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Hot wire thermopol cutting using CNC machine

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KEYWORDS	ABSTRACT
Hot Wire Computer Numeric Control G-Code Microcontroller	Recently, the Hot Wire CNC Technology is use for the purpose of cutting of the materials like thermopol and foam for the packaging of products. This technology saves labor costs and increases production. The main objective of the research is to determine the influence of wire temperature on the quality of cuts achieved through hot wire cutting technology and explore the optimal material combination for low power consumption in wire cutting technology. The technique utilizes controlling the current regulation of the Nichrome wire, to reduce the power consumption. The Hot Wire CNC Machine is controlled by a micro controller which sends a special code called G-Code to the stepper motors and the current regulation is controlled by PWM (Pulse Width Modulation) through Power transistor. The results of the study show a sufficient reduction in power consumption when using the combination of Nickel-chromium materials.

1. Introduction

A NC (numeric Control) machine was control by program which based on numeric values, Letters, and symbols. In NC machines, memory cards are used to feed the programs in them, But NC (numeric control) technology has some limitations like once an error occur in the program then its debugging and modification is very hard, and it takes huge time for execution. Also, the NC technology cannot run twenty-four hours in a day in the industries.

Industries need more advancement in this technology for the improvement and increase in their production. After some period of time a new technology was launched which is CNC Machine (Computer Numeric Control).

This technology was used throughout the world and still this technology is used in every industry and company. CNC (Computer Numeric Control) Machine covers all constraints of NC (Numeric Control) Machine. CNC is a machine in which movement, motion, speed etc. of the machine are controlled by a program which is based on alphanumeric data known as G-Code. The main objective of the research is to determine the influence of wire temperature on the quality of cuts achieved through hot wire cutting technology and explore the optimal material combination for low power consumption in wire cutting technology.

2. Few Applications of CNC Technology

2.1 CNC In Manipulator Technology

Now a day, in every industry CNC is widely used, but the technology changes with respect to time. A unique type of CNC technology is used. As we mentioned above CNC is used in all industries, that would be a small industry or large industry. CNC is used as a manipulator also, the major application of CNC that is used in industries is the robotic arm, many companies and industries use this application especially in automobile.

2.2 CNC in Cutting Technology

For the purpose of cutting technology, industries used laser cutting technology; the laser cutting working criteria is to cut the objects by laser beam e.g., acrylic sheet, Wood and Metallic sheet etc. This type of technology has become necessary for the manufacturing process. Laser CNC Machines give high accuracy, but the disadvantage of Laser technology, which is high power consumption.

2.3 CNC as a 3D Printer

CNC technology is also used in 3D Printers that operate on lasers technology but utilize consistent motion until the product is complete. But the Disadvantages of 3D printers is the cost of different type of Filament that is used in the printer.

3. Types of CNC Machine

CNC machines are working in a wide range that's behave of performs in different areas. Computer Numerical Control (CNC) machines are intended to create a large assortment of things. In that capacity, there are different types of CNC machines.

3.1. CNC Mills

CNC Mills is used in various industries; the process flow of the machine is to cut the design by rotation of the spindle. The machine is controlled by G-code. The cutting design that you are generated; the g-code controls the motors movement and spindle speed to the given design. It is a three-axis machine. This machine is mainly used to engrave steel, wood and other hard materials. (CNC computer numeric control)

3.2 CNC Lathes

The lathe machine is another type of CNC machine. The working of lathes machines is to minimize the diameter of the shaft or rod or to provide different shapes, the motor moves the shaft with a high speed then a blade touches to the shaft to minimize the diameter. This machine moves automatically by reading the g-code. These CNC machines are very successful in the exactness they offer contrasted with manual machines." (CNC computer numeric control)

3.3 CNC Routers

A CNC switch is utilized for cutting steel, wood, aluminum, composites, plastic, and froth. The CNC Router also cuts the drawing by rotating the spindle as we seen in the CNC Mills (CNC computer numeric control).

Both router and mill work on the same principle and are almost similar in functionality and operation. A CNC mill has slower spindle speed as compared to CNC router.

3.4 CNC Plasma Cutters:

"CNC Plasma is used to cut heavy and hard materials like steel and different types of metal. The methodology of plasma cutting is, a highly pressure gas is out from the nozzle and machines automatically moves with the help of g-code. CNC plasma is also used in different industries all over the world. (CNC computer numeric control)

4. Hot Wire CNC Machine Structure

The physical structure of the machine is shown in Fig. 1. A hot wire CNC machine is an advanced technology that is used to cut materials like thermocol, foam, plastic etc. The advantage of Hot wire CNC machines, its work on 2-axis and produce a 3D structure. This technology is mainly used in every type of packaging industry, to secure the product from damage.
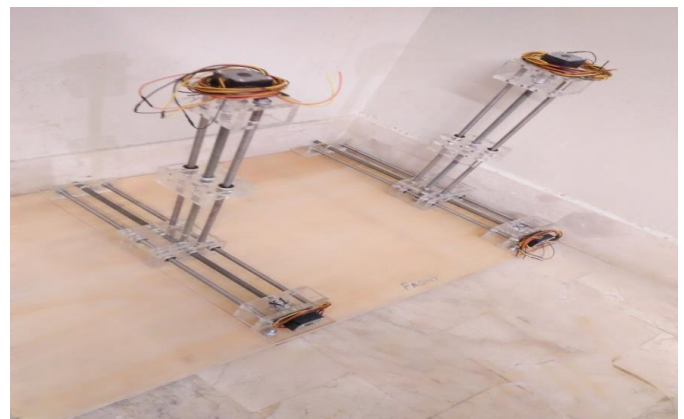

Fig. 1. Physical Structure of Hot wire CNC machine

5. Methodology

A hot wire CNC machine is the advanced technology that is used to cuts Objects like thermocol, Foam, Plastic etc. This advanced machinery has been used world widely. The advantage of this technology is its low power consumption as through current regulation the power consumption is regulated as required by given materials. Another advantage of hot wire CNC machines, its work on 2-axes and produce a 3D structure. This technology is mainly used in every type of packaging industry, to secure the product

from damage. The technology can also be utilized in automotive industry for cutting foam materials used in seats headliners and interior trims.

The hot wire CNC machines are the most valuable machines for the aircraft designer industries, for Architectural Models industries, even these machines are the need for every company and industry, who had work for securing the product for damage.

The basic operation of the hot wire CNC machines is to control the motors whether they move clockwise or anti clockwise. The most important parameter of the hot wire CNC machines is the selection of wire. And to control the flow of current in the wire, and also observed the machines status.

The area and volume of the any CNC machines is an important role. Sometimes during the cutting process, the machines exceed their limits or range, this cause because of wrong command sends to the CNC controller (micro controller). This problem is overcome by using a limit switch.

By using a computer, we can program the machine and send the command in the form of G-code and also the status of the hot wire CNC machines can be observed.

6. Physical Components

6.1 Stepper Motor

A stepper motor is a special motor that converts electrical pulses into mechanical movement. The main component of stepper motor is permanent magnet rotor encompassed by a stator. The stepper motors work in step and direction, most of the stepper motors have four stator windings that are paired with a center-tapped common. as shown in Fig. 2.
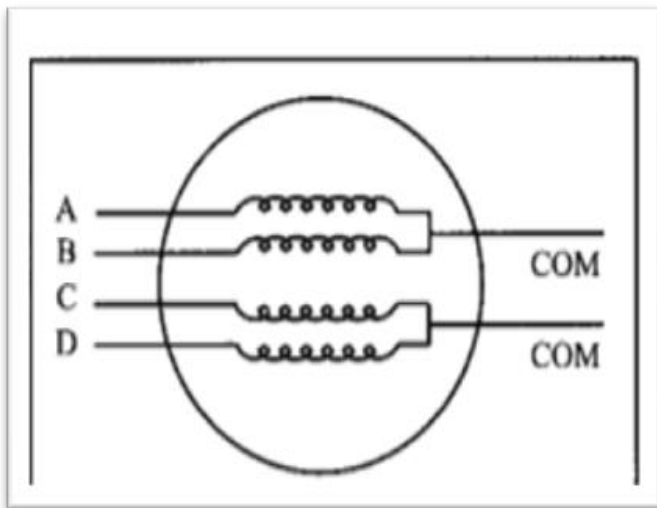

Fig. 2. Stator Windings of Stepper Motor

6.2 Hot Wire

As the property of a conductor is when it is subjected to current then due to internal resistance of wire, heat dissipation occurs, and the wire becomes hot. Using this property of producing thermal heat cutting of thermopol or foam can be accomplished. There are various types of hot wires which produce thermal heat; some of them are given below.

- Nichrome
- Titanium
- Stainless steel
- Tungsten
- Iron Chrome Aluminum (Fe-Cr-Al) or etc.

These wires are widely used, but the most commonly wire use which is nickel chrome (NiCr), has become more popular due to its high resistivity as compared to other conductors.

Ni-chrome is derived from two metals or in other words "it is a mixture of two metals that is Nickel and Chromium". The Ni-chrome wire is commonly in electric appliances such as heaters.

There are two types of Ni-chrome wire that can be found, Type A and Type C.

Ni-chrome is twisted in coils to a specific electrical obstruction, and when the current flows through the wire, the wire becomes warm. As the magnitude of current increases through the wire, it becomes hotter.

Nichrome, a non-magnetic 80/20 alloy of nickel and chromium, is the most common resistance wire for heating purposes because it has a high resistivity and resistance to oxidation at high temperatures. When used as a heating element, it is usually wound into coils. Its resistivity at 20ºC is $650\ \Omega/cm$ to $675\ \Omega/cm$) and a high boiling point (~1400 °C). With such a high resistivity and high boiling point, this makes nichrome a decent conductor of power and perfect material for making wires and other protection gadgets.

The calculation of hot nickel chrome wire is as follows.
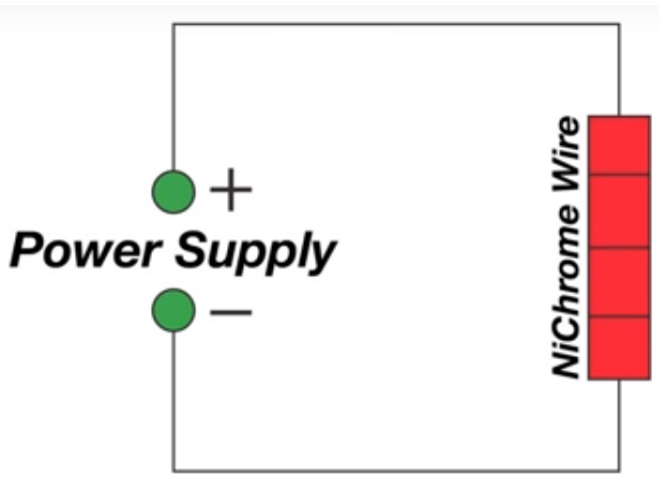
Fig. 3. Nickel-chromium wire connected to Power Supply

In order to calculate the power supply requirement, the nickel chrome wire is placed in series as shown in Fig. 03.

For the calculation, we must be clear about ohm's law and joules law i.e.

$$I = V/R \tag{1}$$

And

$$P = V \times I$$

The first step to determine the overall resistance of the hot wire Ni-chrome circuit, the total resistance of the Ni-chrome wire circuit is a function of the wire's overall length and the wire's resistance per foot. For the better calculation we can take the help of the table 1 given below

Table 1

Gauge Wire	Diameter (mm)	NiCr A	NiCr C
10	2.591	0.06248	0.06488
11	2.311	0.07849	0.08151
12	2.057	0.09907	0.1029
13	1.829	0.1254	0.1302
14	1.626	0.1587	0.1648
15	1.448	0.2001	0.2078
16	1.295	0.2499	0.2595
17	1.143	0.321	0.3333
18	1.016	0.4063	0.4219
19	0.914	0.5015	0.5208
20	0.813	0.6348	0.6592
21	0.7239	0.8002	0.831
22	0.6425	1.015	1.055
23	0.574	1.273	1.322
24	0.5105	1.609	1.671
25	0.4547	8.029	2.107
26	0.4039	2.571	2.67
27	0.3607	3.224	3.348
28	0.32	4.094	4.252
29	0.287	5.09	5.286
30	0.254	6.5	6.75
31	0.2261	8.206	8.522
32	0.2032	10.16	10.55
33	0.1803	12.89	13.39
34	0.16	16.33	17.01
35	0.1422	20.73	21.52
36	0.127	26	27
37	0.1143	32.1	33.33
38	0.1016	40.63	42.19
39	0.0889	53.06	55.1
40	0.0787	67.64	70.24

In this project 24 gauge and 18-inch-long Ni-chrome wire is used, so with the help of above table we found that value of ohms per foot of 24-gauge Ni-chrome wire which is 1.60900.

Eq. 1 becomes,

$$R_N = (18/12) \times 1.60900.$$

$$= 1.5 \times 1.60900$$

$$= 2.4135$$

Now we can find the power supply requirement,

$$V = I * RN \tag{2}$$

The wire temperature is a direct result of current flowing through the Ni-chrome wire. The electrical voltage is a pressure gradient trying to push the electron through the Ni-chrome wire, the resistance is trying to prevent the flow of electron and the current is actual flow of electron through that wire, if you generate a large amount of current, it will cause a large amount of friction with the Ni-chrome wire as the electron pass through and that friction is dissipated as heat in the wire.

The most foam products require up to 626°F and 330 °C for cutting with the help below Table 2 we can find the value of current.

Table 3

Approximate Amperes to Heat Ni-Chrome Wire

Gauge Wire	Diameter (mm)	°F 400	626	800	1000
		°C 205	330	427	538
10	2.591	16.2	23.3	29.7	37.5
11	2.311	13.8	19.2	24.8	31.5
12	2.057	11.6	16.1	20.8	26.5
13	1.829	9.8	13.6	17.6	22.5

14	1.626	8.4	11.6	15	18.8
15	1.448	7.2	10	12.8	16.1
16	1.295	6.4	8.7	10.9	13.7
17	1.143	5.5	7.5	9.5	11.7
18	1.016	4.8	6.5	8.2	10.1
19	0.914	4.3	5	7.2	8.7
20	0.813	3.8	5.1	6.3	7.6
21	0.7239	3.3	4.3	5.3	6.5
22	0.6426	2.9	3.7	4.5	5.6
23	0.574	2.58	3.3	4	4.9
24	0.5105	2.21	2.9	3.4	4.2
25	0.4547	1.92	2.52	3	3.6
26	0.4039	1.67	2.14	2.6	3.2
27	0.3607	1.44	1.84	2.25	2.73
28	0.32	1.24	1.61	1.95	2.38
29	0.287	1.08	1.41	1.73	2.1
30	0.254	0.92	1.19	1.47	1.78
31	0.2261	0.77	1.03	1.28	1.54
32	0.2032	0.68	0.9	1.13	1.36
33	0.1803	0.59	0.78	0.97	1.17
34	0.16	0.5	0.68	0.83	1
35	0.1422	0.43	0.57	0.72	0.87
36	0.127	0.38	0.52	0.63	0.77
37	0.1143	0.35	0.46	0.57	0.68
38	0.1016	0.3	0.41	0.5	0.59
39	0.0889	0.27	0.36	0.42	0.49
40	0.0787	0.24	0.31	0.36	0.41

Eq. 2 becomes,

$$V = 2.90 \times 2.4135$$

$$V = 6.99915 \approx 7v$$

The requirement of power supply is 7v and 2.90 A to achieve the temperature of almost 626°F and 330°C.

7. Feed Back Component

Limit Switch

Limit switch is used for determining the presence or absence of any Object. Basically, there are three points such as common point, normally close point and normally open point. When the actuator is mechanically linked to the switch, its contact breaks. There are two types of limit switch snap action and slow make and break. Snap action has spring mechanism as compared to slow make and break. Due to spring mechanism, it is widely used because of the contacts switch at high speed. In CNC machines it plays an important role. Due to some reason, the sending command is wrong then limit switch prevents the product by changing its contact and stop the machines.
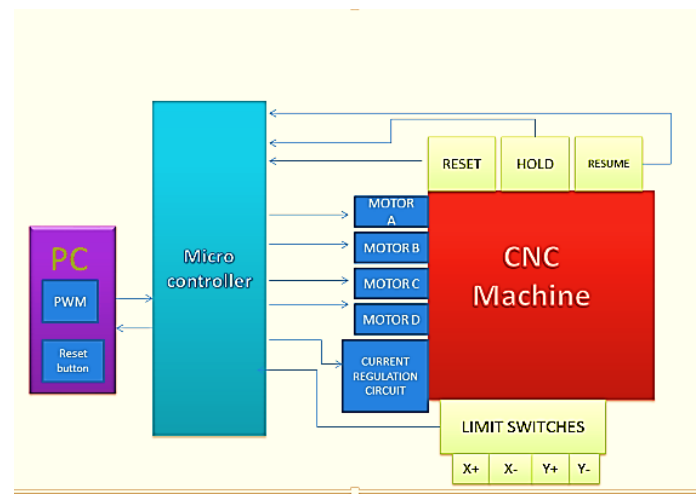
8. Block Diagram

Fig. 4. Block Diagram

As shown in the Block Diagram given in Fig. 04 Personal Computer (PC) sends a G-code that is generated using Estlcam Software which is send to the micro controller. The micro controller reads the G-code and sends the information to the Stepper motors in the form of steps and direction. A calculated power supply is provided to the nickel chrome wire which is attached to the CNC machines. The wire is controlled by Pulse Width Modulation (PWM) with the help of opt coupler and power transistor. A limit switch is used to sense the machine status, if the machines exceed their limit; the limit switch sends the information to the controller to stop the machine. Three emergency switch buttons are used i.e., Reset, Hold, and Resume. During cutting, the whole process is observed by a Personal Computer (PC).
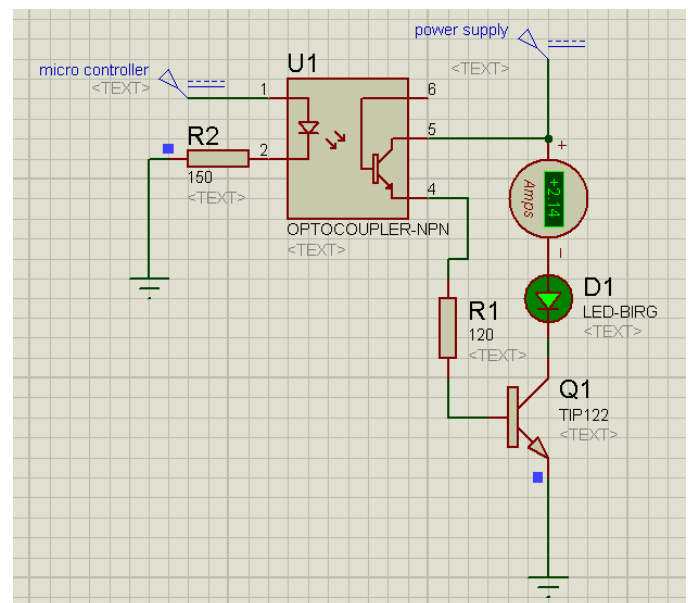
9. Schematic Design

Fig. 5. Schematic Diagram of OPTOCOUPLER controlled by PWM

Above schematic diagram shows how to control the hotness of the nickel chrome wire by using an opt coupler. A PWM (5V) is applied at the input of the opt coupler, R2 is used to limit the current then light is emitted and base of the opt coupler is drive. Now the current is passing through the R1 resistor, R1 is also used to limit the current. As we know the requirement of nickel chrome wire to become hot at 2 to 3A, because of that a power transistor is used (TIP122). TIP122 is used for switching, the current flows through the wire and the wire becomes hot.
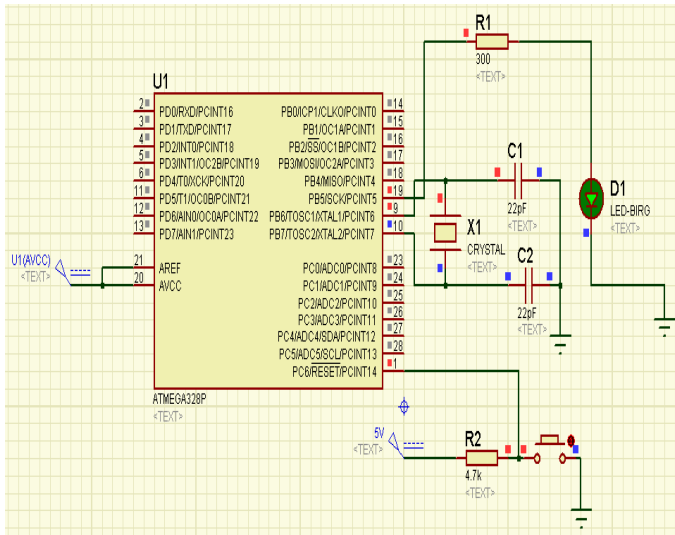
Fig. 6. Schematic Diagram of AVR Board with Atmega328P µC

The schematic diagram shown in Fig. 06 is of AVR Board by using an Atmega328P micro controller. Mostly micro controllers operate with 5V, in Atmega328P the external clock is located as pin 9 and 10.X1 is the crystal with a value of 16MHz provided to the controller to run. Crystal is used to produce the oscillation and parallel capacitor C1 and C2 are used to decrease the resonance frequency. Pin 1 is the reset pin when a push button is applying current flows through the R2 resistor to the ground.

10. Results

Research objectives are classified in three categories;

To Create Various AutoCAD Designs and Generate its Corresponding G-Code.

To Derive CNC Machine as per Generated G-code.

To Regulate Hot Wire Temperature as per material requirements.

To Create Various Auto Cad Design and Generate its Corresponding G-code
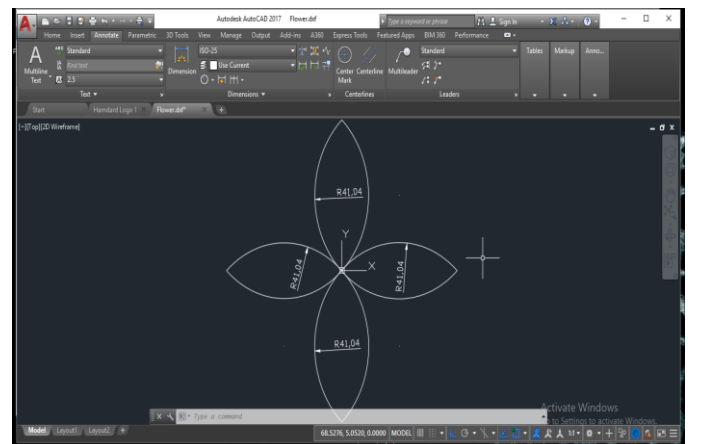
10.1 Logo of Hamdard University

With the help of Auto Cad software, we can design different types of structure to cut, as given below structure is a Logo of Hamdard University then generate its G-code according to the design of Logo of Hamdard University [16]. As you see in Fig. 08, there are four circles drawn with a diameter of (120mm, 140mm, 150mm, 170mm) and vertical line (100mm) and use some Auto Cad command like Trim, mirror etc to create a design.
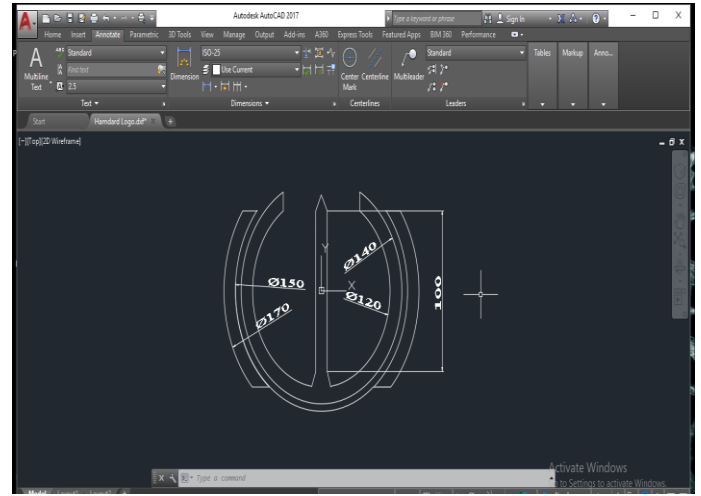
Fig.7. CAD file used to generate Gcode for different length of cut

10.2 Flower Design

With the help of Auto Cad software, we can design different types of structure to cut, as given below structure is a Flower Structure then it generates G-code according to the design of Flower. As you see in Fig. 09, there are four circles drawn with a Radius of (41.04mm) and use some Auto Cad command like Trim, mirror etc to create a design.

Fig. 8. CAD file used to generate Gcode for different length of cut

Objective # 02

To derive CNC machine as per generated G-code

According to the dimensions of Logo of Hamdard University, the below Fig.s Shows the accuracy to cuts a circle of (120mm and 140mm). The results of logo as you see in the Fig. 10

Fig. 10. The result of flower design

Fig. 11. The result of Hamdard University logo design

Objective # 03

To regulate hot Wire temperature as per material requirements

The selection of wire is an important part for Hot Wire CNC Machine, because due to the regulation of current the wire temperature depends on wire resistivity [15]. Different wires have different resistivity, but the highest resistivity is Nickel chrome wire because of that reason we are using Nickel chrome wire in our project. With the help of PWM, we can increase the value of current as well as temperature. The thermopol and foam are cut at a temperature at 220 °C and 330 °C respectively as shown in Table 03.

Table 3

Dutycycle%	Current(A)	Power(W)	Temperature(C)
10	1.32	3.03	40.34
20	1.67	4.85	92.4
30	1.99	6.89	131.211
40	2.22	8.57	163.29
50	2.44	10.35	197
60	2.58	11.58	220 (Thermopol)
70	2.83	13.3	265
80	3	15.66	298.2
90	3.16	17.37	330(Foam)
100	3.23	18.15	345.67

Fig. 12. Hot wire Temperature Vs Hot Wire Current
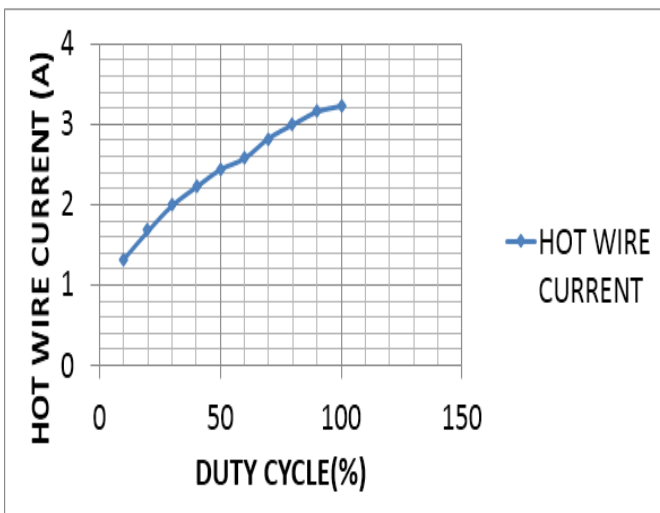
Fig. 13. Duty Cycle Vs Hot Wire Current Graph
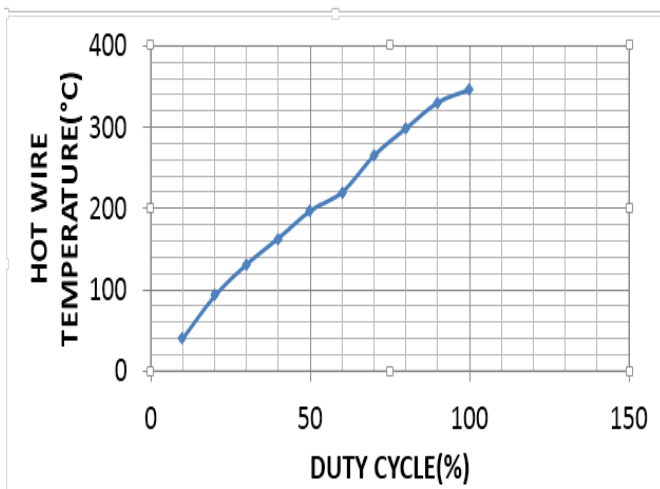

Fig. 14. Duty Cycle Vs Hot Wire Temperature Graph

11. Conclusion And Future Work

Currently the using CNC machine available in industry that only cuts specific materials to create various designs, various other materials are limited due to hot wire constant temperature also the constant temperature for different material causes higher power consumption. The main objective of this research is to create various AutoCAD designs, develop a mechanical structure of CNC machine, and to design and develop the electronic interface of actuators for CNC machine. Also, to design current regulation circuit through power BJT to control the current according to different type of material.

The future directions in the area may be to investigate the integration of Artificial intelligence techniques, such as deep learning algorithms to optimize cutting paths, automate parameter adjustment and predict cutting quality. Also, we can develop advanced control system for CNC machine in hot wire theromopol cutting machine.

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