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Hot-plate Controller using PID

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Contents

Abstract

The objective of this project is to implement a hot plate controller using a PID controller unit. Here, we have used totally analog electronics-based concepts and a PID controller to keep temperature at a desired level. The implemented hot plate can be heated up to 200 $°C$. The PID controller takes the difference between the input temperature and the sensed temperature as the error signal, and then gives the sum of the proportional, derivative, and integral signals to the error signal as the output. Then, the firing angle controller unit controls the power by using PID output and keeps the temperature of the hotplate at the desired level.

1 Introduction

This is an analog electronics-based project. The primary concept which we have followed in this project is controlling the temperature of the hotplate by using a PID control unit. For the sake of ease and proper organization, the project has been divided into four main subtasks. The PID controller unit, sensor interfacing unit, firing angle, and power supply unit The difference between user input and sensor output is fed to the PID as an error signal. The PID controller generates proportional, derivative, and integral signals from the error signal. The firing angle unit generates a PWM signal according to the PID output to control the firing angle. Finally, from the power supply unit, a plate will be heated to the desired level. A specially designed hot plate can be heated up to 200 $°C$. As the hot plate's input power supply, a 230-volt domestic power supply should be provided.

2 Functionality

2.1 Sensor interfacing unit

Measuring the current temperature of the coil is essential in order to control the temperature of the coil. Therefore, a temperature sensor is used to measure the current temperature. The sensor interface unit also takes the set temperature from the user as an input. It subtracts the voltage, which is calibrated according to the set temperature and the sensor output. Then, it generates the error signal. This error signal feeds the PID controller unit.

2.2 PID controller unit

PID is a feedback-based control strategy that adjusts the system's output based on the difference between the desired setpoint and the actual variable. Instrument Society of America[1].The proportional term provides an output signal that is proportional to the error signal that is given by the sensor interface unit. The integral term sums up the error over time and produces an output to reduce any steady-state error. This aids in reaching the hot plate at the precise temperature set by the user. The derivative term measures the rate of change of the error and produces a control output to decrease overshoot. With the optimal combination of these three terms, we can reduce the time taken to reach the set temperature and maintain it exactly at the required level.
The proportionality constant is represented by the letter "Kp" and determines the proportion of the error signal that is applied to the control output. Increasing Kp will increase the responsiveness of the system. However, it can also lead to overshoot and instability.
The integral constant, represented by the letter "Ki," determines the amount of past error that is summed up and used to adjust the control output. This term involves reducing steady-state error. But it can also lead to instability if the value of "Ki" is too high.
The derivative constant, represented by the letter "Kd," determines the rate at which the error is changing over time and uses this information to adjust the control output. This term helps to reduce overshoot. The optimal values of these constants are achieved by a process called tuning.
The sum of proportional, integral, and derivative signals will be fed to the firing angle unit

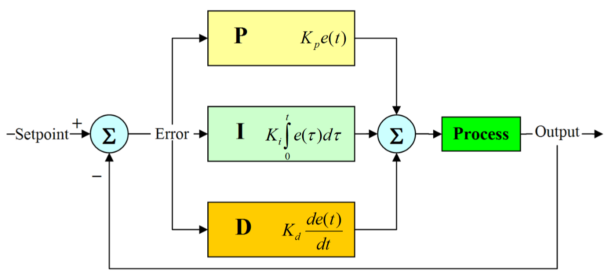


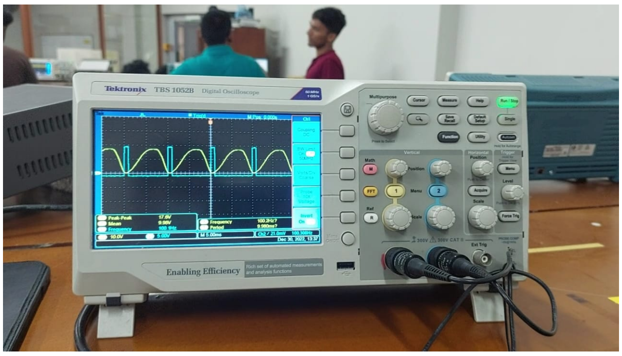
Figure 1: *functionality diagram of a PID controller*

2.3 Firing Angle Unit

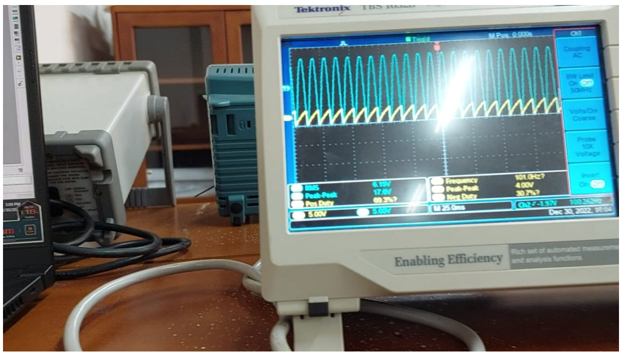
Introduction

The firing angle unit controls the amount of power supplied to the coil based on PID output. Zero crossing detection, ramp generation, PWM signal generation, and the TRIAC control circuit are the main subunits of the firing angle unit.

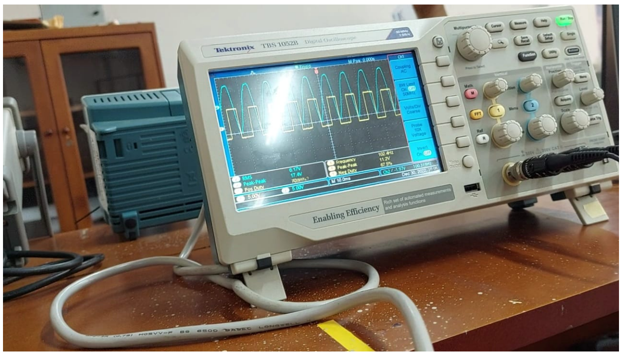
1. Detection of Zero Crossings
   In order to detect zero-crossings, each half-cycle of the AC waveform is given an equal pulse. This enables control of every half-cycle of the AC waveform in the same way. When the voltage of the rectified AC waveform is lower than 0.7V, the output of the zero-crossing detector is 12V; it is zero otherwise.



2. Ramp Generation
   The ramp is generated by charging and discharging a capacitor. When the output of the zero-crossing detector is less than the threshold voltage of the transistor, the capacitor will be charged. When the output of the zero-crossing detector is high, the transistor will be saturated and the capacitor will be discharged. The ramp works as a threshold for PWM signal generation.



3. PWM signal generation
   The main task of this subunit is to create a PWM signal, which is used to control the AC power. When the ramp voltage is lower than the PID output voltage, the output of the subunit is 0V and otherwise, it is 12V. The width of the pulse gradually decreases when the output voltage of the PID increases. Conversely, pulse width increases when the output of the PID drops.

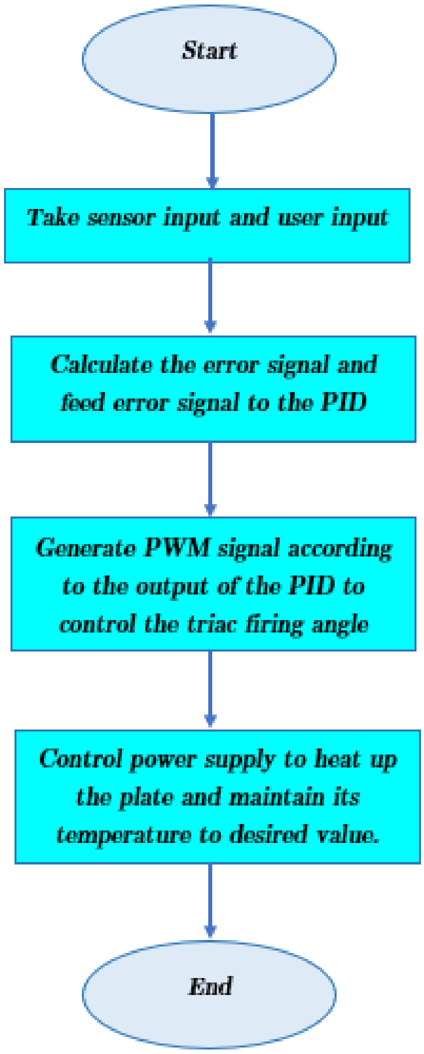


4. TRIAC Control Circuit
   The PWM signal is passed to the optocoupler through a transistor. The optocoupler creates electrical isolation between the low- and high-voltage circuits. The TRIAC, which is connected to the optocoupler, acts as a switch to the AC source. The optocoupler's output signal, which is connected to the TRIAC, controls the AC waveform.

2.4 Power Supply Unit

The hotplate draws power from the domestic power supply ($230\ V, 50\ Hz$). But the sensors, opamps, and most of the other components use low voltage to function. For instance, op-amps function at -12V and 12V. The function of the power supply unit is to supply the required voltages to relevant components.

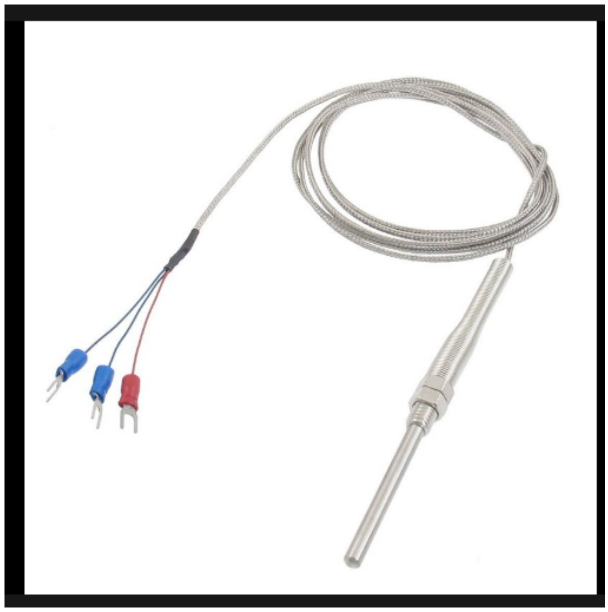
2.5 Functional block diagram



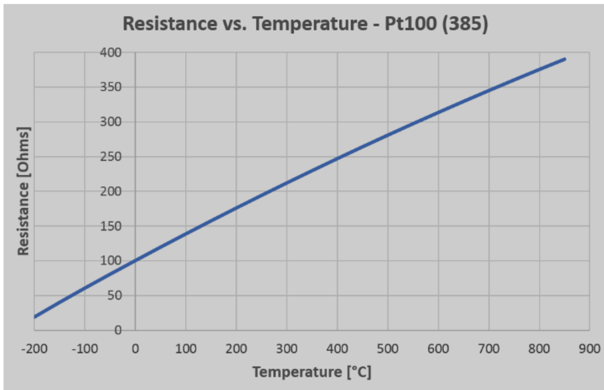
3 System model with design parameters

3.1 Sensor interfacing unit

There are several options available in sensing the temperature of the hot plate. When deciding a sensor to be used, the requirements that should be fulfilled by the sensor are, a linear relationship between voltage and temperature, compactness, high operating temperature, availability in the market, quick response time and simplicity in signal processing. One of the available options is a thermocouple but it is not suitable for our project due to the need for a reference temperature and the complexity of the signal processing required. We decided to use a PT100 which is an RTD (Resistance Temperature Detector). The sensor has an operating temperature of up to 800C and has a resistance that varies with temperature. The sensor interface produces an output voltage corresponding to the resistance of the sensor by the use of a constant current built from a BJT and amplifies and calibrates the result. The resulting voltage is then passed through a subtractor which calculates the error signal between this voltage and the voltage corresponding to the temperature set by the user. The resulting error signal is passed to the PID.
UA741 Op-amps were used throughout the interface as they perform well as voltage followers.



(a) *PT100 sensor*



(b) *Relationship between resistance vs temperature*

Figure 2: For *100 kHz*

Required temperature (input temperature by the user) and the current temperature are displayed by the OLED display.

3.2 PID controller unit

PID controller unit consist with an inverting amplifier, integrator circuit, subtractor circuit and a scaling adder. UA741CP op-amps are used to build those circuits due to its high gain, low input bias current, low input offset voltage and low cost. In each inverting amplifier, subtractor and integrator circuits, a pre-set is used as a feedback resistor and by changing the resistor value of the three pre-sets, Kp, Ki and Kd values can be changed.

3.3 Firing angle unit

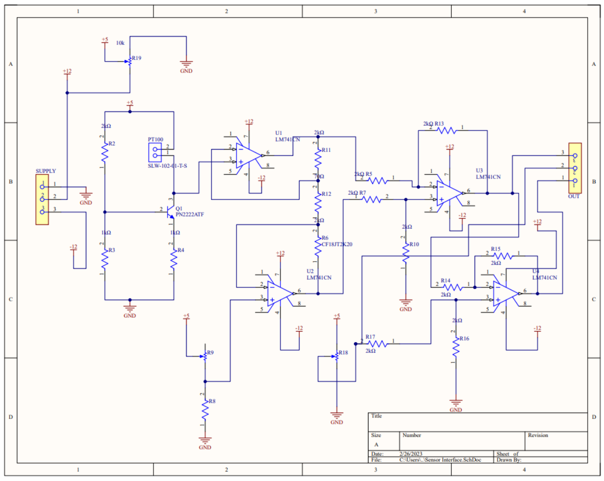
We're using LM324n op-amps for the triac firing angle circuit because they have enough slew rate to charge and discharge the 50V, 10uF capacitor with the generated impulse function (which is generated by comparing the full wave rectified 30V signal with 0.7V of the diode). For all the op-amps, we have used 12V and 0V as the power supply because we need to get a PWM signal as a positive output. For calibration purposes, two pre-sets have been added to user input voltage and to control the PWM signal amplitude. Because of that, a triac circuit can be independent from other input and output circuits. To handle both the 12V DC supply and the high-power supply for the load, we are using the optocoupler MOC3021, which can function up to 400V high power voltage. Moreover, triac BT137 has been used to slice the output AC supply voltage with respect to the input PWM signal to the optocoupler. On the high-power side, the triac can operate at up to 600 volts.

3.4 Power supply unit

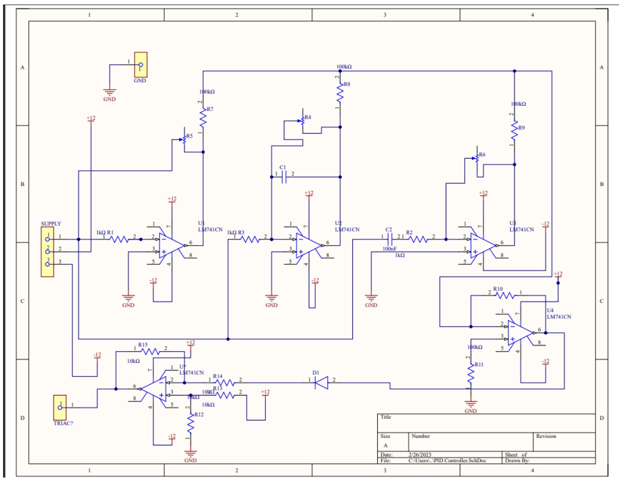
The power supply unit consists of a center-tapped transformer, a rectifier bridge, capacitors, and voltage regulators. A center-tapped transformer converts domestic voltage into 12 volts. To obtain full wave rectification of the AC signal, a rectifier bridge is used. Unnecessary noises are avoided by the capacitors.

4 Schematic

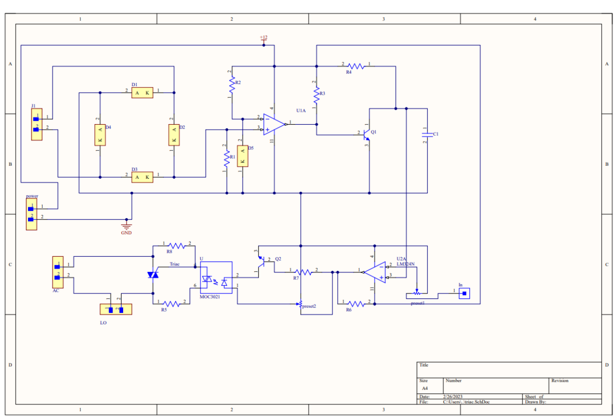
4.1 Sensor interfacing unit



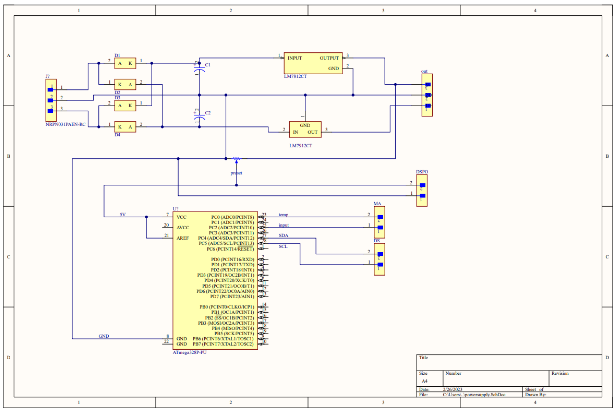
4.2 PID controller unit



4.3 Firing angle unit



4.4 Power supply unit



5 Simulation results

5.1 PID controller unit

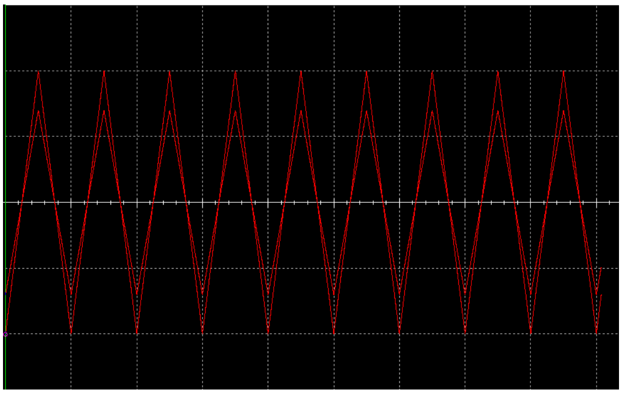


Figure 3: proportional sub unit

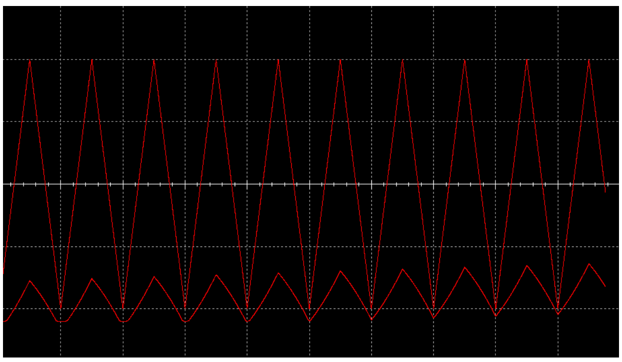


Figure 4: integral sub unit

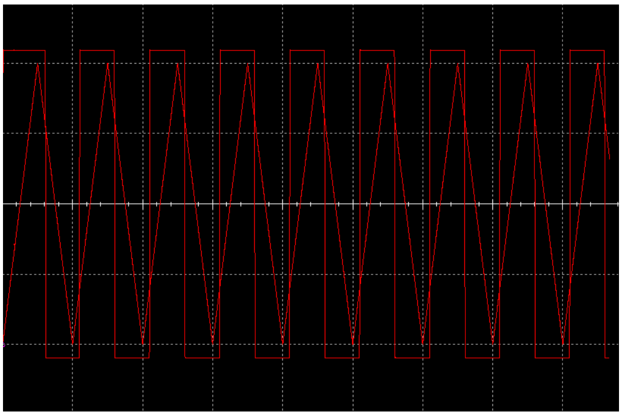


Figure 5: derivative sub unit

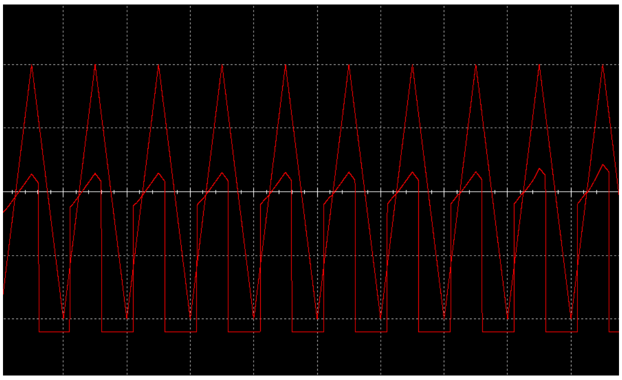
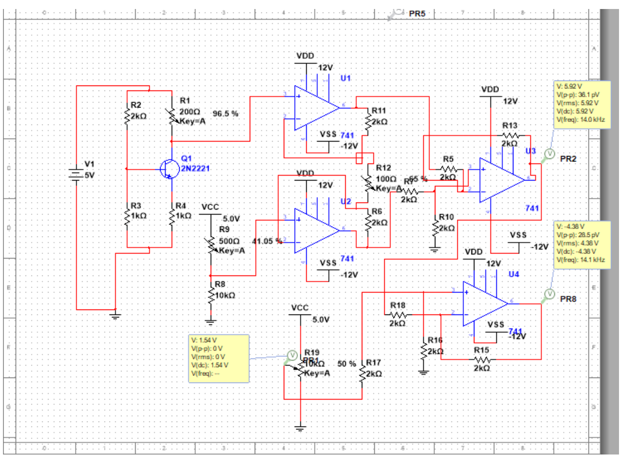


Figure 6: summation of the above 3 output

5.2 Sensor interfacing unit



5.3 Firing angle unit

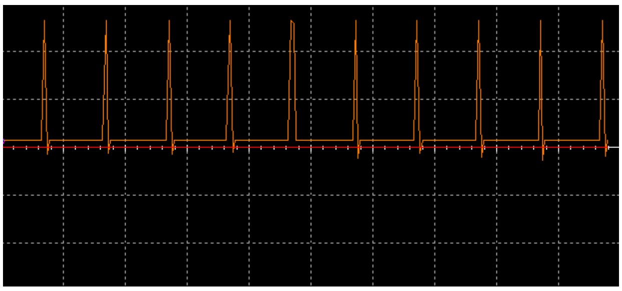


Figure 7: impulse function

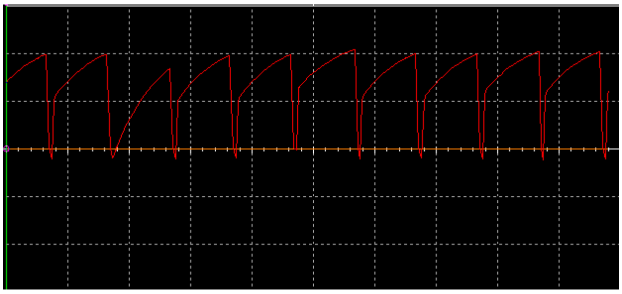
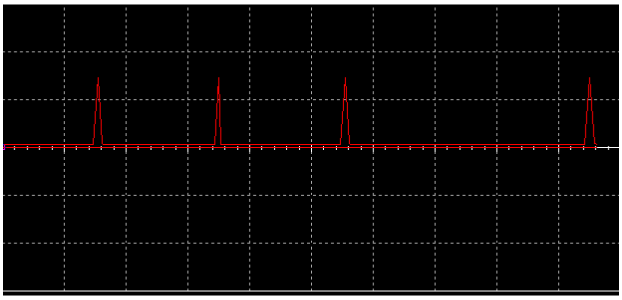
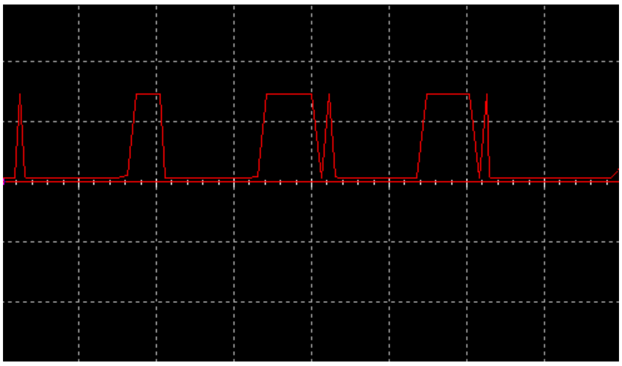
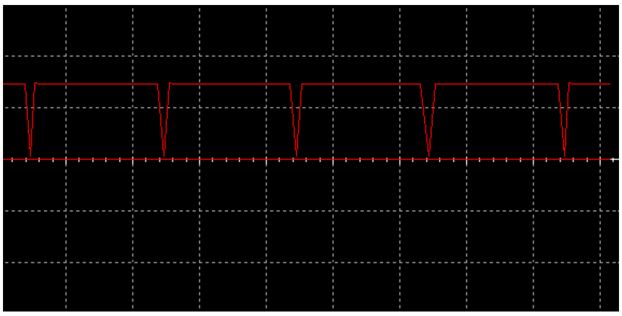


Figure 8: ramp generation

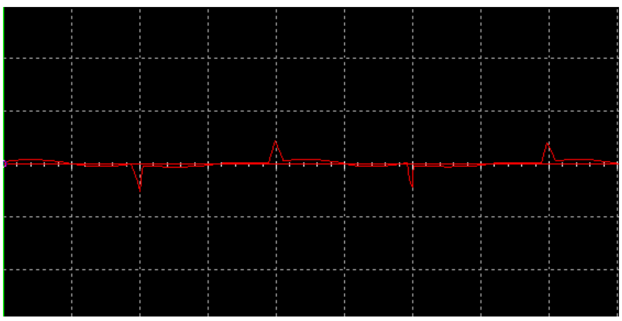
5.4 PWM signal generation

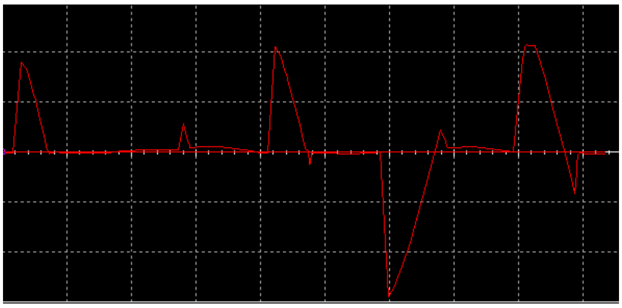


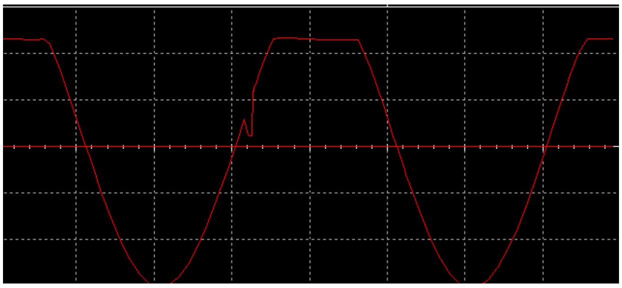




5.5 Output

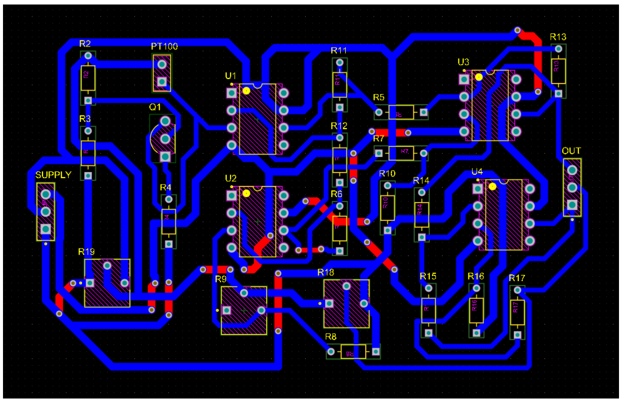




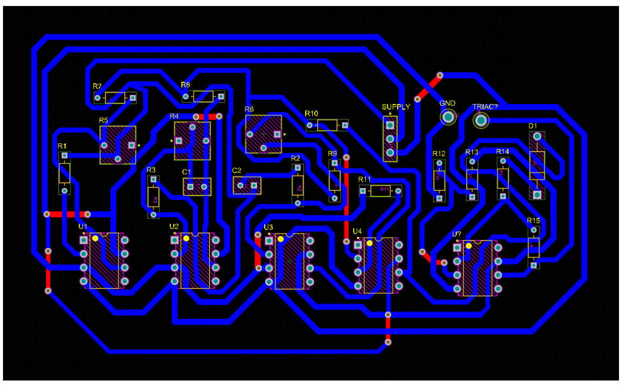


6 PCB design

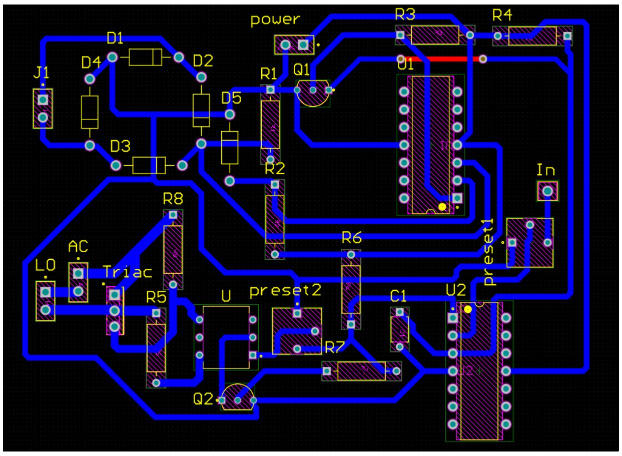
6.1 Sensor interfacing unit



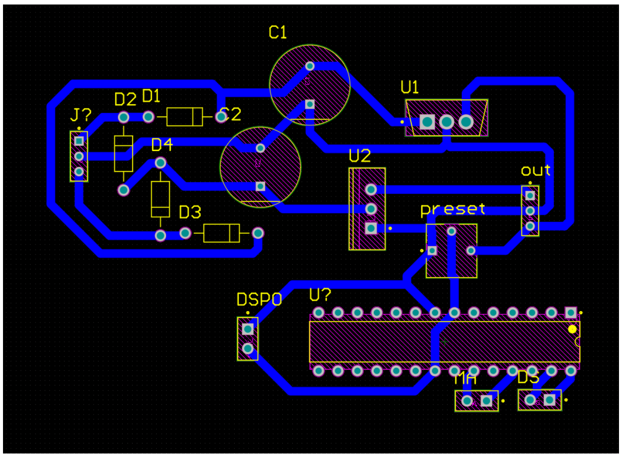
6.2 PID controller unit



6.3 Firing angle unit

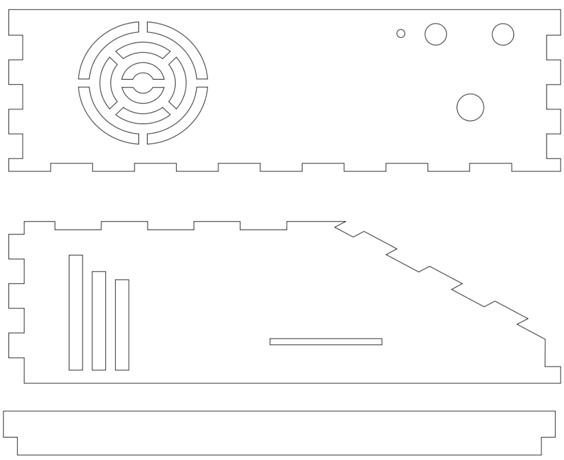


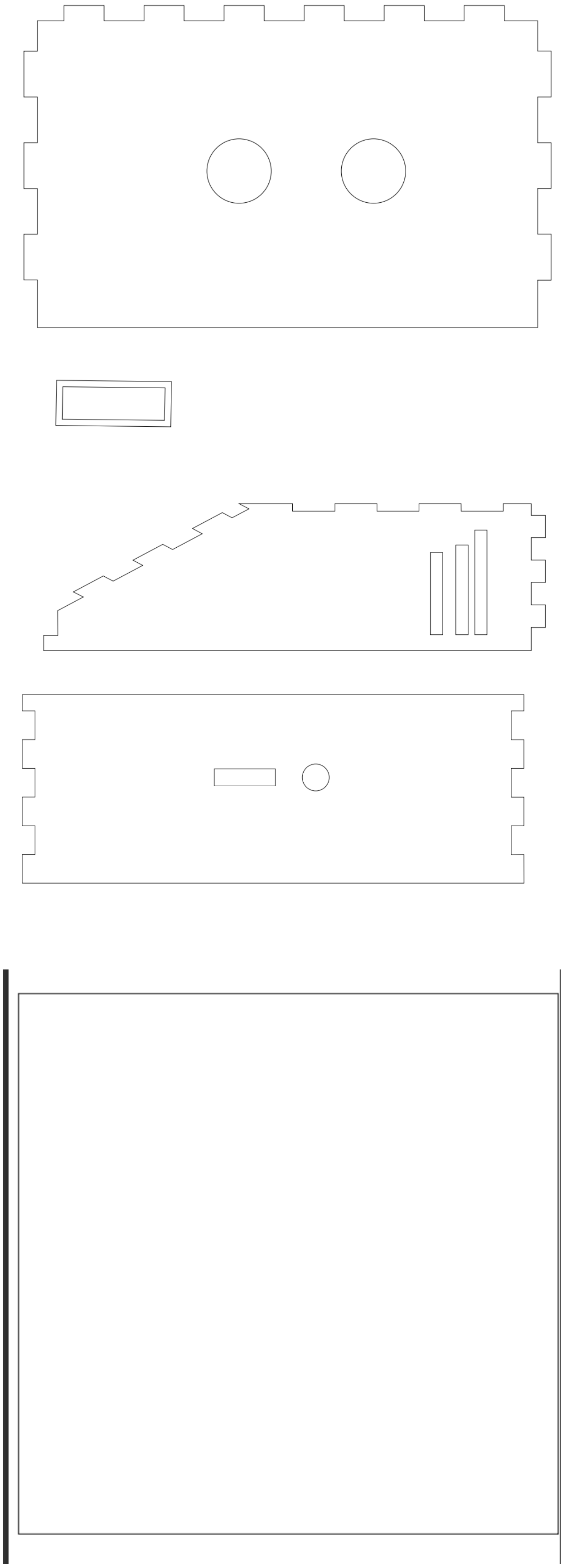
6.4 Power supply unit



7 Enclosure Design

For enclosure design, wood is used since it is inexpensive and can withstand heat up to a considerable level than plastics.





8 Individual contribution of each group member

Group Members	
Name.	Contribution
Disanayaka R.M.R.H. (200134R)	Power supply unit design
Liyanage P.H.S. (200352H)	PID control unit design
Ranaraja S.V. (200506K)	Firing angle unit design
Yalegama M.M.O.A.B. (200740V)	Sensor interfacing unit design

9 Conclusion and future works

In conclusion, the hot plate has been implemented by interconnecting four sub units which are sensor interfacing unit, PID controller unit, Firing angle unit and the power supply unit. The hotplate can be heated up to 200 $°C$. Also, the user can easily get the required information that he needs from the OLED display.
We are hoping to improve our hotplate design further in future. For that, we expect to tune the PID controller circuit precisely to get the optimal Kp, Ki and Kd values.
From those optimal values, we can heat up the coil up to desired temperature more quickly and maintain the hotplate temperature exactly at the desired temperature./

References

[1] Karl J Astrom. “PID controllers: theory, design, and tuning”. In: *The International Society of Measurement and Control* (1995).