Design of Styrofoam Cutting Machine Based on CNC 2 Axis Using Hot Wire

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ABSTRACT

The development of the creative industry in the manufacture of decorations from styrofoam materials is increasing rapidly, the need for a 2-axis CNC-based automatic styrofoam cutting machine (Computer Numerical Control) using hot wire can facilitate the process of cutting styrofoam in large quantities and uniformly with machine drive on the X and Y axes. The purpose of this study is to design and manufacture a CNC based styrofoam cutting machine that can be programmed so that it can facilitate the cutting of styrofoam in large quantities and uniformly with movement on the X and Y axes. The method used is an experimental method in which the G-Code processing process is sent to the software which then produces 2 axis movements, namely on the X and Y axes. Then the styrofoam cutting process is continued using a hot wire whose temperature has been regulated using voltage and current which produces styrofoam cutting according to the size of the styrofoam used, which is 88 cm long, 42 cm high with a thickness of 2 cm and the accuracy level obtained for the X axis of 99.84% and the Y axis of 99.91%.

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1. INTRODUCTION

The development of the creative industry is currently growing rapidly. One example is the creative industry in making decorations of Styrofoam. Decorations from Styrofoam can be used in many ways, such as: congratulations on weddings, graduations, promotions, condolences, student art assignments, making safety pads for goods, decorations at carnival events, cultural festivals, and others. CNC stands for Computer Numerical Control. CNC is a system that uses a computer to control industrial machines such as lathes, milling machines, or laser machines. By using CNC, the machining process can be done more accurately and efficiently. CNC usually consists of computers, controllers, and related machines. Computers are used to store product designs and produce programs that controllers will use to control machines. The controller is a device that processes the programs created by the computer and sends signals to the machines to carry out the machining process. Related machines are industrial machines that the controller will control to carry out the machining process. There are styrofoam cutting tools that are manual and automatic. Examples of manual styrofoam cutting tools are cutter and hot wire. The increasing development and needs of industry, higher education institutions and vocational schools for CNC (Computer Numerical Control) machines in Indonesia are mostly based on the emergence of GRBL technology (software to control CNC movements that can be uploaded to the Arduino library). To fulfill its function, Styrofoam must be shaped in such a way to get the expected shape. The trick is to cut the material according to the desired shape. This cutting can be done in the form of two-dimensional cutting movements or 3D movements [1]. Styrofoam is also commonly found in the community in the form of several products, as a substitute for balsa wood to make aircraft aerofoil in aeromodelling, as well as for other uses [2]. CNC is a machine that is controlled by a computer using a numeric programming language as a movement command [3]. In general, in the work of CNC machining, it takes work that is fast and has good quality but with lower processing costs. This has become an attraction for industrial consumers to use CNC machines compared to using conventional machines. With the advantages in terms of productivity will be a separate competitiveness for industries that use CNC machines. The development from manual machining to machining that uses the CNC system is an advantage in increasing accuracy and speed settings as desired [4]. All CNC machines work on the same principle, the machine places a kind of tool in a sequence of positions determined by the program and the styrofoam cutting CNC machine also has the same working principle using hot wire as a styrofoam cutting tool [5]. In simple terms, the working principle is that electric power passes through a hot wire (usually 0.30 mm Nickel wire) then the wire is heated to the desired

temperature according to the input voltage. The wire arc is heated through an electrical resistance around 180˚C by passing a current through the wire [6]. Hot wire is a method that is widely used in styrofoam cutting [7].
In 2017 a research was conducted entitled "Design of 2 Axis CNC Machines". The way the CNC machine works is to make products with the same shape and dimensions from the production process which is carried out repeatedly by using the dental plaque test parameters [8]. In 2020, a research entitled "Design and Development of Semi-Automatic Styrofoam Cutting Tools Using the RULA Method was conducted in Kalisari Village". The workings of the CNC machine are semi-automatic styrofoam cutting tools using the RULA (Rapid Upper Limb Assessment) method which is a method developed in the field of ergonomics that investigates and assesses the working position of the upper body [9]. In 2020, a research entitled "Design and Development of CNC Wire Cutter for Styrofoam Products was conducted". The way the Cutter CNC 2 axis Styrofoam cutter works is to convert electrical energy into heat energy. This CNC wire cutter already uses numerical control using CNC programming and the cutting precision is much faster [10].
This research makes a CNC-based styrofoam cutting machine to make it easier to work and the size of the styrofoam cutter itself will be made small. This tool can cut Styrofoam according to the size of the image on the laptop, cut using Hot Wire and a GRBL controller in the form of G-Code, to drive the heating system using a stepper motor that can move towards X and Y. While the first RoadMap CNC machine uses a 2-axis system, the second using a semi-automatic styrofoam CNC cutting machine using the RULA foam cutter method and the third, a 2-axis CNC machine by sending the G-Code file to the microcontroller via the universal G-Code Sender software.

2. RESEARCH METHOD

Research in the process of making this machine uses experimental methods, including the design process, the manufacturing and assembly process and the testing process, the styrofoam cutting machine can be seen in **Fig. 1**.

Fig. 1 CNC2 Axis Based Styrofoam Cutting Machine Using Hot Wire.

The tool designed uses an aluminum profile V slot 240 with a thickness of 2 cm and the dimensions of the machine are 1080 mm long, 330 mm wide and 600 mm high. The type of cutter used is nickel wire with a thickness of 0.3 mm. **Fig. 2** is a flow diagram of the work system of a 2 axis CNC styrofoam cutting machine using hot wire as shown below.

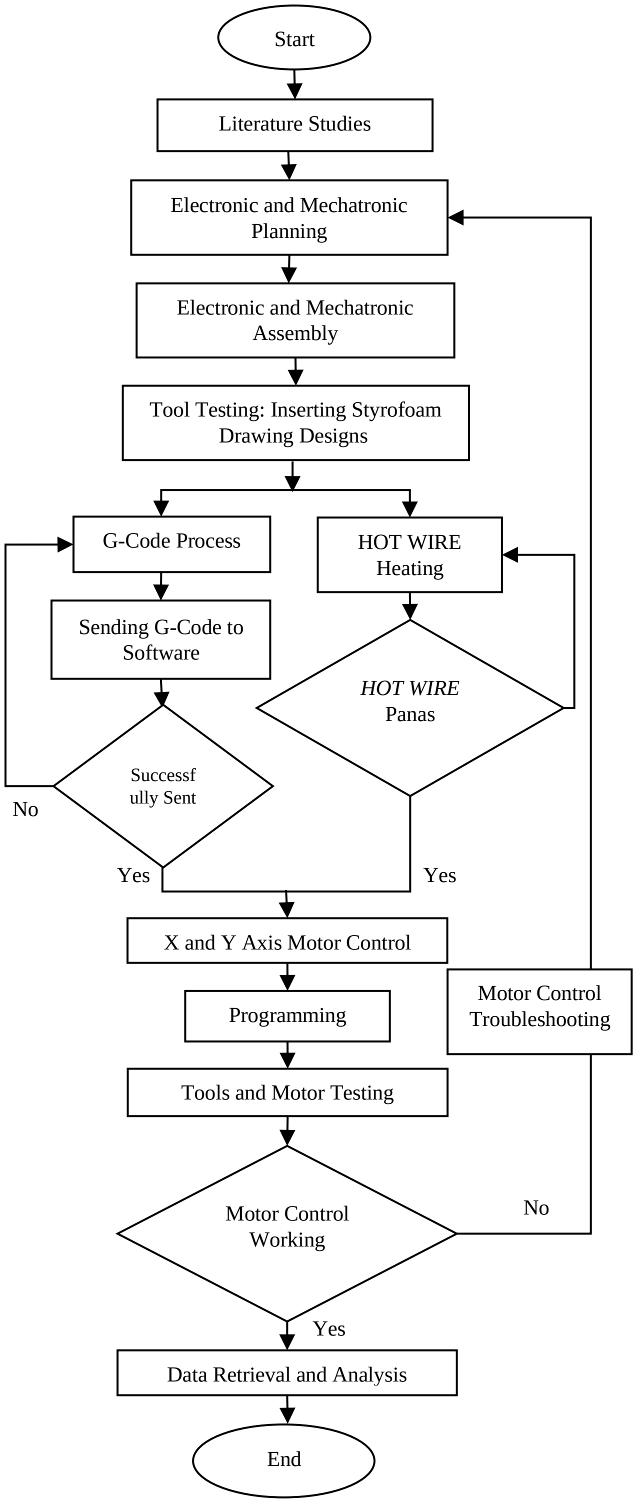

Fig 2. Workflow Diagram of 2 Axis CNC Based Styrofoam Cutting Machine Using Hot Wire

Based on the flow diagram in Fig 2, the process of working on a 2-axis CNC-based styrofoam cutting machine using hot wire starts from a literature study to find reference sources then the mechanical and electronic design process, then after the design is carried out the mechanical and electronic assembly process is carried out. Next do the styrofoam image design, after the design process is done, then the experimental method is carried out, namely the G-Code processing by sending the G-Code to the software and the hot wire heating process. If the G-Code is successfully sent and the hot wire heating process is successful, then proceed to the X and Y axis motor control process, if not, then go back to processing and sending the G-Code and hot wire heating process. Then after the motor control process has been completed then proceed to the programming process and then testing the motor.

Figure 3 is a block diagram of a 2 axis CNC-based styrofoam cutting machine using hot wire consisting of input, process and output. Based on the block diagram in Figure 3, the input starts from working on the Styrofoam image design and the G-Code program, then the G-Code processing process is processed on the microcontroller, namely the TB6600 driver for the Nema 17 stepper on the X axis and the TB5660 driver for the Nema 17 stepper on the Y axis. Then the microcontroller adjusts the DC DC converter so that the voltage and temperature used on the hot wire are as expected. Furthermore, it will produce an output in the form of hot wire whose current will be regulated by a DC DC converter which will then be used for the styrofoam cutting process and produce movement on the Nema 17 stepper for the X and Y axes.

3. RESULTS AND DISCUSSION

In this study there are results and analysis of the trial system testing of Styrofoam cutting machine based on CNC 2 Axis using Hot Wire:

3.1. X and Y Axis Calibration Settings

Voltage and temperature regulation in this tool is to regulate the temperature of the hot wire by using voltage and current calibration to get the right temperature for the styrofoam cutting process precisely and maximally. **Table 1** shows the X-axis calibration process on a NEMA 17 stepper motor.

Table 1. X Axis Calibration Process

Stepper Motor
Deg/*step*: 1.8
Steps/rev: 200
Micro Stepping
Pulse/step: 16
Pulse/rev: 3200
Pulley Teeth
Pulley teeth: 16
Belt Pitch
Pitch: 2
Lead (mm/rev): 32
Result
Steps per mm: 100
Resolution (mm/step): 0,01

With the number of pulley teeth as many as 16 teeth and belt pitch as many as 2 pitches, the default condition of the stepper motor is 1.8 deg/step with the number of micro steps as many as 16 pulses/step. Based on the default specification of the machine components used, the X axis calibration results are 100 steps per mm. **Table 2** shows the Y-axis calibration process on a NEMA 17 stepper motor.

Table 2. Y Axis Calibration Process

Stepper Motor
Deg/*step*: 1.8
Steps/rev: 200
Micro Stepping
Pulse/step: 16
Pulse/rev: 3200
Pulley Teeth
Pulley teeth: 20
Belt Pitch
Pitch: 2
Lead (mm/rev): 40
Result
Steps per mm: 80
Resolution (mm/step): 0,0125

With the number of pulley teeth as many as 20 teeth and belt pitch as many as 2 pitches, the default condition of the stepper motor is 1.8 deg/step with the number of micro steps as many as 16 pulses/step. Based on the default specifications of the machine components used, the X-axis calibration results are 80 steps per mm.

3.2. Temperature Variation and Current

Taking hot wire temperature measurement data based on voltage (V) and current (A) on the device using multimeter. **Table 3** shows the minimum voltage used is 1.3 V obtained hot wire27C temperature and maximum voltage used is 10.1 V on the grounds that if the voltage is greater than the maximum voltage it will cause the hot wire (nikelin wire) smoldering which will then cause the cutting results to be less precise and offset will be large so that the measurement error will also increase and the cutting results are not maximum.

Table 3. Temperature Measurement Based on Voltage, Current and Temperature of Hot Wire

Voltage (V)	**Current (A)**	**Hot Wire Temperature (˚C)**
1,3	0,00	27
2,2	0,00	27
3,1	0,07	31
4,1	0,15	38
5,1	0,23	52
6,1	0,29	76
7,1	0,38	85
8,1	0,47	104
9,1	0,56	170
10,1	0,67	190

3.3. Styrofoam Cutting

Styrofoam cutting is the process of cutting Styrofoam, a type of plastic foam material, into desired shapes and sizes. This is typically done using specialized tools such as hot wire cutters or foam cutting saws. The hot wire cutter uses an electrically heated wire to melt the foam, while the foam cutting saw uses a rotating blade to cut the foam. Styrofoam cutting is commonly used in a variety of applications, such as crafting, modeling, and packaging. It can be used to create complex shapes and intricate designs, and is a popular material for use in a variety of artistic and creative projects.

Based on **Table 4**, styrofoam measurement dimensions are calculated based on the size contained in the software and the size obtained in the cutting results.

Table 4. Styrofoam Cutting and Measurement Result

Software Dimension (mm)	**Measurement Result (mm)**
MEKATRONIKA (517x57) MEKATRONIKA 07	 (520x60)
Bosowa Politechnic Logo (39x32)	 (35x40)

Software Dimension (mm)	**Measurement Result (mm)**
Bosowa Politechnic (170x108) 	 (140x100)
Happy Semhas (618x103) HAPPY SEMHAS	 (630x100)

3.4. X and Y Error Value Counting

Error value Data on the X and Y axes are taken based on the dimensions and measurement results of styrofoam. The existence of the error value is influenced by the presence of melt in the styrofoam cutting process which resulted in a difference in dimensions both on the X axis and on the Y axis, where the difference in dimensions produces a percentage of the error value as shown in **Table 5**.

Table 5. Counting Error Values of X Axis

Software Dimension (mm)	**Measurement Results (mm)**	***Error* (Software Dimension-Measurement Results)**	***Error (%)* (Error/ X Software Dimension 100%)**
517	520	3	0,5
39	35	4	0,10
170	140	30	0,17
618	630	12	0,019
450	470	20	0,04
Average			0,16 %

Based on Table 5, obtained x-axis accuracy = 100% - 0,16% = 99,84%. In **Table 6**, obtained Y-axis accuracy = 100% - 0,09% = 99,91%. Error values on the X and Y axes indicate that there is a percentage difference in value between the design in the software and the measurement directly. With an accuracy value for the X axis of 99.84% and Y axis accuracy value of 99.91%.

the x-axis and y-axis accuracy of the machine are quite high, with values of 99.84% and 99.91% respectively. This indicates that the machine is capable of producing cuts with a high level of precision and accuracy, with a small percentage difference between the designed shapes in the software and the actual measurements taken. The high accuracy values of the x and y axes are likely due to the use of a CNC (Computer Numerical Control) system, which allows for precise and automated control of the cutting process. Overall, the results indicate that the machine is capable of producing high-quality cuts with a high level of precision and accuracy.

Table 6. Counting Error Values of Y Axis

Software Dimension (mm)	Measurement Results (mm)	*Error* (Software Dimension-Measurement Results)	*Error (%)* (Error/ X Software Dimension 100%)
57	60	3	0,05%
32	40	8	0,25%
108	100	8	0,07%
103	100	3	0,02%
80	85	5	0,06%
Average			0,09%

The analysis of the data suggests that there is a small difference between the dimensions of the shapes designed in the software and the actual measurements taken. The error values indicate that the measured shapes are slightly larger than the designed shapes, with an average error of 0.09%. This indicates that there is some degree of imprecision in the cutting process, although the small error values suggest that the overall accuracy is still quite high. The error percentages are relatively small, with the largest being 0.25%, indicating that the machine is capable of producing shapes with a high level of accuracy and precision. Overall, the results suggest that the machine is capable of producing high-quality cuts with a high level of precision and accuracy.

4. CONCLUSION

In the manufacture of this machine, experimental methods are used, namely the process of moving the X and Y axes, the G-Code delivery process is used, then the code will be processed in software and then produce output in the form of axis movement for hot wire whose heat has been regulated based on the right voltage and current.

Based on the design, manufacture and testing of the entire system in the manufacture of this machine has been designed and built styrofoam cutting machine based on CNC 2 axis using hot wire with an accuracy of X axis 99.84% and Y axis 99.91%, the percentage of dimensional differences in the software and measurements are directly influenced by the melt due to the process of cutting by hot wire. However, there are some limitations related to the machine that has been made, namely the hot wire type of nikelin with a size of 0.3 mm which is only able to use a maximum voltage of 12 volts. If a larger current is used, it can cause the hot wire to smolder. In addition, related to the dimensions of the styrofoam media used, it can only be 88 cm long and 42 cm high with a maximum thickness of 15 cm. Therefore, for further development, this machine must use a thicker type of hot wire and the dimensions of the working area are also larger.

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