from the 12V supply. Once the output becomes higher than the 0.7V the transistor goes to saturation region and the capacitor gets discharged through the transistor. This ramp signal will be used as a threshold variation to generate the PWM signal.

After the ramp generation, the ramp signal will be fed to the non-inverting terminal of a LM339 comparator opamp. The output from the PID unit will be subtracted from 12V and fed to the inverting terminal of the same opamp. When the ramp voltage becomes higher than the above subtracted value, the output from the comparator opamp becomes saturated (12V) otherwise it will be zero. When the PID output voltage increases the width of the generated PWM pulse will be increased and vice versa.



The generated PWM signal will be supplied to an MOC3021 optocoupler IC through a transistor. Optocoupler is a device which is used to create an electrical isolation between the low voltage and high voltage driven circuitry. BT138 triac is connected to the output of the optocoupler which acts as a switch to control the domestic ac power fed to the hotplate. The controlling operation will be done by an output signal supplied to the gate of the triac. When the error signal becomes low the average ac power will be reduced by the triac. A heat sink will be mounted on the triac to protect it from heating.[2] [4]



7 Results

For the demonstration purposes we used a 100k resistor load instead of the hotplate which is fed by a 12V ac power supply instead of 230V ac voltage. We calculated the voltage range which is needed to operate the system in between 0°C and 200°C temperature range and designed input voltage variator accordingly. To check the functionality we gave a set point voltage to heat upto 150 °C and then we connected our PT100 RTD sensor to the sensor interfacing circuit (which is initially at the room temperature) and then we submerged it in a boiling water sample. Then we check the waveform which is supplied to the load resistor by triac using a multi-channel oscilloscope.

When the temperature sensor gets heated up by the boiling water we observed that the oscilloscope output waveform is cut gradually by the triac and the rms value of the ac signal becomes lower and lower. When we remove the temperature sensor from the boiling water the rms value of the ac waveform start to increase gradually.

The schematic designs and pcb layouts were designed using Altium designer and the enclosure for the final product were designed using solidworks. For the simulation purposes we used both Multisim and Proteus simulation software.

8 Enclosure Design

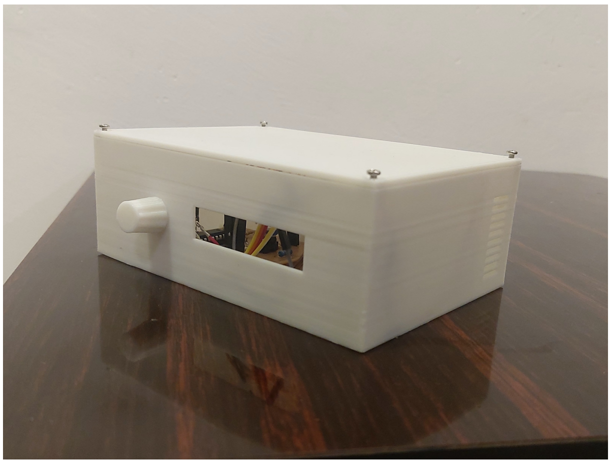


Figure 10: Enclosure

When designing the enclosure, we had to consider multiple parameters to design a proper final product. We chose the material of the enclosure such that it can withstand sudden heating occurrences since we used a center tapped transformer to regulate the power.

Mainly our enclosure is a rectangular shaped box which has two internal compartments to separate center tapped transformer and the pcbs. There are few holes to manage the cables and power lines in the enclosure and some custom-made designs for ventilation purposes. To operate a set point value externally we included a knob made with the same material which can be fitted with the rotating dial of the potentiometer which is connected with the sensor interfacing unit.Final design was manufactured through 3D printing.

9 Acknowledgement and future works

PID hot plate temperature controller is our first analog electronic-based project. In order to succeed in this challenge, we were given guidance and help from many. Firstly we would like to thank Dr. Sampath, Dr. Jayathu, and Dr .Chameera for evaluating the project and providing progressive feedback and advice for future improvements. Then we would like to thank the staff of the analog laboratory and the electronic workshop in the department of Electronic and telecommunications for providing us with a comfortable atmosphere and the necessary equipment and tools to work on our project. Also, we express our sincere gratitude to everyone who helped us in all aspects.

As for future improvements to the product, we hope to use it with a practical household heating element, and we hope to include a digital display to display the operating states of the system and a proper mechanism to give the set temperature value to the system.

10 Appendix

10.1 Schematics

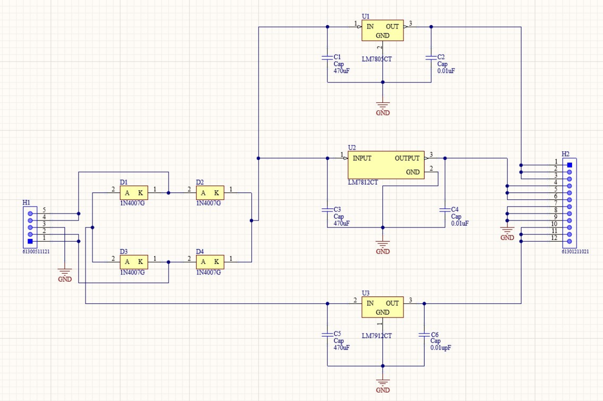


Figure 11: Power regulation Schematic

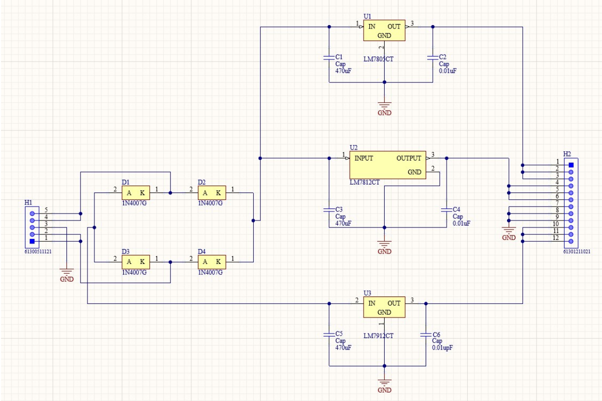


Figure 12: Sensor Interfacing Schematic

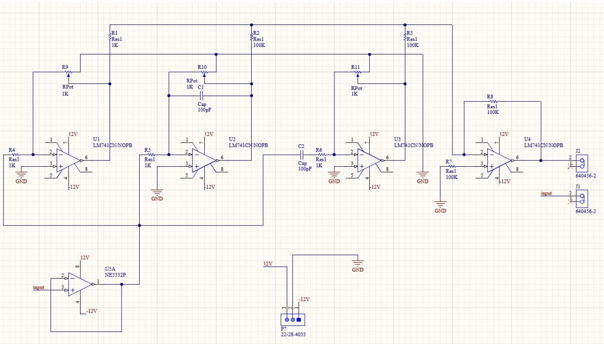


Figure 13: PID Unit Schematic

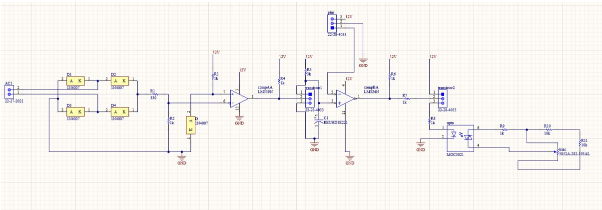
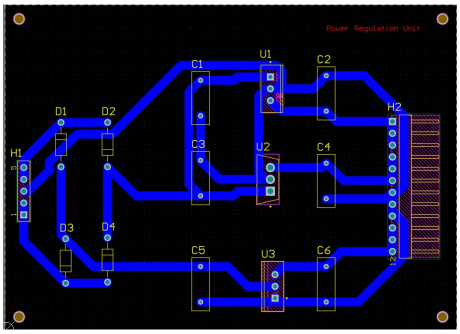
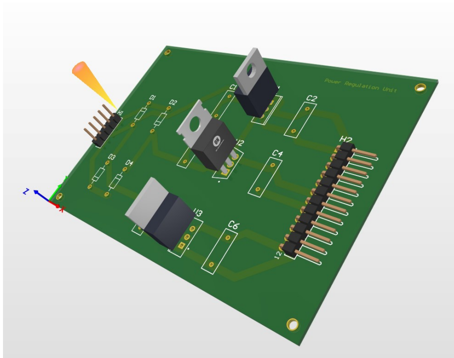


Figure 14: Firing Angle Controlling Schematic

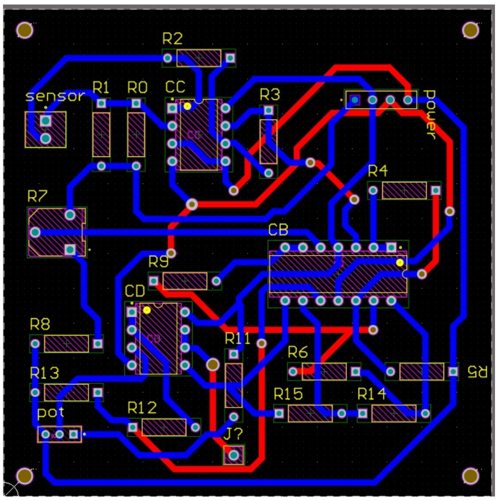
10.2 PCB layouts

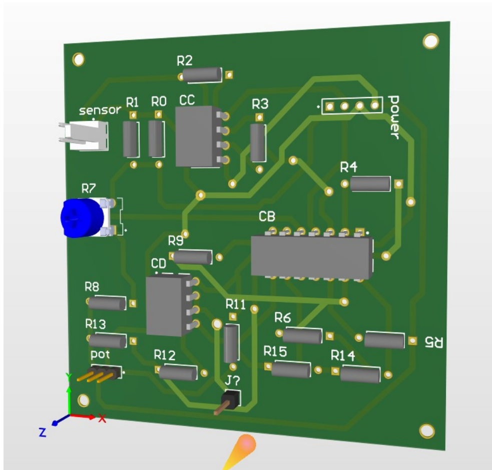
- Power Regulation Circuit



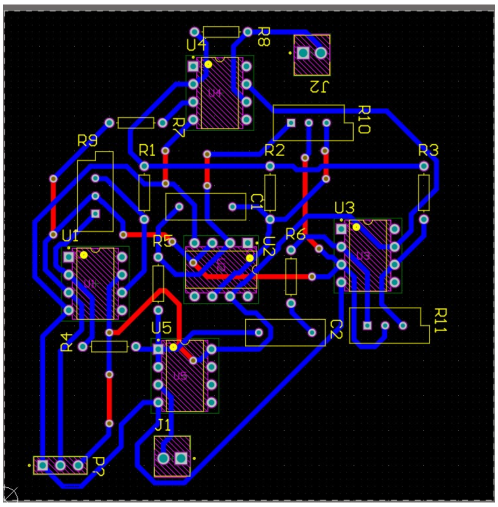


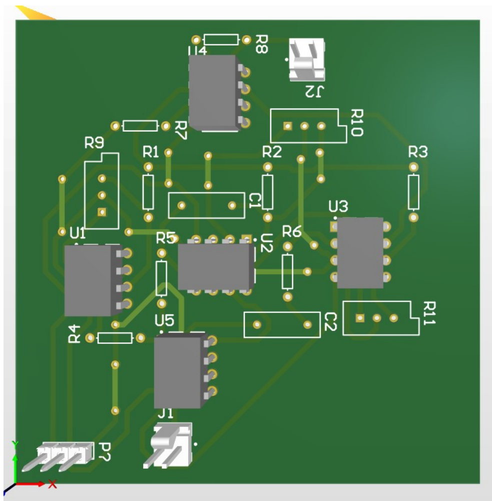
- Sensor Interfacing Unit



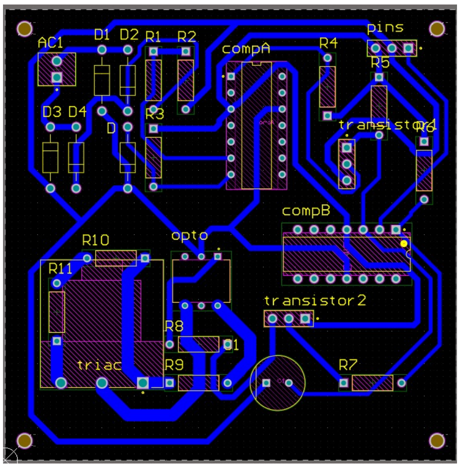


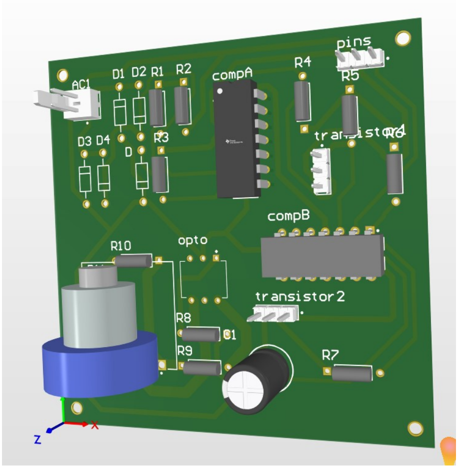
- PID controlling unit



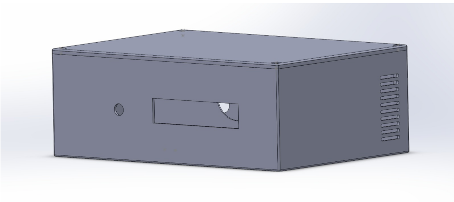


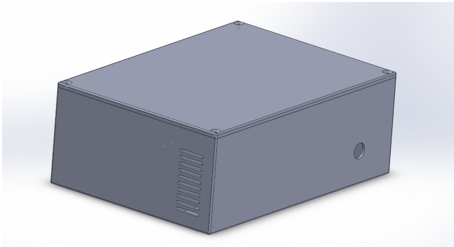
- Firing controlling unit

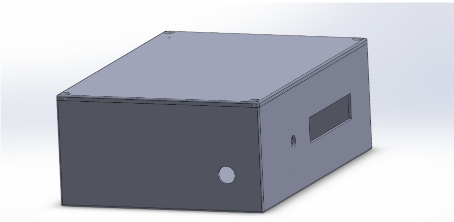


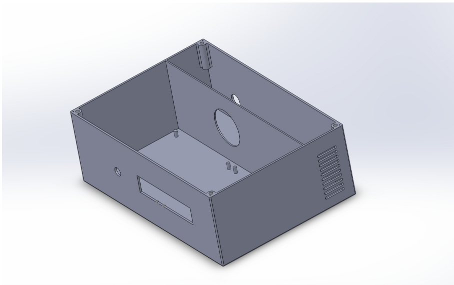


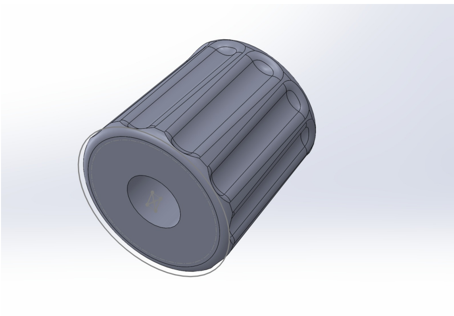
10.3 Enclosure











11 Contribution

Index Number	Name	Contribution
200114G	W. H. P. De Silva	Sensor Interfacing Unit, Schematic Designing, firing angle and Sensor Interfacing Unit PCB designing, Assembling the final product, Documentation
200312L	S. Kowrisaan	Power regulation unit schematic designing, Documentation
200476P	A. A. H. Pramuditha	PID controlling unit designing, PID controlling unit and power regulation unit PCB designing, PCB soldering, Assembling the final product,Documentation
200722T	K. D. Wijerathne	Firing angle controlling unit designing, Enclosure designing, PCB soldering, Assembling the final product, Documentation

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Datasheet for Hot Plate Temperature Controller

Specifications and Operating Conditions

- Supply voltage: 230V, 50Hz AC voltage
- Power Consumption: Up to 2kW loads can be handled.
- Working Temperature Range: 0°C to 200°C
- Controlling Mechanisms: PID Controlling
- Applicable Power Sockets: 2 pin standard plug sockets

  This equipment comes with a PT100 RTD (linear and highly accurate) temperature sensor. When equipment is used, the temperature sensor should be placed near to the hot plate. There are two separate power lines to connect hot plate to the controlling unit. Perfectly tuned PID controlling unit is used to control the temperature at a desired level. User input temperature value can be given by rotating the dial based on its scale. For the electrical isolation and controlling the average power supplied to the hot plate, MOC3021 optocoupler and BT138 TRIAC is used in the circuit.