B.TECH. PROJECT REPORT

On

An approach for monitoring and control of temperature for Manufacturing process

By

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DISCIPLINE OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY INDORE

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An approach for monitoring and control of temperature for Manufacturing process

A PROJECT REPORT

Submitted in partial fulfilment of the
Requirements for the award of the degrees

Of
BACHELOR OF TECHNOLOGY
in
MECHANICAL ENGINEERING

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INDIAN INSTITUTE OF TECHNOLOGY INDORE
NOVEMBER 2019

CANDIDATE’S DECLARATION

We hereby declare that the project entitled **“An approach for monitoring and control of temperature for Manufacturing process”** submitted in partial fulfilment for the award of the degree of Bachelor of Technology in ‘MECHANICAL ENGINEERING’ completed under the supervision of **Dr. Yuvraj K Madhukar (Assistant Professor),** IIT Indore is an authentic work.

Further, we declare that we have not submitted this work for the award of any other degree elsewhere.

SAURABH KUMAR

SAURAV KUMAR

CERTIFICATE by BTP Guide

It is certified that the above statement made by the students is correct to the best of my/our knowledge.

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Assistant Professor

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Preface

This report on “An approach for monitoring and control of temperature for Manufacturing process" is prepared under the guidance of Dr. Yuvraj Kumar Madhukar.

Through this report we have tried to give detailed information on design and development of a system which can control temperature of a heating source. In this case it was the welding torch of GTAW welding machine, which is an industry grade equipment.

We have tried to the best of our abilities and knowledge to explain the content in a lucid manner.

Saurabh Kumar

Saurav Kumar

B.Tech. IV Year

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Acknowledgements

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We are very grateful to the entire working staff of the Central Workshop for assisting us and it would not have been possible without their help.

Abstract

Many manufacturing processes often require heating or melting of the metals; it includes annealing, tempering, welding, cutting, etc. However, it's always been difficult to maintain the desired temperature throughout the process in order to ensure uniform properties. Nonuniformity in processing temperature often results in the variation in mechanical as well as in metallurgical properties of the same part/ object/ material.

The objective was to control the heating temperature of material. It was achieved by dividing the project into two phases. In the first phase, the heating temperature of the sample was controlled by heating it with a halogen bulb. In the second phase, an industry grade equipment was used. Sample was heated by using a GTAW welding process. Feedback control was used in both the parts.

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7. MOTIVATION

This project can be used in betterment of many heating techniques. Pulse-width modulation is a good way of controlling the average power of a device very efficiently. Nowadays it is even used in modern day TVs for controlling the brightness. Buck converter is used for DC power conversion, it can directly integrate in the power line. There is approximately 0% resistive losses in a Buck converter as compared to a mechanical potentiometer.

By controlling the melt-pool temperature, the quality of the bead will significantly improve. This will result in uniform properties throughout the bead. It can be used in Additive manufacturing and different welding techniques hugely improving the quality of bead.

8. Phase – I

8.1 Introduction

A sample was heated at a constant temperature and held for a desired period. To make this happen the power of the heating source was controlled by using a Buck Converter and a proportional-integral-derivative (PID) controller. Pulse-width modulation (PWM) was used to modulate the electrical signal to control the DC power. It was achieved by sending the analog signals from Arduino to Buck converter. The temperature within the range of 80-500 ° C was controlled successfully with the developed system with an error of 5 ° C.

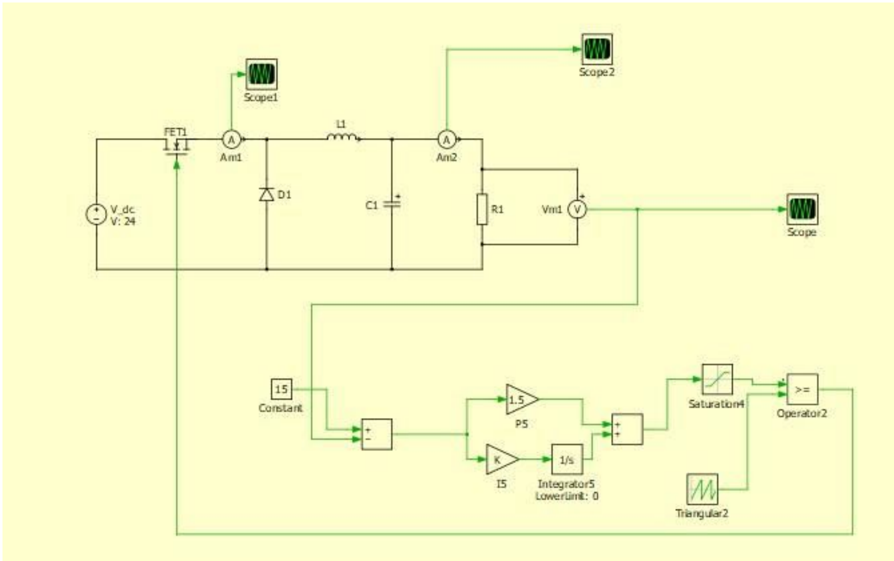
The output of a power source was controlled by creating an additional electrical circuit known as Buck Converter [3]. The basic mathematical calculation for the power stage of buck converter can be found in an article published by Texas instruments [4]. A simulative study was done for the same on the PLECS software platform. Here switch-mode technique PWM [5] was used to control the output voltage of power supply. The advantage of this Buck converter could be realised in terms of its higher efficiency compared to linear voltage regulators. In addition, it can be used for high power requirements. Further, the linear regulator are not rated for the current above two amperes. MOSFET is an electronic switch that can be operated using a low voltage signal generated by Arduino. Inductor and capacitor were used to store electrical energy and give it back when MOSFET was in the off state. It also smoothens voltage resulting in a constant DC voltage output. However, there are some practical limitations of Buck converters, i.e. significant losses in the circuit due to an internal reference voltage and conduction losses [6]. PID controller was used to control the duty cycle of the signal sent to MOSFET. The signal sent was regulated by the PID controller itself based on the feedback received from the temperature sensor.

8.2 Experiment Details

The setup consists of a halogen bulb (250 W) as a heating element, DC power source (30V, 10A max), buck converter, thermocouple sensor, steel plate(SS316) as a sample and Arduino UNO.

8.2.1 Buck Converter

Buck converter used in the experiment consists of the following components; a capacitor (100µf, 50V): for smoothening the voltage, an inductor (4.4 mH 10A) operating at a frequency of 10 KHz: to store the electrical energy, a 15A schottky diode: to complete the circuit in switch-off mode and an IRF540 MOSFET with a heat sink to distribute the heat generated in the environment. Buck converter used in this experiment is shown in Fig. 1 and Fig. 2 .

1. 

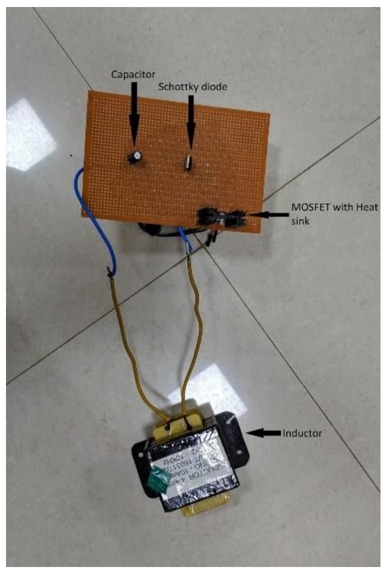
2. 

Fig. 1 Circuit setup of Buck Converter   Fig. 2 Buck Converter

8.2.2 Development of the experimental setup

A DC power source of 30V, 10A was used for switching ON/OFF the halogen bulb. The generated/ radiated energy from this halogen bulb was used to heat the steel sheet of 0.5 mm thickness. A K-type thermocouple was spot welded on the stainless steel sheet which was used to monitor the temperature in real-time. This thermocouple was connected to Arduino UNO for feedback control. A MAX6675 module was used to digitize the signal received from a type-K thermocouple. Further, it sends digital signals to Arduino for feedback control of the setup. This information was processed and sent to the PID controller, which modifies the duty cycle of the buck converter to control the power of the bulb. Buck converter uses PWM as a primary operating mode. It controls power by controlling the voltage supply, and the current was drawn out by the principle of Ohm's law. It was operated at a frequency of 10kHz. Programming for the automation of the setup and PID controller was done on open-source Arduino IDE platform. The entire experimental setup used for the purpose is shown in Fig. 3.

3.

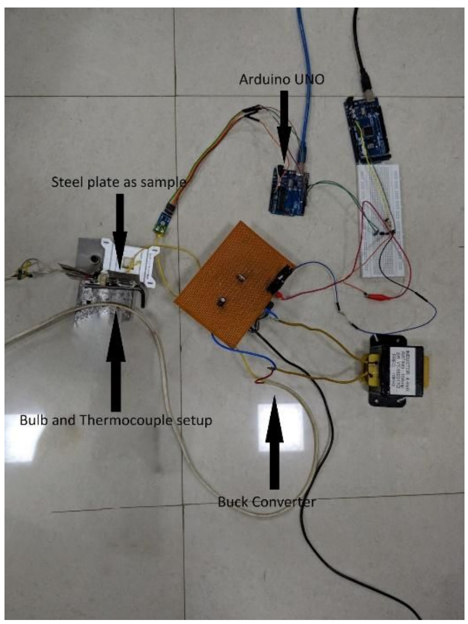
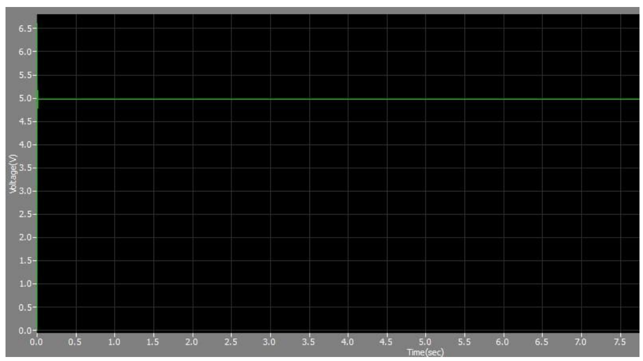


Fig. 3 Setup

8.2.3 Pulse-Width Modulation

The PWM was used to control the DC output power. It is a method of controlling electrical power by modulating it into pulse signals. Hence, controlling the average power. The PWM was chosen over mechanical relay to ensure the high frequency. However, this would interrupt the power intake of the system. It is due to the switching of MOSFET which results in a discontinuous flow of power, as shown in Fig. 4. The buck converter was used to make the continuous and uniform flow of power intake. It achieves it by storing the energy in inductor and capacitor in the form of the magnetic and electrical field, respectively. It resulted in a continuous flow of power through the circuit, as shown in Fig. 5.

4.



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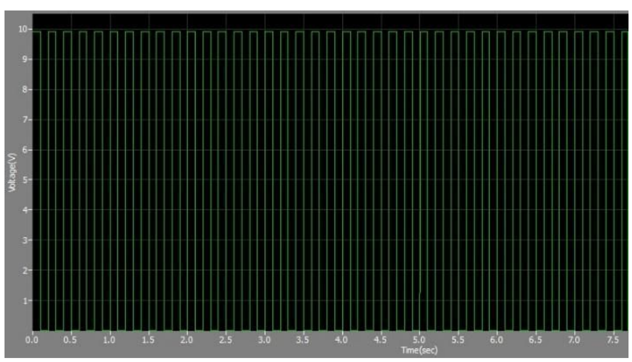
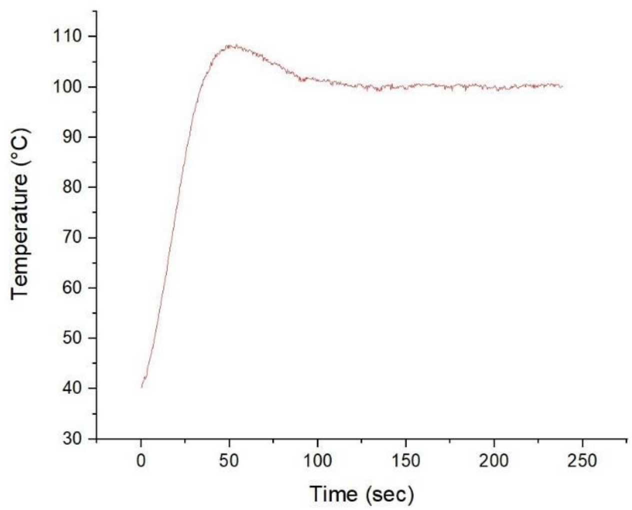


Fig.4 Fig.5

8.3 Results

The temperature obtained and measured via thermocouple is a function of the input power. In order to control the temperature, a feedback control loop was made which takes the temperature as an input parameter to control the power. This information was fed to Arduino. Further, a PID algorithm was taking over to make the decision based on setpoint temperature. It works on continuously calculating an error as the difference between the desired setpoint and the measured temperature in real-time. Then, it applies a correction factor based on Proportional, Integrational, and Derivative. Each of these parameters has an individual role to play in achieving the setpoint temperature. Theses constants were determined based on several iterations. The derivative term was kept zero for all the iterations of the experiment to avoid the fluctuations of the output voltage. As it works on changing the correction factor according to the rate of change of error. A higher value of proportional and integral term lads to change in correction factor quickly. Hence, it results in control of temperature in lesser time.



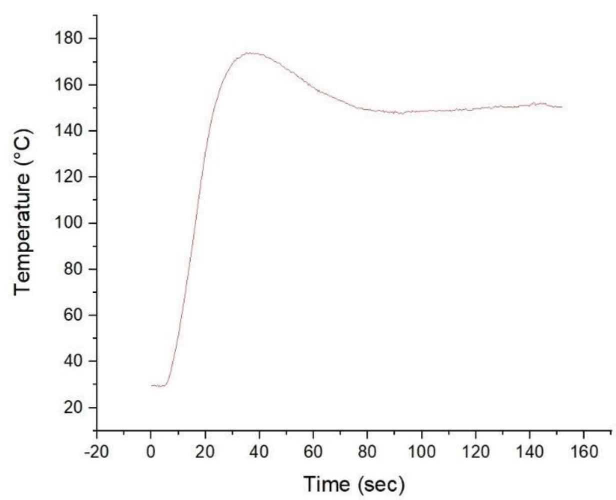
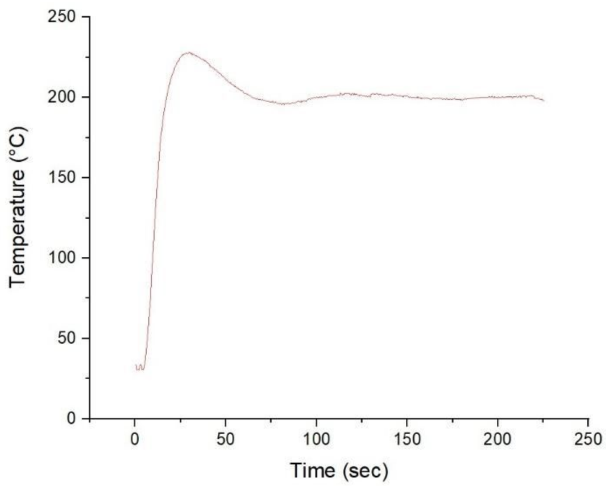


Fig.6

Fig.7



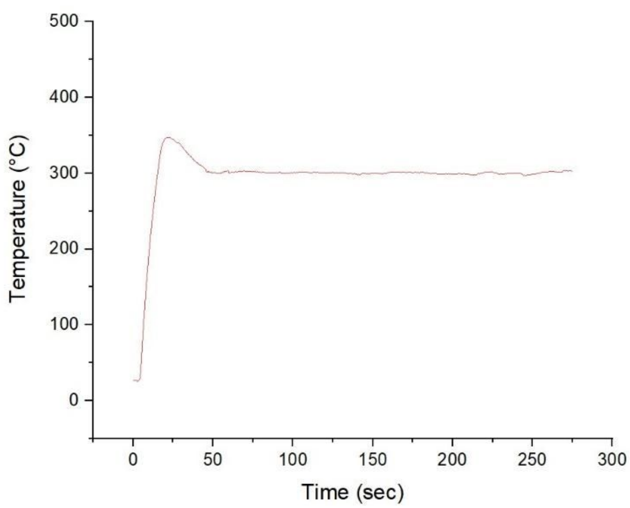
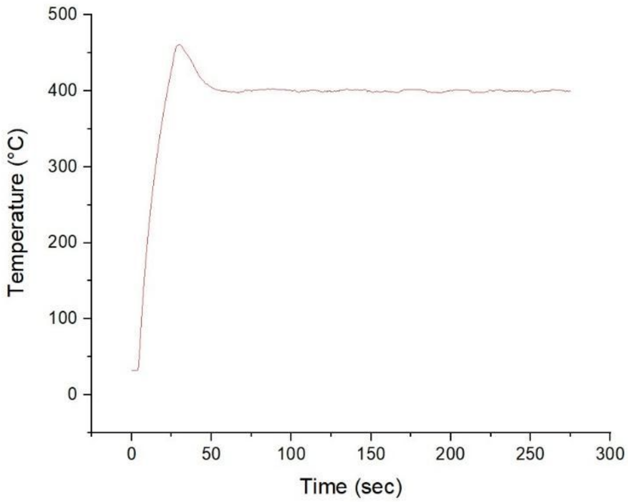


Fig.8

Fig.9



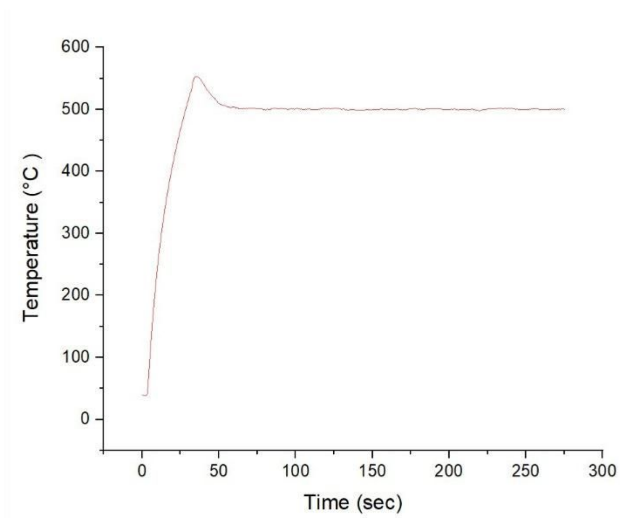


Fig.10 Fig.11

8.4 Conclusion

The experiment was successfully conducted to control the heating temperature of the metal sheet. With the developed system, the range of controllable temperature suits metal and alloys having low recrystallization temperature and melting point, e.g. Aluminium and its alloys, zinc, lead, etc. Based on the conducted experiment, the following conclusion could be drawn :

- The MOSFET pulsing and buck converter could regulate DC power output more effectively. The added Arduino in the circuit could make any DC power source programmable.
- The temperature control within the range of 80–500°C was successfully achieved.
- The stability of the temperature was obtained in approximately 120 seconds.
- With the developed system, the temperature error was found to be in the range of 5℃.

9. Phase – II

9.1 Introduction

With the successful completion of part 1 of the experiment, an attempt was made to control the temperature of an industrial grade equipment. GTAW welding machine was used for this purpose. GTAW welding machine has a foot-paddle mechanism which is used for controlling the power of the machine. It has a mechanical potentiometer inside it. On pressing the foot-paddle mechanism, the mechanical potentiometer changes the resistance. This results in change in the power of the welding machine. The objective was to control this power in accordance with melt-pool temperature by keeping the temperature constant. The goal was to automate this entire process so that the user will only need to input the temperature at which the bead is being deposited. To control the power, the foot-paddle mechanism was replaced with a digital potentiometer. And this digital potentiometer was controlled by making a circuit and was controlled by sending signals through a data acquisition device using LabVIEW.

12.  13. 

Fig.12 TIG Welding Machine Fig.13 Foot-Paddle Mechanism

9.2 Experiment Details

The setup consists of a GTAW welding machine, a steel plate(SS316) as sample, a breadboard, DAQ card NI USB 6001, digital potentiometer X9C103, a mechanical relay and pyrometer.

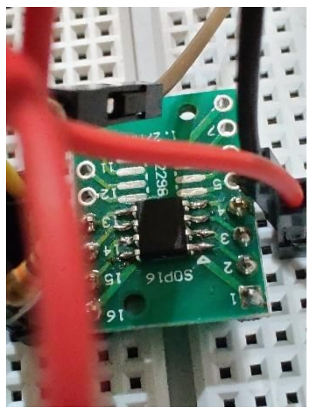
9.2.1 Data Acquisition Device

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 6001 was used in this experiment. It consists of 8 analog input pins with maximum sampling rate of 20kS/s(kilosamples per second), 2 analog output pins with sampling rate of 5kS/sec and 13 digital input-output pins. This DAQ can be used in a variety of platforms like Microsoft

Windows, MAC, and Linux etc.

9.2.2 Setup

The crucial component of this setup is a digital potentiometer named 'X9C103'. It is a 10k ohm digital potentiometer which divides 10k ohm total resistance into 100 steps. Each step is of 100 ohm.



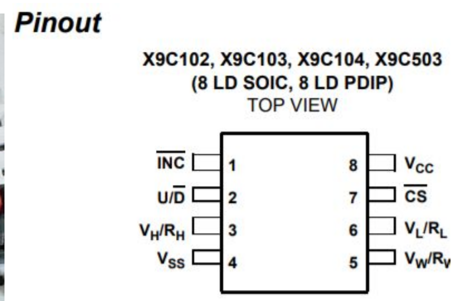


Fig.14 Fig.15

Above figure shows the basic connection pins of digital potentiometer. INC pin takes a square wave whose on state is of 5v and off state is of 0v. U/D pin control the direction of movement of the wiper. Vcc and Vss are 5v and ground pins respectively. CS pin turns on and off the potentiometer. V_H and V_L are the voltages that need to be divided. V_W is the wiper terminal of potentiometer.

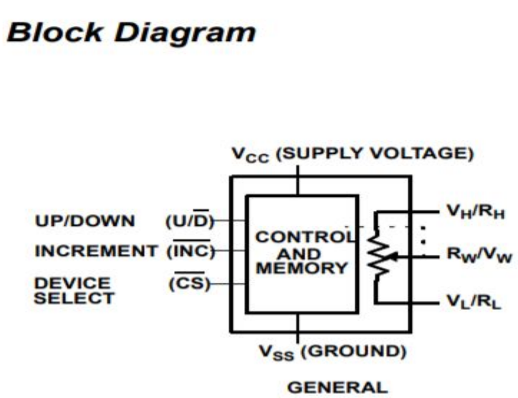


Fig.16

Truth table of the potentiometer:

Mode Selection

$\overline{CS}$	$\overline{INC}$	U/$\overline{D}$	MODE
L	↓	H	Wiper Up
L	↓	L	Wiper Down
↑	H	X	Store Wiper Position
H	X	X	Standby Current
↑	L	X	No Store, Return to Standby
↓	L	H	Wiper Up (not recommended)
↓	L	L	Wiper Down (not recommended)

Fig.17

Whenever there is a high to low transition on the square wave it results in the movement of wiper whose direction is decided by the U/D pin.

Digital potentiometer is imitating the working of a mechanical potentiometer used a the foot pedal of TIG wilding mechanism. Using a breadboard ; INC,U/D, Vss pins of digital potentiometer are connected to DAQ card. Square wave is sent by DAQ card to INC pin as per requirement. U/D pin is controlled by a different pin of DAQ card.

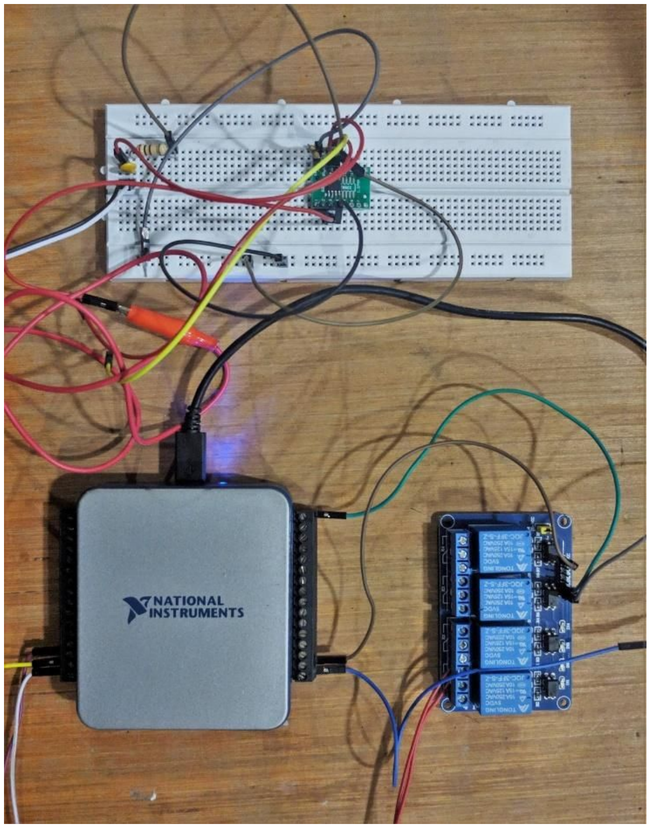


Fig. 18

5v and 0v wires coming out of TIG welding machine are connected to V_H and V_L pins of digi-pot. Wiper wire of machine is connected to V_W pin. An extra mechanical relay has been used to switch on and off the gas connection. An RC filter has been used between wiper and ground terminals of potentiometer to nullify whatever noise that may come into the system. A pyrometer has been used for temperature measurement as it is a non-contact type measurement device which is needed for this setup. Sample being heated by the welding torch of TIG welding machine has been shown in Fig. 19 and 20.

Fig.19 Welding torch OFF state

Fig. 20 Welding torch ON state

9.2.3 LabVIEW and development of program on LabVIEW platform

LabVIEW TM (Laboratory Virtual Instrument Engineering Workbench), a product of National Instruments TM, is a powerful software system that accommodates data acquisition, instrument control, data processing and data presentation. The version of LabVIEW used was 2017.

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.

The graphical nature of LabVIEW makes is more interactive to use and is more user friendly. Comparative to Arduino, in LabVIEW the program can be controlled in real time, it can show the signals acquired and generated in real time and also make changes in them. Whereas in Arduino the program needs to be uploaded to the device first and after that no changes can be made. For the dynamic control of temperature, LabVIEW was used instead of Arduino.

The front panel consists of options for entering the setpoint temperature and setting the upper and lower limits of the temperature, there's also an option for controlling the frequency of the square wave which is being sent INC pin of digital potentiometer. Through this one can control the sensitivity of the welding machine for controlling the power output. Block diagram is also shown in Fig. 21 .

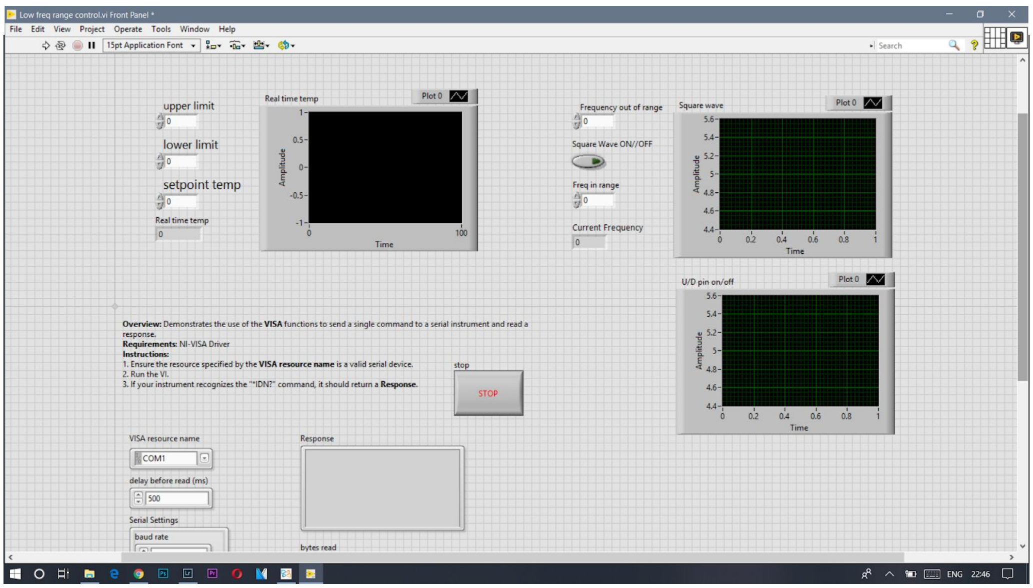


Fig.21

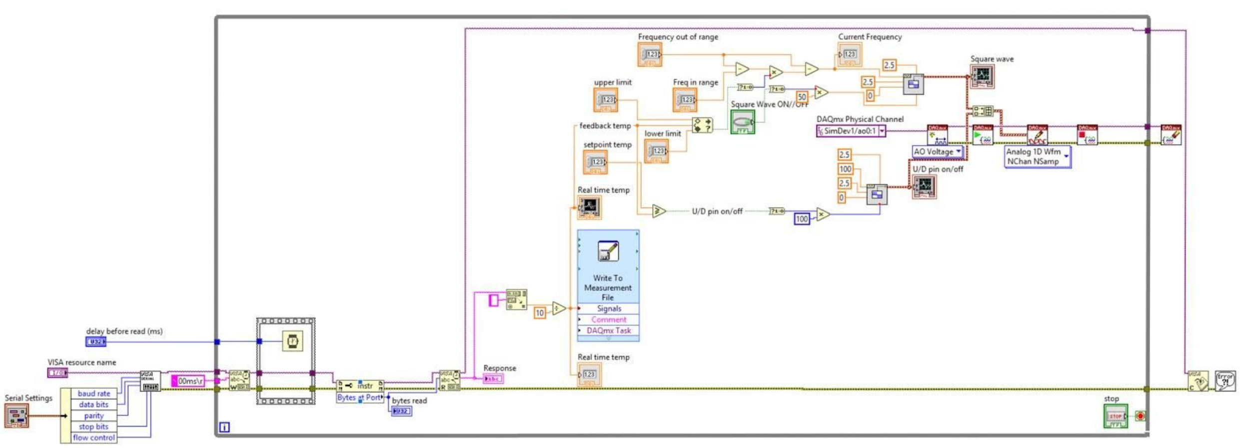


Fig.22

9.4 Results

With above designed system, temperature upto 1200°C was successfully controlled within ±25°C. Temperature was dynamically controlled by user as shown in Fig. 23 below.

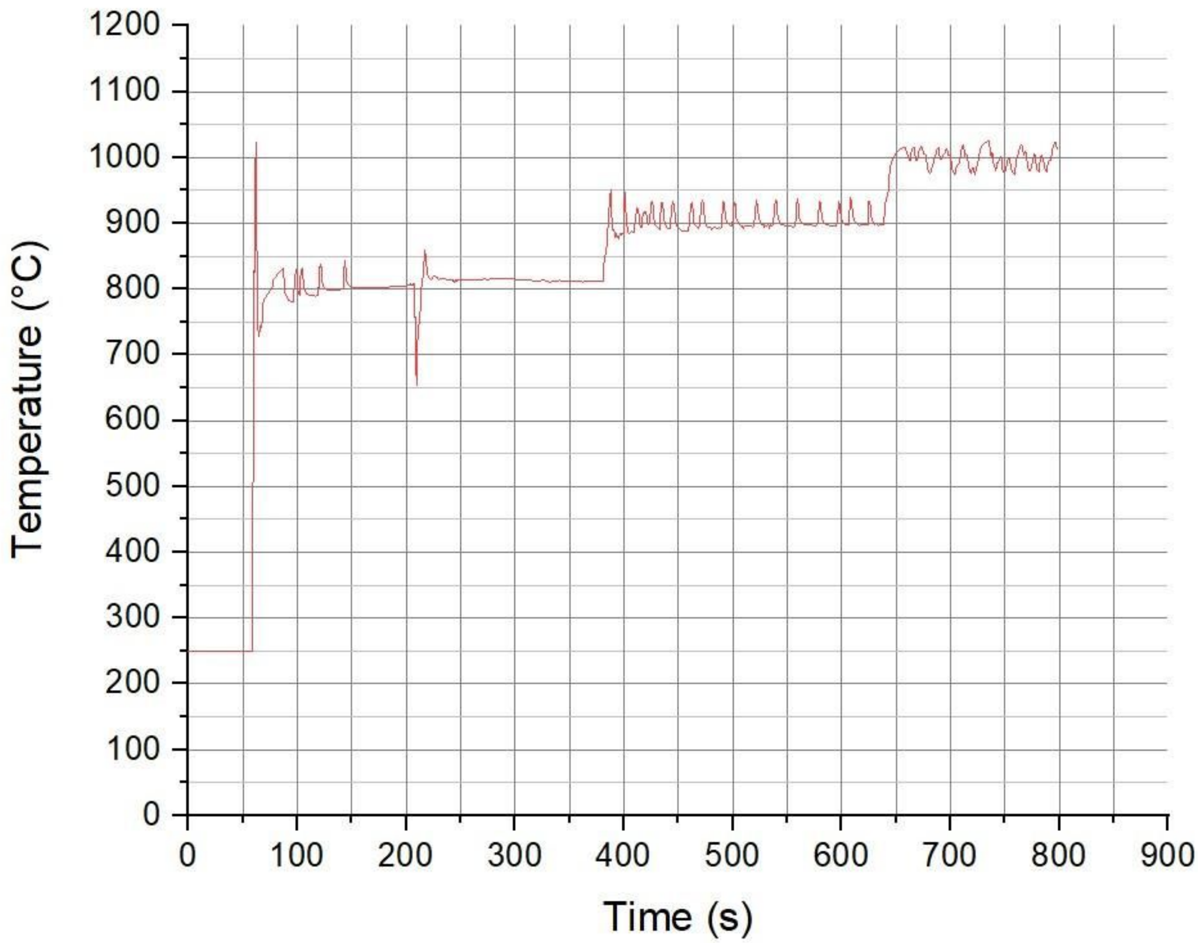


Fig. 23

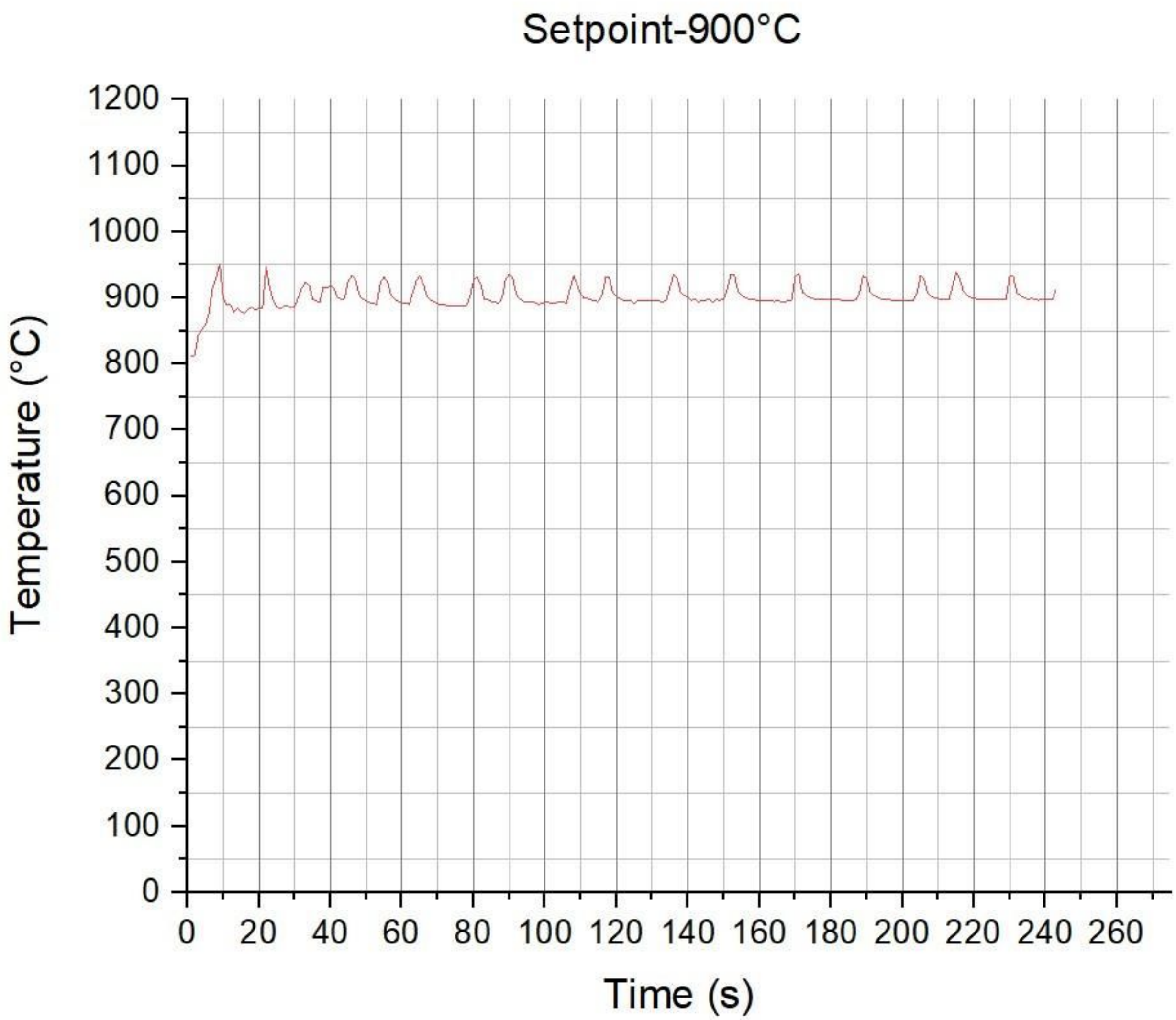

Setpoint-900°C
Temperature (°C)
Time (s)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
0 20 40 60 80 100 120 140 160 180 200 220 240 260

Fig. 24

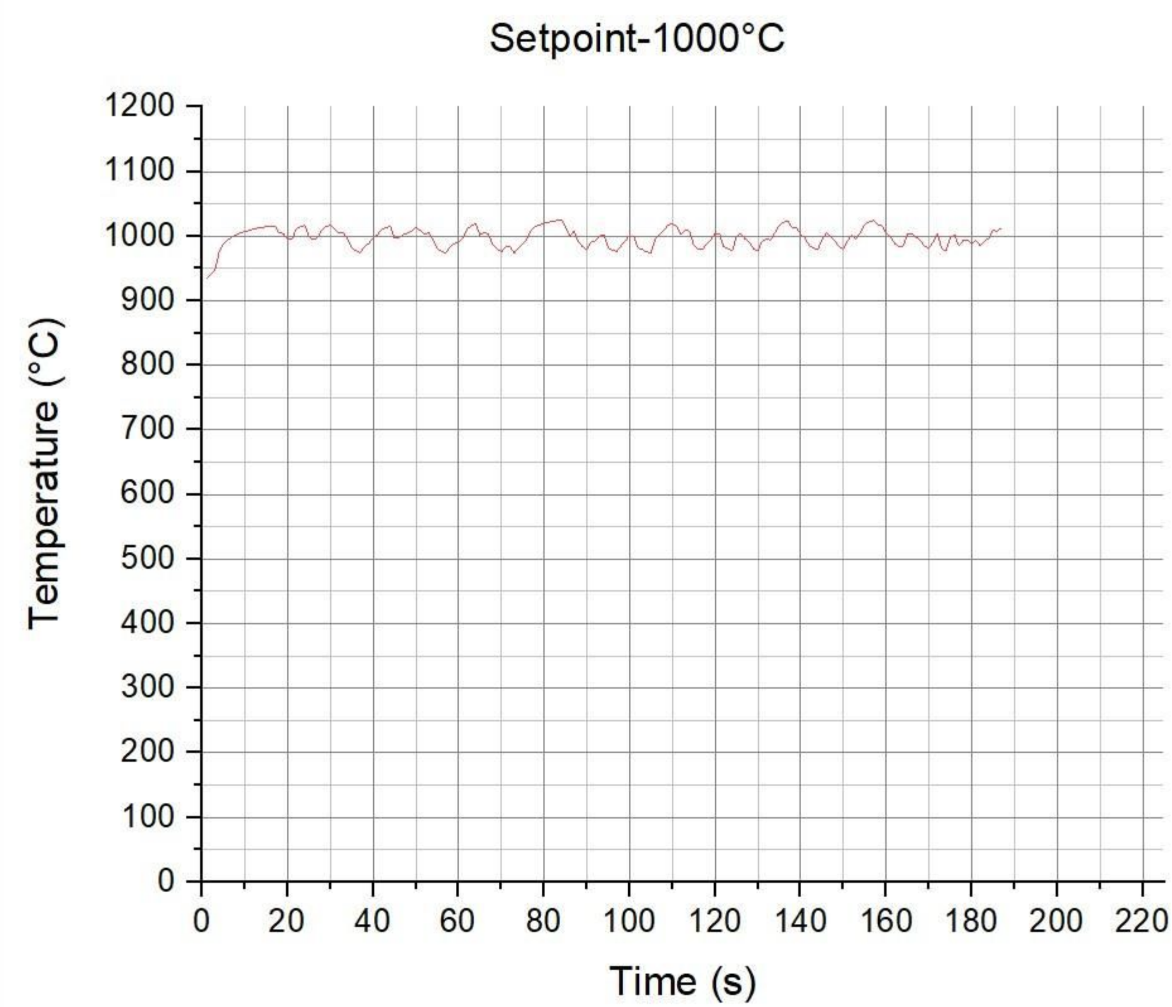


Fig. 25

9.4 Conclusion

- The experiment was successfully conducted to control the heating temperature.
- Temperature within the range of 800-1200°C was controlled.
- The stability of the temperature was obtained in approximately 15 secs.

- With the developed system, the temperature error was found to be in the range of ± 25°C.

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