ARDUINO CNC HOT WIRE CUTTER

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Abstract- **Wedding decorations are considered incomplete without decoration. The decoration business must prepare a skilled and creative workforce and improve the artistic creation skills of employees to provide several choices of decorating styles to clients. The material that was recently used in decorations is styrofoam. The purpose of this research is to design a CNC machine to get good results and neatly cut Styrofoam using a hot wire. This research also contributes to solving problems with Styrofoam cutting usually a problem with detailed and complicated work that can be solved automatically using a CNC machine. Tool hardware design requires Bluetooth connection, driver to the stepper motor, driver A4988 to CNC shield, and step down to the heating wire. Software design includes uploading GRBL firmware, creating G-code using Inkscape Software, and connecting Android applications to CNC machines. The result shows that for 2-dimensional styrofoam cutting with 1cm thickness, the best results are obtained in the range voltage of 7.4-8.5V. Styrofoam also testing is carried out using the same voltage 8.5V but with different feed rates and the result with 400 mm/min shows the best cut performance. The results of cutting 3-dimensional Styrofoam showed that for a voltage of 8.5V, a feed rate of 300mm/min, and a thickness of 10cm Styrofoam produced the best cutting texture from others. This shows that the heat generated by the wire is directly proportional to the feed rate.**

Keywords: **Arduino Uno, CNC, Cutting Foam, Hotwire, G-code.**

1. INTRODUCTION

Wedding decorations are considered incomplete without decoration. Apart from aesthetic reasons, such as decoration making the venue more pleasing to the eye, making the event livelier, and making photo documentation more beautiful. The decoration is also sometimes a matter of image, and it causes people to be willing to spend very deeply on the cost of this decoration.
The wedding decoration business must prepare a skilled and creative workforce and continuously improve the artistic creation skills of employees and decorators to provide clients with several choices of decorating styles. For example, bringing up decorations from cork or styrofoam is indeed popular, even though many people are looking for it in various digital media. Now styrofoam can be formed easily so that decorations can be made as desired, including for the aisle.

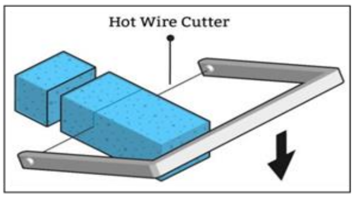


Fig. Isometric view mechanical design

For beginners, it may be difficult to cut Styrofoam. It looks simply, but it takes a careful technique in cutting Styrofoam. In addition to cutting styrofoam, there are several tools that you can use. To get good and neat results, you can cut Styrofoam using a hot wire. The working system of this tool is to melt Styrofoam with a heated wire to produce a smooth cutting edge. Detailed and complex work can be done automatically using CNC easily and in large quantities and with exactly t results efficiently and widely used in different categories .
A CNC Hot Wire Cutting Foam machine is used to cut and form a 3D foam with a predetermined shape without the need for hard tools and lasers. The type of cutting used in the machine is called Hot Wire, or a special type of cutting wire (Nickel-Chromium Wire), The wire will be hot when an electric current is applied . Nickel-Chromium wire evaporates and melts the foam when an electric current passes through it, so users can easily get any shape they want and are more cost-effective.
The proposed system that we used to cut styrofoam is by using a CNC machine that is rarely used in decoration. The most common literature is using CNC machine to make a PCB layout, laser engraving, a 3D print, and many other applications. The problem that is usually found in decoration by manual hot wire is human error that causes the

decoration isn’t neatly perfect and hard to reach certain corners. To solve the problem, this research aims to design a CNC machine to get good results and neatly cut Styrofoam using a hot wire.

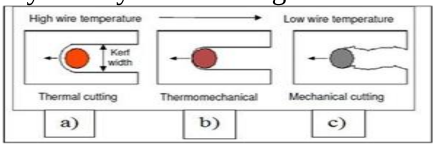


Fig. Cutting Mechanism

Development in the past Decade due its wide range of applications in Defense, surveying, surveillance, photography, agriculture, disaster management, etc. Aeromodelling is one of the popular hobbies among all age groups across the world. This rapid development of RC aircraft happened due to the miniaturization of radio electronics, power systems, high power industry in India aeromodeller and UAV Designer need automated machines to cut this foam accurately precisely with no error also which will give them more time for iterating their design & get optimum results. This research aims to design & develop foam cutting Hobby aircraft Remotely piloted Aircraft and Unmanned Aircraft's vehicle has undergone significant r density batteries, and motors along with the availability of strong & lightweight & easy to use Foam polymers like EPS, EPP, XPS, polystyrene. Many aircraft models are made with these foams to achieve intricate shape for advanced Aerodynamics, stability, and performance. Manufacturers use foam molding processes. This is cost-effective for mass production. Hobbyists prefer to use hand tools or hand-hot wire cutters etc. for cutting these different shapes out of foam. Mostly in this emerging UAV and aeromodelling machines for the rapid prototyping of foam wing & other foam shapes.

A. Overview Of research work

To reduce cutting time and increase its efficiency for current use in UAV industries, we had done a literature review, then we studied different mechanisms. We took references from various research papers. We designed our project through CAD modeling and using AutoCAD FUSION 360. After that, we did fabrications and assembling. We tested our models by cutting different foams to reduce errors and overcome their earlier limitations. We also reduced the overall cost so that smallscale manufacturing industries can also afford it. Manufacturers use foam molding processes. This process is suitable for mass production, to produce many identical parts, like fuselage or wings (in the case of RC models). 1. Hobbyists that prefer to make their models at home with hand tools are usually limited to much simpler shapes that are obtained via bending plain Styrofoam sheets around multiple cross-sectional elements. 2. Another method adopted is the layered object manufacturing (LOM) technique used for rapid manufacturing. They build their models from thick (approximately 30-100 mm) layers of XPS that were cut with the hot wire and glued together to form the intended object. Hotwire (heated with an electric current) must follow precisely contours of cross-sections which are achieved with templates glued on both sides of each layer; it needs skill and labor to achieve the desired result. The momentum research is an endeavor to fabricate a framework that can serve comparable requirements (yet not restricted to) of flying airplane modelers. 3. A member of RC Groups forum has made a numerically controlled hot wire cutter that uses diving Foam software for cutting long one-piece wings. Hans Seybold from Germany has made an NC hot wire cutter with 4 degrees of freedom. He used a unique mechanical layout where a bow with hot wire is positioned in space with 4 filaments of variable length controlled by 4 stepping motors. He likewise fostered a program to drive the bow along the ideal course which uses the plain content depiction of all directions of the shape. All information is available for free on the internet at Hot-wire cutter by Hans Seybold 4. Probably the most advanced technology is used in the Aero Tetris Company located in Russia. They use a 6 axis NC machine which allows achieving an accuracy of 0,09- 0,5 mm with wire inclination up to 165 degrees. During the cutting process speed and temperature are varied. The organization sells sets of Styrofoam parts for building huge models.

B. Formulation of the problem

This research aims to overcome existing problem & to implement new methods 1. To improve Precision & accuracy of foam cut using hot wire foam cutting 2. Try to use open-source programs for controlling CNC foam cutter 3. Try to make it cost-effective for hobbyist, designer 4. Use easily accessible parts a. Finding out the need of the project 1. To save time build time-prototyping for designer 2. To make machine using accessible parts 3. Easy to use machine based on open-source software 4. To help UAV designer to design aircraft design with less expensive material like foam b. Development of new prototype modal To overcome and meet the objectives of the project. We had designed the machine from scratch using CAD software. This design will include 3d printed parts for motor mounting, frames, smooth rod for providing structural rigidity, threaded rod & Stepper motor mechanism for linear movement of Cutting tool i.e. hot wire. This complete assembly will be controlled using Micro controller and Stepper Drivers on G-CODE command generated using open-source software like http://www.diyrcwings.com/ or wing g code generator software

WORKING PRINCIPLE

The working of foam sheet cutting machine is similar to reciprocating crank mechanism. In foam sheet cutting machine rotary motion is converted into linear motion. The rotary motion is given by stepper motor which is attached to lead screw. The lead screw gives rotary motion to nut fitted on it. The nut is connected to tool mounting plate. Slotted arrangement is made for 3 tools. Along with the motor rotation screw also rotates simultaneously. This rotary motion is given to the nut on lead screw. And the nut will slide on lead screw. This will give the linear motion to the tools. And hence the cutting operation is carried out

2.1 Cutting Criterias Of Hot wire Cut -

Foam Are Cut On Various Cutter Situations To Discover Suitable Cutter Situations And The Variety Properties Of Cutter In Convincing Criterias. The Cutter Criterias Is A Heat Wire Foam Cutter Is The Hot Wire Of Material With Its Measurement, Cutter Rate, Cutter Temperature Of The Kerf Width. Kerf Width On Hole In The Middle Of Foam Parts Where They Isolated Through Cuts. Cutter Situations Are Changed By Fluctuating The Pre Flexible Cutter Criteria; Cutter Temperature, Cutter Rate And Wire Are Measured.

Fundamentally It Has Two Kinds Of Hot Wire Foam Cutter Steps And A Heat Me-chanical Shearing Technique. In Heat Mechanical Shearing And The Hot Wire Contacts The Foam, Applying Power To Shear Away Foam Material. In A Warm Cutter, Hot Wire Doesn't Contact Foam Material, The Foam Disintegrates Because Of Heat And Forming The Cuts.

2.2 Foam Cutting Build

Fig. Foam Cutting Build.

The Analysis Set Utilized In Investigation Is Portrayed As Shown In (See Fig. 1). This Essen-tially Comprises A Nickel-Chromium Wire Tightness Instrument, The Feed Rate Control System With The Current Control Equipment. Foam Placed On A Stage With Feed Off Into Heat Wire At A Consistent Speed. Warming On Wire Is Done Through Current Which Is Provided Through Associating Both Hot Wires Ends Of An Electric Supply. Foam Built With 30% Of Material Is Made Up Of 3D Print.

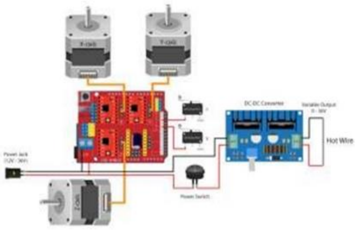


Fig. Working Diagram.

The Wire Tensioning System Consists Of A Nickel-Chromium Wire Tensioned Through Loads Dropped Toward The Single Side Of Wires. The Principle Loads Of 500g Are Utilized To Pressure The Wire Side. The Foam Taking Care Of Part Comprised Of A Square Thread Screw Of 6 Mm Pitch Has Combined With Stepper Motor Of Nema 23 Modal Is Driven Through An Embedded System By Arduino Mega Model 2560 Placed Pulse Width Modula-tion Signals Helped On A Stepper Motor Regulator 12-Volt Force Supply. Foam Parts Placed On Stage Are Associated With A Rotating Threaded Screw. Current Is Provided Wire Through Double Direct Current Supply. A Computerized Thermocouple Thermometer Was Utilized To Quantify The Temperature Of Wires. As Cutter Temperature Is Required To Estimated The Thermal Element, The Hub Is Placed At A Wire 5 Mm Off Cutter.The Stress On The Wire Is Dictated To The Quantity Of Grade Loads Utilized. Seat High Force Supply Is Utilized To Quantify, Manage A Current Inventory And Hot Wire. Feed Rate Is Calculated By The Step Counts On Motors And Screw Drives Pitch. Analysis Completed Utilizing Double Nickel-Chromium Wires On The Widths 0.6 Mm And 0.32 Mm. Common-ly, Wire Widths 0.2 Mm To 0.5 Mm Is Advantageous On Hot Wire Foam Cutters.

2.3 Foam Cutter Sample

The Analysis Was Utilizing Foam, From The Utilized In Art Work. The Density Of An Ex- ample Is 1.04 G/Cm3. Melting Point Is 239oc, Warm Conductivity Is 0.0334 W/ (M K).

2.4 Difference Of Temperature Through Current

At A Point When Current Is Tried On Wire And This Warms Up, It Goes On Steady Tem- perature Following The Specific Measure Of A Times. The Steady Temperature Is Estimated As Various Current Capacities. This Is Complete Before Removing Interaction To Discover A Current Worth Of Obtaining A Specific Temperature Value. That Examination Is Done Through Nickel-Chromium Wire With Diameter Across 0.6 Mm And 0.32 Mm. The Wire Is Frequently Accessible. The Diameter Of Wire Ranges 0.2 Mm To 0.5 Mm Are Advantageous To Hot Wire Foam Cutters. 0.6 Mm Distance Across Wire Would Stand With Higherpres- sures Than Reach To 0.32 Mm Wire Also, 0.6 Mm Wire Is Utilized For The Test Since Wire Listing Would Be Effortlessly Kept Away From With That[10].

Table1. Difference Between Wire Temperature And Current On 0.32 Mm.

Current In Amps	Wire Temperature In ^{0}C
0.5	41
1.0	86
1.4	172
2.0	253
2.2	251
2.4	351
2.6	332
2.8	372
3.0	425

Table 2. Difference Between Wire Temperature And Current On 0.6 Mm Wire.

Current In Amps	Wire Temperature In ^{0}C
0.5	28
1.0	45
1.5	65
2.0	98
2.5	125
2.6	137
2.8	148
3.0	158

METHOD

The method used in tool testing is used to obtain data on the results of system work and find out how the tool can work. Tool testing is done by creating a G-code format file on a PC and then transferring it to Android, the existing G-code on Android, and then inputting it into the GRBL Controller application [8]. When it works, the CNC will work according to the image code. The method used in system design begins with the design stage which is continued with the manufacture of the system until it is completed according to the plans made. System design begins with the stage of collecting equipment such as mini-PCs and monitors, and then installing the Arduino board and the CNC Shield port, for communication through the CNC we need to install the HC-05 port and set up Bluetooth. [9]– [11]. Search for sources of information in the form of books or journals in which related to Arduino and CNC Shield microcontrollers and their applications, then references from the internet in the form of explanatory videos related to materials such as CNC cutting styrofoam, Bluetooth settings related to the system to be worked on.

Fig. Research flow study

Figure 1 shows the research flow chart starting from the literature study, design, tool testing, data analysis, and the conclusion of the research. Literature sources can be in the form of a final project, thesis, and journal. Data obtained could be in the form of results reading tool measuring nor data from source literacy next processed to analyze and get a conclusion.

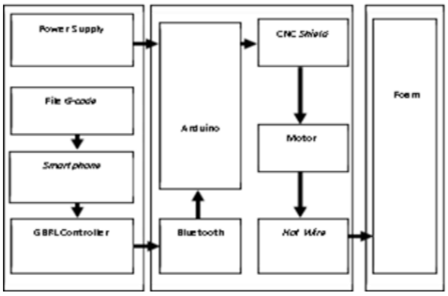


Fig. Block diagram

The design stages of CNC Hot Wire Cutting Foam start from the design of the block diagram as shown in Figure 2. The system used by Arduino Uno as the process is to control the stepper motor and Bluetooth connection [12], [13]. In designing a 3-axis CNC machine control system, several processes are shown in Figure 3. Arduino Uno and CNC Shield are turned on with a power supply, then to the input section the G-code file is transferred to Android, then with the help of the Android Controller GRBL application it can transfer it to Arduino via Bluetooth, after that Arduino processes commands and then transmits commands to CNC Shield, The CNC Shield shares these commands with the installed motor drivers. The G-code file is transferred to Android, and with the help of the Android Controller GRBL application, it can transfer to Arduino via Bluetooth [14], [15]. After that Arduino processes the command and then transmits the command to the CNC Shield, the CNC Shield divides the command to the installed motor driver, Then the driver runs and controls the stepper motor with a limit switch as a movement limiter

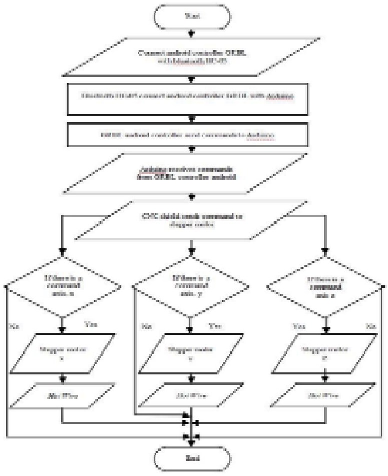


Fig. Flowchart

Process study inside it has several components and materials used. The material used is styrofoam and the main components used in this study include step-down XL4016, Hotwire, Driver A4988, Stepper motor, Arduino, and Power supply 12V 10A. An isometric view of the mechanical design of a hot wire CNC machine is shown in Figure 4.

Figure 4. Isometric view mechanical design

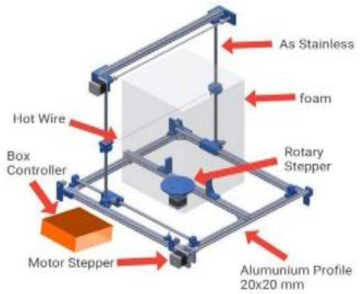


Fig. Isometric view mechanical design

2. CONSTRUCTION

Drawing of the model to get an idea of materials required and positioning of the material used. The basic structure was prepared by traditional method using drafter and scale. Then pasted and cute accordingly as the designed.

Materials &Tools

This project was made with things I had lying around. I used a Step-Down transformer to avoid overheating the nichrome wire. A setup is also installed for ArduinoUno and stepper motor driver for movement of workpiece.

Material required are listed below

1. Birch plywood (560 mm x 720mm).
2. Screws (roughly 22x4 mm)
3. 1 Eye bolts M6 or 1/4 inch
4. 2 Carriage bolts M6x40 mm or 1/4 inch
5. M6 nuts and washers or 1/4 inch
6. 2 knobs M6 or 1/4 inch
7. Nichrome wire (I used 0.5 mm, 30 cm)
8. Bronze bushing (optional 6 mm ID) or 1/4 inch
9. Large washer M12
10. Wire
11. Sliding pair
12. Belt drive
13. Carriage for workpiece (260mm x260mm)
14. Step Down Transformer (230 to 12 volts)
15. Nema-17 stepper motor
16. Wheat-stone bridge
17. ArduinoUno and its module
18. Codes forArduinoUno
19. 220VAC -24VDC power supply
20. Desktop with Inkscape and universal-code sender installed ON/OFF SWITCH
21. Essential tool for cutting and fitting of machine.
22.

II. PROCEDURE OF INSTALLING

Assembly of machine: -At first will mark the points of installation for where the drilling is to be done. After the drilling holes using drill machine clean and rim the holes for the attachment of slider pair and stepper motor with the baseboard. Now fix the heater wire stand and its power circuit which include wheat-stone bridge connected to hot wire and a stepdown transformer of 230VAC to 24VDC.

Installation of Arduino Uno: -Arduino Uno is installed on the corner of board so that is usability and distance from other instruments will be maintained. Arduino Uno is programmed with 2-axis control program via desktop using Arduino IDE software. Output of Arduino Uno is given to stepper motors via connection cables. Universal G-code sender (UGS) is asoftware which allow us to establish connection in controller and machine. Also, we can control the machine via controller because of UGS software.

DESIGN OF FOAM CUTTER

Mechanical Cad Design The Designing Is One Of The Most Important Phases Of The Production, Wherein Many Adjustments Are Made To Produce A Design And Its Miles Selected As A Model. The CAD Designs Are Made By Using Solid Works Software.

Selection Of Components

Aluminium Profiles-In This Project We Have Used 20x20mm And 30x60mm Aluminium Profiles. These Dimensions Of The Profile Are In Standards. These Profiles Are Made Of High Strength Tempered Al Alloy 6063 - T5[1]. The 20x20 Profile Weighs Approximately 0.74 Kg Per Meter. The Diagonal Section Thickness Is 1.5 Mm

L-Clamp -These L-Clamps Are Durable And Versatile. They Are Made Up Of High-Quality Aluminium. The Dimensions Of The L-Clamp Are 30 X 30 Mm And Can Be Utilized For Locking The Aluminium Profile Of 30 X 30 Mm. These Are Straight Angle Corner Stands With Two 8.8 X 5.9 Mm Oval Holes (+/- 0.05% Accuracy).

Nema Stepper Motors -The Stepper Motors Used In This Project Are NEMA 17 (4.2 Kg-Cm Torque) And NEMA 23 (180 Kg-Cm Torque) Stepper Motors Respectively. In This Binder Jetting 3D Printer, We Have Used Two Planetary Geared NEMA 23 Stepper Motors. It Also Has A Step Angle Of 1.8°. The Number Of Phases In This Motor Is 2. The Rated Voltage Of This Motor Is 3.2V And The Rated Current Is 1.4A. The Resistance Per Phase Is 2 Ohm And The Inductance Per Phase Is 2.8mh. The Holding Torque Of This Stepper Motor Is 4.2 Kg-Cm. The Total Weight Of This Stepper Motor Is 300 Grams. The Width And The Length Are 42.3 And 24mm.

Stepper Motor Driver - In This Foam Cutting Machine, We Have Used Motor Drivers For The Dynamic Control NEMA 17 Stepper Motors. The Stepper Motor Driver Used Is A4988, It Is Used To Drive NEMA17 Stepper Motors. The Power Input Of This Motor Is Of Range 9 ~ 40 V DC. The Normal Output Current Is 3.5 A. The Peak Output Current Is 4A And The Micro Steps Are 1, 2/A, 2/B, 4, 8, 16, 32. The Stepper Drivers Are Used To Control Direction And Speed.

Hot Wire -The Foam Can Be Cut Using Different Cutting Situations. The Different Criteria For The Cutting Of Foam Are Dependent On The Nickel-Chromium Wire Material, Wire Dimensions, Wire Cutter Temperature, Wire Cutter Speed And The Kerf Width. Mostly Two Types Of Nickel-Chromium Wire Foam Cuttings Are Available Such As Heat Mechanical Shearing And Unique Heat Cutting Method. We Use Heat Mechanical Shearing. By Using Different Diameters Such As 0.6 And 0.32 The Temperature.

Arduino Uno -The Micro-Controller Used In Arduino Uno Is Atmega328p. The Working Voltage Is 5V. The Working Voltage Is Of Range 7-12V. It Has 14 Digital IP And OP (Out-put) Pins. It Has Six Analog Input Pins. It Uses A Primary Control Board To The Powder Levelling Motor. It Has A Memory Of 32 Kb. It Belongs To The AVR Family Controller. This Controller Has 14 Digital Input Output Pins Out Of Which 6 Provide Pulse Width Modulation Output. SRAM Of Arduino Was 2 KB And EEPROM Of 1 Kb. Arduino Uno Works With A Clock Speed Of 16 MHZ. It Has One USB Port And One Power Adapter Port. The Board Gets Power Through Both Ports .Using The USB Port Program Gets Uploaded

CNC Shield - Basically, A CNC Shield Controller Used To Control The 3-Axis Machine. The CNC Controller Has A Stepper Motor Driver Slot. It Consists Of One X Axis, One Y Axis, One Z Axis And One A Head Connection (Extruder)[5]. The CNC Shield Works On 12 V DC Supply. It Also Consists Of Reset Button, Driver Enable Pin, Set Xyz Drive Module Step And Direction Pins, A-Drive Module Step And Direction And Power Supply Pin. The CNC Shield Connects To The Arduino, Data Comes From The Arduino. Complete Control Of The Stepper Done Using This CNC Shield

Limit Switch - Limit Switch Is An Electromechanical Device. When It Gets Triggered By Any Physical Force It Switches. The Limit Switch Consists Of NC, NO, COM. In This Pro-ject The Limit Switches Are Used To Limit The Movement Of The Axis And Also Used For Homing. The Limit Switch Is Connected With A CNC Shield. When The Motor Runs And The Axis Once Presses The Limit Switch, The Circuit Becomes Open, The Motor Stops.

Dc-Dc Converter -DC To DC Converter Isan Electromechanical Device The Converts One Voltage(V) Level Input Of Direct Current (DC) Of Another Voltage Level Of Direct Current. There Are Two Types Of DC-To-DC Converter Are Isolated And Non-Isolated Types. Non-Isolated Types DC To DC Converter Is Consists Of One Coil, Capacity Coupling, SEPIC And Zeta. Isolated Types DC To DC Converter Consists Of Transformer Coupling Type, Forward Transformer Type, FLY-Back Transformer Type. DC To DC Converter Is Connect-ed With Hot Wire. The Input Voltage Of Converter In This Project 12 V.

Smps Power Supply -The Entire Power Supply For This Foam Cutting Machine Is Given By SMPS Power Supply 24V 20A. It Rectifies The AC Voltage To DC Voltage And Provides A Constant Power Supply. It Also Includes A Wired Power Switch. A Power Cable Is Included.

Timing Belt - The Material With The Bet Neoprene Rubber With Fiberglass Core. The Core Wire Material Of This Timing Belt Is Glass Fiber. The Itch Of This Is 2mm. The Width Of The Belt Is 6mm. The Total Length Of This Belt 10m. The Shape Of This Timing Belt Is An Open Loop

3. DESIGN AND ANALYSIS

Table 1 Dimensions of parts

Part	**Material**	**Dimensions(mm)**
BasePlate	MildSteel	1720*310*10

LeadScrew	EN8	Ø 25, Pitch5havingdoublestart
LeadScrewNut	EN8	Ø 50
Railsupport	ChromiumplatedSteel	Ø25
NutPlate	MildSteel	2*Ø5
Slider	MildSteel	200*120*5
Bush	Aluminium	Ø5
ToolPlate	MildSteel	100*55*5
Tool	Ironcarbide	Ø5
MotorPlate	MildSteel	205*150*5
Washer	Mildsteel	Ø5,Ø 12
Key	MildSteel	4*4*35

Analytical Formulation

When the wire enters the foam block it is straight. But the high heat energy melts the EPS in direct contact with the wire. Thereafter the wire is in contact with this semi-melt only. As the wire starts to advance against the melt, it starts experiencing a drag force which is assumed to be constant per unit length of wire as the temperature of the wire is constant throughout the wire. After some transition time, dynamic equilibrium is attained and a bow shape trajectory of wire is generated. In this steady state condition, the free-body of the wire.

Force Analysis

From literature it can be found that some researchers [9] have used load cells to measure the force experienced by the hot wire during cutting of EPS. Further they formulated an empirical relation by data fitting of experimental results using linear regression. The erstwhile force model depends on the effective heat (Qef f). Effective heat is a function of effective length (le), current and feed rate. The empirical force relation is given by,The present analytical model is used to predict the drag force that the wire experiences during the straight cut of EPS by fitting the experimentally found bow shape and tension to the analytical expression of bow shape The present analysis agrees with the erstwhile empirical model for no/low bowing conditons - for instance at feeds less than 350 mm/min and 1.5 A. However, in the present study, the absolute forces were found to be much higher than those of the earlier researchers in low current and high feed situations as shown in Figure 16. This could be due to: • The present analytical model explicitly accounts for bowing while the erstwhile empirical model does not account for bowing. • Since le is much larger in the current study, the cut surface area is also much larger resulting in significantly more heat loss. This results in a reduction of the effective heat generation from the nominal I2R value, and hence an increased force is expected in the present case. • Roller support: Springs were used in the present experiment instead of pneumatic cylinders in the erstwhile work as roller supports. Springs allow more flexibility, resulting in higher bowing of the wire. While pneumatic cylinders as roller support tend to snap off the wire at greater force values. • Workpiece size: The erstwhile model was formulated by working with small workpieces (30 mm - 50 mm) while the present analysis has been made on large scale prototypes (700 mm). The present model predicts force per unit length and the absolute forces could be impacted by a size effect.

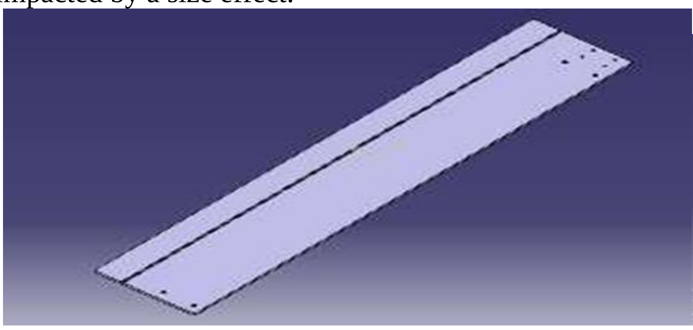


Fig. 1 Base Plate

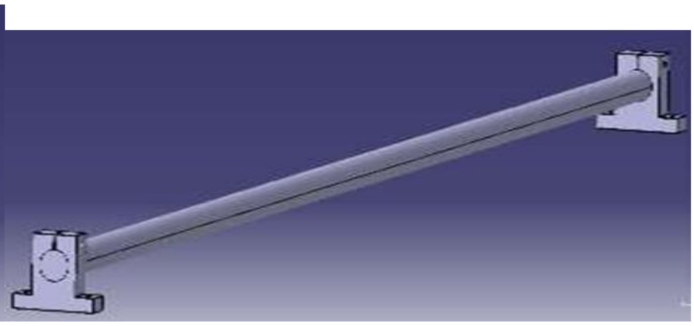


Fig. 2 Rail Support

Figure 1 shows base plate made up of Cast iron which is 10 mm thick and holds all the machine parts on it. It contains a slot for cutting tool movement. Figure 2 shows Rail support arrangement which is used for slider. It consists of chromium plated rod which is non-corrosive and is bolted to base plate. The rail support assembly is mounted on base plate.

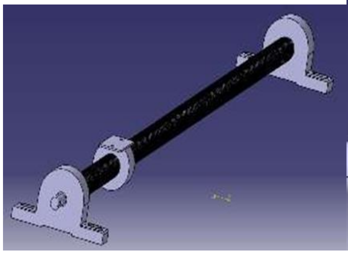


Fig. 3Leadscrew assembly

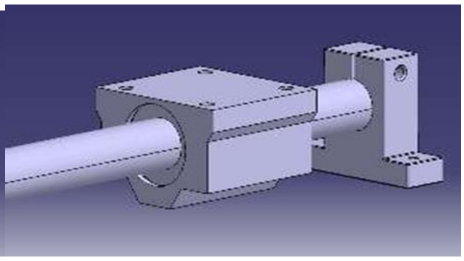


Fig. 4LM Guide

Figure 3 showslead screw assembly consist of leadscrew and nut, which is fitted in bearing housings used to transmit motor power to tool through slider.Figure 4 showsslider and rail support arrangement for mounting. Leadscrew arrangement and LM Guide arrangement is connected through slider which is bolted to nut welded plate and slider on LM Guide.

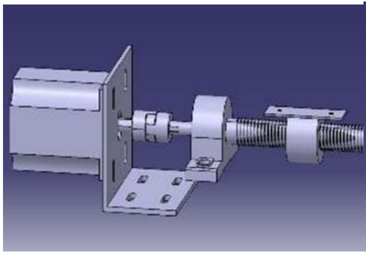


Fig. 5 Motor mounting

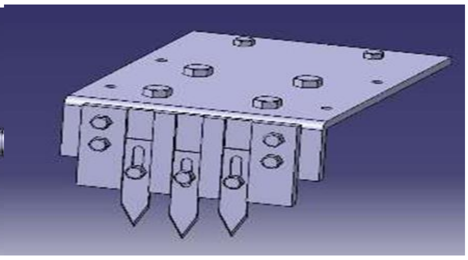


Fig. 6 Tool Mounting

Figure 5 shows the motor mounting which contains motor is supported with motor mounting plate which is bolted to base plate. And motor shaft is coupled to the lead screw through flexible coupling. Figure 6 shows a Tool mounting arrangement for 3 tools on tool mounting plate. And this plate is bolted to the slider. Tool mounting is bolted to the slider which is connected to nut welded plate.

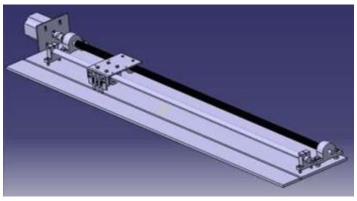


Fig. 7Final Assembly

EXPERIMENTAL SETUP

. **Hot-wire CNC machine** A CNC controlled hot wire machine with Nichrome (NiCr) wire as the heating element was used to cut EPS foam in the desired shape. The machine consists of a rigid frame of Aluminium extrusions. A NiCr wire was attached on the vertical axis mount plates which were fixed to the timer belt on vertical columns with the help of springs that act as roller supports. Figure 3 shows the actual experimental set up that was used for quantifying bowing. A computer using MultiCNC software converted CAD files (in .dxf format) to G codes for the microcontroller. The microcontroller, through stepper motor and drives, moves the wire using linear motion guides through the timer belt-pulley mechanism. A twoaxis configuration was used to analyse bowing during straight cutting of EPS foam by hot wire. In this configuration, the motors on the left and the right were synchronized for motion along the X-direction

Work material

A low density (16 kg/m3) EPS block was used for all the experiments. A NiCr wire of length 800 mm and diameter 0.32 mm (28 gauge) was used as the hot cutting element. Straight cuts of rectangular prismatic EPS blocks were carried out along the positive Xdirection. The bowing was recorded for 50 mm, 100 mm and 150 mm of travel distance. It was observed that around 150 mm the wire attained a steady state of bowing. Hence, a block size 700 mm width (along Zdirection), 200 mm in height (along Y-direction) and 150 mm length (along wire feed, X direction) was selected for carrying out the experiments.

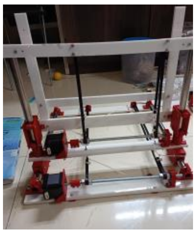
Properties

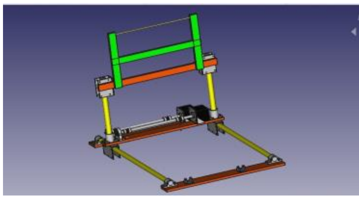
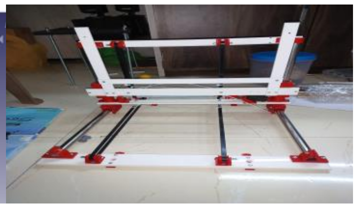
of EPS To build an understanding of the bowing phenomenon it is important to understand the behavior of foam at high temperature. Hence, Differential Scanning Calorimetry (DSC) and Thermogravimetric analysis (TGA) were performed for the EPS sample. The material properties were examined and compared with literature.

Properties of Nichrome

At high temperature, the knowledge of wire temperature becomes important. This parameter controls the thermal field in the foam cutting region. The wire temperature was recorded using a K type thermocouple (range 0-1200◦C) for various currents levels. The measured temperature of wire in air is different from what is likely to be the actual temperature of the wire in the cutting region for the same current. However, it can be argued that given that the wire is thin (φ 0.32 mm) and the thermal conductivity of EPS is low (approximately 0.03 Wm−1K−1), the difference is probably not significant. Figure 6 shows the temperature vs current plot for the present experimental set up. The measured temperatures as well the expected temperatures as provided by the supplier of the NiCr wire.

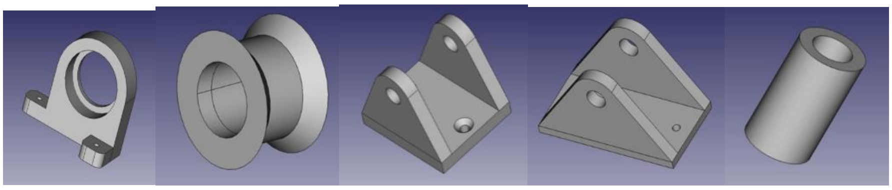
4. MATERIAL



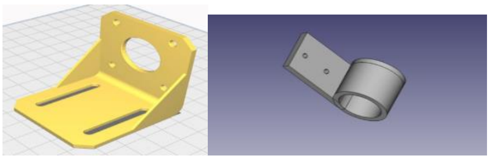





Stepper Motor Driver 12V DC Power Supply Nichrome Wire Arduino Uno CNC Shield



Bearing Mount Pulley Holder Idle Pulley Holder X Axis Idle Pulley Holder Spacer



NEMA17 Stepper Motor Mount Y axis Top Stopper

7.1 PRODUCT

7.2 DESIGN PARAMETERS

Design Goals:

1.Cutting Speed: The speed at which the cutting tool moves through the foam material. Balancing speed with precision is essential to avoid excessive material deformation.

2. Cutting Accuracy: The degree of precision in cutting foam according to the digital design. Measured in terms of tolerances and alignment with the intended shape.

3.Foam Type Compatibility: The ability of the machine to handle various foam types, including rigid and flexible foams. Adjustments may be required for different foam densities and textures.

4. Tool Temperature Control: Maintaining the optimal temperature of the cutting tool. Ensuring clean and accurate cuts without melting or excessive deformation.

7.3 DESIGN CALCULATIONS:

1. Cutting Speed Calculation: Cutting speed is calculated based on the desired feed rate and the rotational speed of the cutting tool. It ensures efficient cutting without causing excessive foam deformation. Formula: Cutting Speed (mm/min) = Feed Rate (mm/min) / Tool Diameter (mm) x π

2. Cutting Accuracy Calculation: To achieve cutting accuracy, the resolution of the Arduino control system and the precision of the stepper motors are considered. The calculation ensures that the machine can accurately follow the design pattern. Formula: Cutting Accuracy (%) = (Steps per Revolution x Microstepping) / Total Steps x 100

3. Foam Type Compatibility Analysis: Compatibility with various foam types involves analyzing the machine's ability to adjust the cutting parameters, such as speed and temperature, based on the foam density and texture**.**

4. Tool Temperature Control Algorithm: The control algorithm calculates the required heating element temperature based on foam type and thickness, ensuring clean cuts without melting or deformation.

7.4 ADVANTAGES

1. Precision and Accuracy: The integration of Arduino control ensures precise and accurate foam cutting, resulting in consistent and high-quality products.

2. Cost-Effective Solution: Compared to proprietary CNC systems, our machine provides a cost-effective solution for businesses and hobbyists, reducing initial investment costs.

3. Customization Potential: The open-source nature of Arduino allows for customization and easy integration of additional features or upgrades to meet specific user requirements.

4. User-Friendly Interface: We have designed an intuitive user interface that simplifies the process of inputting designs and controlling the cutting operation, making it accessible to a wide range of users.

7.5 DISADVANTAGES

1. Initial Learning Curve: Users who are new to CNC technology may face a learning curve in understanding the machine's operation and programming, which can be time-consuming.

2. Maintenance Requirements: Like any precision machine, regular maintenance is required to ensure optimal performance and longevity. This includes cleaning, calibration, and occasional component replacement.

3. Complexity of Design: The integration of Arduino control and precision components can make the machine's initial design and construction more complex compared to simpler foam cutting methods.

4. Limited Cutting Capacity: While versatile, the machine's cutting capacity may be limited in terms of the size and thickness of foam it can handle, depending on its design and

7.6 APPLICATIONS

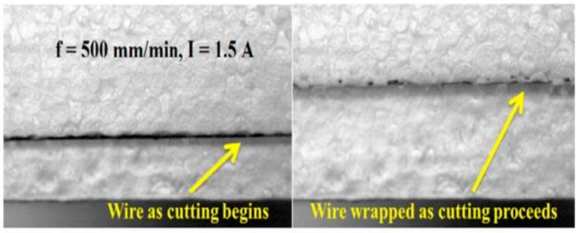
1. Packaging Industry: In the packaging industry, our machine can be used to create custom foam inserts for product packaging, ensuring the safe transport and storage of delicate items.

2.Construction and Insulation: It is valuable in construction for shaping foam insulation materials precisely, enhancing energy efficiency in buildings.

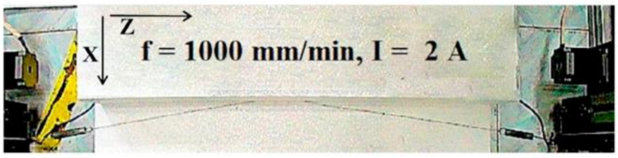
3.Art and Design: Artists and designers can employ the machine to craft intricate foam sculptures and prototypes, unleashing their creative potential.

RESULTS

Bowing of the hot wire We infer that bowing is experienced by the wire when there is 'physical' contact between the wire and the foam. As the foam touches the wire - which is moving at a greater feed than the ablation rate and is at very high temperature - it starts degrading. This degradation process was inferred from the TGA and DSC results along with the observations under high speed camera (Photron FastCam Mini ux100) at 1000 fps as shown in Figure 8. Here, it was seen that the cells lose its boundary and wrap the wire beyond the glass transition temperature (105 ◦C - 160 ◦C) and with the temperature being further raised, the EPS starts becoming viscous and molten beyond its melting point (161 ◦C). At higher temperature, volatilization starts (248◦C) and finally ablates releasing gases (370 ◦C - 400 ◦C).



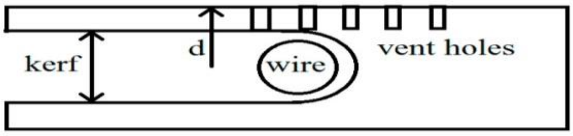
The bowing of the wire at very high feed and low current was prominent enough to be easily visible to the naked eye just before the wire completely exits the EPS block as shown in the Figure



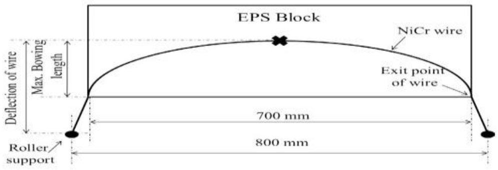
The wire profile generated from the experimental data is shown in Figure 10 and Figure 11. Bowing was quantified and plotted as a quadratic fit at 95% significance level. At a current of 1.5 A (Figure 10), bowing is noticeable even at a feed rate of 500 mm/min with 1000 mm/min producing very large bowing effect compared to that at wire current of 2 A At a current of 2 A, feed rates of 250 mm/min and 500 mm/min (Figure 11) result in hardly any bowing. However, at a feed rate of 1000 mm/min, significant bowing can be seen.

Bowing Regime

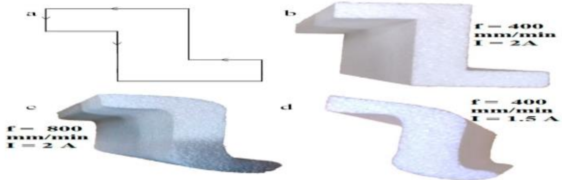
To create a predictor of whether bowing will occur or not, a graph was formulated using the experimental data as shown in Figure 12 at various feed rates and currents. The 'crosses' represent 'no bowing' and 'diamonds' represent observable 'bowing'. Regression was carried to check the contribution of each of the dependent variables in formation of bow. It was seen the contribution of current is dominant and effect of feed is somewhat lower. Increasing the model complexity by introducing square terms in fact reduces the F value and thus were not included. In practical cutting applications bowing of the wire is unavoidable. Bowing has no severe effect while producing straight cuts in EPS. But while producing



simple shapes such as shown in Figure 13 (a), errors in form are observed. The step shape was cut at various feeds and currents for validating the bowing regime. Due to the bowing of the wire in transverse direction, when the wire has to shift its motion from transverse direction (along X axis) and move along Y- direction, a curved step is generated instead of a sharp edge. This was because, as the wire traverses and the bowing of the wire begins, the central part of the wire lags behind. This laggard part of the wire is unable to make a straight turn as the direction changes sharply



shows how the step profile looked like when the cutting parameters were chosen from the 'no bowing' regime i.e. at 400 mm/min and 2 A (point b in Figure 12). When the parameters were chosen from 'Bowing' regime i.e. at higher feed (800 mm/min) and the current constant (2 A) (point c in Figure 12), curved edges would be produced as shown in Figure 13 (c). Also when the current was reduced (1.5 A) at a constant feed rate (400 mm/min) (point d in Figure 12), Figure 13 (d) shows how the step was be produced. Here, the difference in curvature that is produced as the feed is increased and the current is decreased can be easily noticed. The curvature in Figure 13 (d) is significantly more as compared to Figure 13 (c). This proves that the effect of current in bowing is more prominent, providing validation to the regression analysis. Hence it is advisable for a process planner to choose the parameters from the 'No bowing' regime for building a more precise prototype at minimum build time.



DISCUSSION:

Ahn et. al. [4] has discussed that a minimum gap of 0.28 mm must be maintained between the foam and the wire to restrict the wire from entering the melt zone of EPS prematurely. But as the feed rate is increased the wire travels towards the foam faster than the rate at which it ablates. Hence, the hot wire interacts with the molten foam and as the temperature rises due to prolonged contact, volatilization of the polystyrene occurs releasing gaseous by-products. These gases evolving from the degradation of foam remain trapped between the wire and molten foam. The gases from the edges of the foam have a scope to effuse through the sides of the block (at z=0 and z=700 mm). But the gases trapped in the center along with the molten layer of foam contributes to further reduction of the wire temperature and slowing down of the cutting process. These gases and the molten EPS combine to provide a resistance to the motion of wire. All these factors contribute in bowing of the wire. Simply put, bowing can be avoided with low feed and high current. But at these conditions kerfwidth is another factor which becomes predominant. So as we move towards ideal cutting conditions the area of influence of the cut increases which affects the precision of the final product. Intricate features cannot be produced when the kerfwidth of EPS is high. Hence, the kerfwidth was experimentally found as suggested by [11]. At a feed rate of 250 mm/min Figure 14 shows the variation of kerfwidth with current. Thus conflicting requirements must be balanced based on the demands of specific workpiece shapes.

CONCLUSION

The paper discusses a novel problem faced by the hot wire industry. The present work makes the following contributions

• The bowing of the wire is an unfavourable phenomenon present in all practical cutting situations. The present work has reported a quantification of this phenomenon.

• The role of different operating parameters on bowing has been reported. It is seen that increased current has a dominant effect in reducing bowing. Lower feeds also reduce bowing somewhat. But increased currents also increase kerfwidth and limit the shapes attainable in practice.

• A bowing regime is presented for selecting mitigating operating conditions

• A analytical-experimental method has been developed to find the exact catenary shape of the bow.

• A force analysis has been presented which will be helpful in predicting the life of the hot wire. High bowing results in higher forces in the wire and hence reduces the tool life. If the wire experiences high forces for a long time, it will tend to snap off resulting in a short service life.

• A novel analysis was made on the impact of gases on bowing. Presence of vent holes was found to significantly reduce the degree of bow. A 13% reduction in bowing with small holes and 19% with larger holes was observed.

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