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AUTOMATIC PROFILE CUTTING MACHINE

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ABSTRACT

For the past years, Automatic profile cutting machines became widely in-demand technologies in almost modern manufacturing industry setup unlike before where these machines were only applied in the automobile and aviation industries.

At present, Automatic profile cutting machines are continually and increasingly upgrading in terms of process speed, precision, efficiency and specific application.

One good example of a specific application is metal plate cutting. Therefore, this project is about making a low cost, flexible and user-friendly Automatic profile-cutting machine.

I. INTRODUCTION

The intent of the project is to design the entire system with minimum cost, providing high precision, long life span, and high machining speeds. It will further utilize a single software front end that can handle multiple file types.

The system will be divided into mechanical subsystems, electrical subsystems, and the software subsystem, each of which has several design options available to achieve the task.

The mechanical subsystems will consist of the frame, the guide, leadscrew, and the gantry. In which gantry which serve as a Y-axis moves on the frame using the movement of leadscrew.

The electrical subsystems consist of stepper motor, which used to runs the leadscrew. The drivers control the speed of the stepper motor.

The software subsystem consist of the Arduino board, which can be dumped by programs as required using Arduino software.

A more in-depth description will be provided for each subsystems later in the proposal.

II. NUMERICAL CONTROL

Numerical control (NC) is the automation of machine tools that are operated by abstractly programmed commands encoded on a storage medium, as opposed to controlled manually via hand wheels or levers, or mechanically automated via cams alone. In modern CNC systems, end-to-end component design is highly automated using computer-aided design (CAD) and computer-aided manufacturing (CAM) programs. The programs produce a computer file that is interpreted to extract the commands needed to operate a particular machine via a postprocessor, and then loaded into the CNC machines for production.

NC, and later CNC, allowed for tremendous increases in productivity for machine tools because the machines could be run automatically without requiring constant attention from their operator.

III. DESIGN BASIS

Mechanical

The mechanical system is composed of the frame section, the drive section, and the guide system. This section will provide a detailed description of each of these.

Drive

The drive mechanics of CNC machines convert torque provided by the electric motors into linear motion of the tool head. Screws with threaded nuts provide a simple and compact way to transmit this power. A ball screw and a ball nut system will be used because of its low friction and high efficiency. ACME screws will not be used because neither of their advantages, a larger weight supporting capacity and the simplicity of self- locking, have application for this machine. Instead, the ability to reduce the required torque needed to produce the specified linear speeds, due to the fact that ball screws operate with a superior efficiency, make ball screws the obvious choice for all three axes. In addition, the lack of heat generation caused by friction and an increased reliability support the decision to implement ball screws and ball nuts as the means of power transmission.

Guide

The guide rails support the weight of the gantry and tool head, while providing the alignment during the movement of the gantry. The linear supported rails will be case hardened steel shafts with ball bushings. However, a more complex shaft or support rail may be required if the weight and loads on the gantry create deflections above the specified tolerances of the machine.

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Frame

CNC frame materials need to have some strength in order to support the weight of the gantry and the cutting head as well as withstand forces resulting from the milling process. Stiffness is also required to prevent any deflections due to both static forces and dynamic forces resulting from the acceleration of the tool head. Weight is important because the mass of the frame contributes to both the static and acceleration forces. The best frame material would accomplish all three, offer excellent machinability, and be available at a low cost.

From the review of the materials, it was decided that aluminum offered the best combination of these five selection factors.

The machine frame is divided into the gantry sides and the base table.

Gantry Sides

The gantry sides support the weight of the upper gantry and the head while traveling on the lower guide rails. Aluminum will be used to create the gantry sides, because, as mentioned, the gantry must be lightweight to reduce inertia forces during acceleration.

Base Table

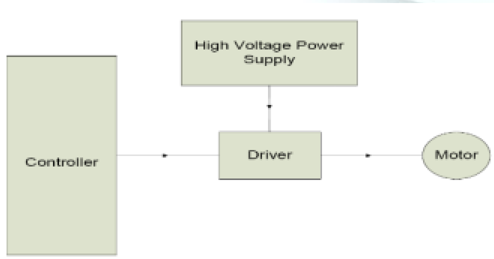
The base table will support the material to be worked on, and act as the base of the machine. Constructing the base table will require a large amount of material and involve a great deal of machining and assembly. Because aluminum can be easily machined, it will be used for the base. In this application, the strength and stiffness qualities of aluminum will be tested. The weight supported by the lower guide rails, the rails that allow the machine to move along the length of the table, might create excessive deflections in the sides of the base table. This could cause a displacement of the tool head that exceeds the design tolerances. It is believed that aluminum will be able to withstand these forces and maintain tolerances.

Electrical

This section provides a detailed description of the primary electrical system: power drive electronics.

Drive Electronics

The drive electronics system, shown in Figure, provides the interface from the motion controller to the physical motors.



Drive System Block Diagram

Motor

The type of motor used in the design of a CNC is important to reducing the overall cost of the machine. By selecting the stepper motor, over the servomotor, the cost of the motor and drive electronics will be significantly reduced.

The motor will provide high torque at lower speeds and the reduced torque level at higher speeds can be overcome by overdriving the motor.

Open loop configuration is proposed because of the position accuracy and repeatability inherent to all stepper motors. This leads to a reduction in the complexity of the driver electronics.

Driver

The driver will provide the required amount of current to the motor. The chopper driver will be used because it improves the high-speed performance of the motor. By overdriving the motor, the toque at higher speeds will be increased.

The driver will receive two main control signals from the controller: step and direction. Design Calculation

IV. COMPONENTS

Z-axis

The z-axis allows vertical motion of the tool head. The total travel of the vertical axis on this machine is 35 cm. An assembly of the z-axis is shown Figure. The following components are included:

Z-axis Ball screw: A 20 mm ball screw was used and shaft steps were machined to allow for ball bearing supports.

Z-axis Ball Nut Flange (Z Housing): This part attaches the Z-axis ball nut to the router support

Z-top (Top (Z-axis Support)): This part allows the support of the z-axis motor through the Z motor mount, and the ball bearing supporting the Z-axis ball screw.

Z-bottom (Bottom (Z axis Support)): The bottom of Z-axis allows for the mounting of the ball bearing and clearance of the end of the ball screw.

Z-sides (Side (Z-axis Support)): These parts provide additional strength to the z-top and z-bottom, which must withstand the thrust force of the ball screw.

Z-Back (Z-axis Support): The Z-back acts as the base component in the z-axis.

The z-top, z-bottom, and z-sides, all mount to this component. The z-back was also used to mount the z-axis to the Y-traveling block.

Z-mount (Router Support): This part connects the tool head, the linear bearings, and the ball screw.

Guides: These precision rails were used to guide the vertical travel of the tool head and were selected over other alternatives in order to reduce the height of the z-axis.

Y-axis

The Y-axis provides tool head motion across the worktable with a maximum travel of 45 cm. The assembled Y-axis, shown in Figure, includes the following components:

Y-axis Ball screw: A 20 mm ball screw was used to provide linear motion along the Y-axis.

Y-axis Ball Bearing Block (UCFL 203): This part holds the thrust bearings required to carry the linear force of the ball screw.

Y-axis Ballnut flange (Y Housing): This part connects the Y-axis ball nut to the Z-axis support and transmits the motion of the ball screw.

Y-Rails: These rails guide the precise linear motion of the Y-axis while supporting the weight of the z-axis and withstanding the force due to the cutting head.

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Y-Back (Gantry Back): This part holds the Y-rails, providing some strength.

This part is supported by two parts: the gantry sides

Base

This assembly provides the solid foundation for the CNC machine as well as support for the X-axis. The assembly, shown in Figure, includes the following components:

Table Ends (Table Front and Table Rear): The table has two end components to which the X-axis ball screw and the X-axis drive motor mount. One end, the table end-motor, supports the X stepper motor through the X motor mount, and the ball screw through a ball bearing (UCFL 203). The other table end supports another ball bearing (UCFL 203).

Table Sides: The table sides add strength to the table ends, which experience the thrust force of the ball screw. They also hold the support rails along which moves the X-axis.

Work Table: The worktable mounts across the table ends and provides 1.5 m of area on which to mount the part to be machined.

Table Supports: The table supports add strength to the base and prevent excessive deflection of the worktable

X-axis

The X-axis provides 45 cm of travel along the length of the worktable. This assembly is shown in Figure. The following components comprise the X-axis:

X-axis Ball screw: a 20 mm ball screw provides Linear motion.

X-axis Ballnut Flange (X Housing): This part connects the Ballnut of the X-axis ball screw to the gantry Bottom and transmits motion from the ball screw to the X-axis.

X-Rails: Supported guide rails were selected for the X-axis due to the weight that had to be supported and the length over which this load had to be supported.

X-axis Bearing Blocks: These use ball bearings to carry the load and to provide precise motion.

X-Cross (Gantry Bottom): The X-cross spans the width of the X-axis. The ball screw flange connects to the center of the X-cross, transmitting motion of the Ballnut to the X gantry.

X-axis Vertical Gantry Sides: The vertical gantry sides act as the ends of the Y- axis at the top. The Y-axis ball screw and Y-back (Gantry Back) all mount between the vertical gantry sides at the top. These parts also hold two ball bearings (UCFL 203) through which rotates the Y-axis ball screw.

V. CALCULATION

DESIGN OF FRAME

For steel (from PSG DB pg. 1.9)

σ_{ut} = 670 N/mm^2

σ_{yt} = 360 N/mm^2

Bending stress

σ_b = σ_{yt} / FOS

σ_b = 360 / 3

σ_b = 120 N/mm^2

Checking for bending failure

P = mass of moving part × 9.81

P = (10 × 9.81) + 500

P = 598.1 N

Z = $(bh^3 - b_1h_1^3) / 6h$

Z = $[(550 \times 550^3)-(450\times450^3)]/ (6\times550)$

Z = 153.03×10^5 mm^3

M = P× l

M = 598.1×550

M = 328955 N-mm

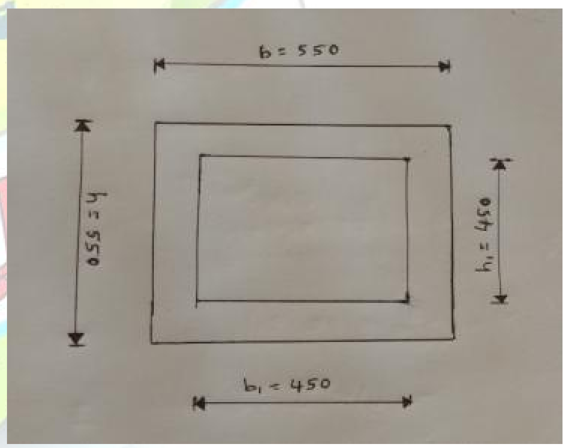
σ_b = M/Z

σ_b = 328955 / (153.03×10^5)

σ_b = 0.021 N/mm^2

$\sigma_{b\,(induced)} < \sigma_{b\,(actual)}$

Design is Safe



DEFLECTION OF FRAME

Deflection y = $5WL^4 \div 384\,E\,I$

I = $(bh^3 - b_1h_1^3) \div 12$

E = 180×10^3 N/mm^2

b = h = 550 mm

$b_1 = h_1$ = 450 mm

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I = $\{(550 \times 550^3) - (450 \times 450^3)\} \div 12$

I = 42.08×10^8 mm^4

y = $(5 \times 598.1 \times 550^4) \div (384 \times 180 \times 10^3 \times 42.08 \times 10^8)$

y = 0.00094 mm

DESIGN OF GANTRY

Moment at A,

$R_B \times 450$ = $578.48 \times 450 \times (450/2)$

R_B = 13.158 N

$R_A + R_B$ = 578.48×450

R_A = (260316- 130158) N

R_A = 130158N

Maximum bending moment.

$R_A - (578.48 \times x)$ = 0

130158 = 518.48 x

X = 130158/518.48

X = 251.04 mm

Maximum bending moment,

M_B = $R_D \times 199 - (578.48 \times 199 \times (199/2))$

M_B = $(130158\times199)-(578.48\times199 \times (199/2))$

M_B = 144.47×10^5 N-mm

Section modulus,

Z = $bd^2/6$

Z = $(450 \times 50^2)/6$

Z = 187500 mm^3

Bending stress,

$\sigma_{b\ (induced)}$ = M/Z

$\sigma_{b\ (induced)}$ = $(144.47\times10^5)/187500$

$\sigma_{b\ (induced)}$ = 77.05 N/mm2

$\sigma_{yt\ (actual)}$ = 600N/mm2

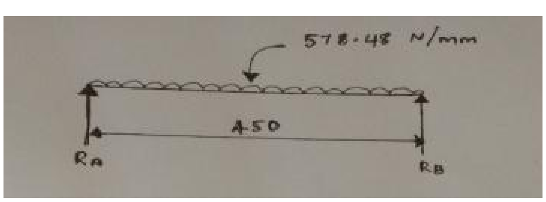
$\sigma_{b\ (actual)}$ = σ_{yt} / FOS

$\sigma_{b\ (actual)}$ = 600 / 3

$\sigma_{b\ (actual)}$ = 200 N/mm^2

$\sigma_{b\ (induced)} < \sigma_{b\ (actual)}$

Design is Safe



DEFLECTION OF GANTRY

Deflection y = $5WL^4 \div 384EI$

E = 69×10^9 N/m^2 = 69×10^3 N/mm^2

I = $bh^3 \div 12$

b = 50 mm

h = 450 mm

I = $50 \times 450^3 \div 12$

I = 379.69×10^6 mm^4

y = $(5\times578.48\times450^4) \div (284 \times 69\times10^3\times379.69 \times10^6)$

y = 0.0118 mm

DESIGN OF BEARING

(PSGDB pg. 4.2) $\frac{L}{40} = \frac{L94}{L90}\left[\frac{\ln(\frac{l}{p})}{\ln(\frac{l}{p10})}\right]^{(1/6)}$

$\frac{L}{L10}$ = $[\frac{\ln(\frac{1}{0.99})}{\ln(\frac{1}{0.9})}]^{(1/1.17}$

$\frac{L}{L10}$ = 0.1342

For 2 year 8 hours

L = 584 hours

L_{10} = L/ 0.1342

L_{10} = 5840 / 0.1342

L_{10} = 43517.14 hr.

(PSG DB pg. 4.6)

500 rpm & 43517.14 hr.

C/P = 11.50

(PSG DB pg. 4.2)

P = $[XF_r + YF_a]$ S

$F_r = 421.32$ $F_a = 865.33$

X= 0.56 Y= 1.08 S = 1.35

P = $[(0.6 \times 421.32) + (1.08 \times 865.33)] \times 1.35$

P	=	1380.46
C/P	=	11.50
C/1380.46	=	11.50
$C_{(induced)}$	=	15875.29 N
PSG DB pg. 4.13		For, SKF 6207
Dia	=	25mm
C_{actual}	=	20000 N

$C_{induced} < C_{actual}$

Design is safe

DESIGN OF LEADSCREW

Lead screw specifications:

Mean diameter (d_m) = 10 mm

Pitch (p) = 1 mm

Length (l) = 450 mm, 390mm

Motor = 490 Nmm

Acme threads 19° thread angle

$$T_R = \frac{Fdm}{2}\left[\frac{l+\pi f dm \sec\alpha}{\pi dm - fl \sec\alpha}\right]$$

$$T_L = \frac{Fdm}{2}\left[\frac{-l+\pi f dm \sec\alpha}{\pi dm + fl \sec\alpha}\right]$$

Where,

T - Torque

F - Lead of the screw

d_m – mean diameter

f – coefficient of friction

l – lead

∅ - angle of friction

λ - lead angle

α - helix angle = ½ thread angle

T_R – Torque required to raise the load

T_L - Torque required to lower the load

For Single Start, Pitch = lead

$$T_R = \frac{Fdm}{2}\left[\frac{l+\pi f dm \sec\alpha}{\pi dm - fl \sec\alpha}\right]$$

$$T_R = \frac{(78.48\times10)}{2}\left[\frac{[1+(3.14\times0.2\times10\times sec14.5)]}{[(3.14\times10)-(0.2\times1\times sec14.5)]}\right]$$

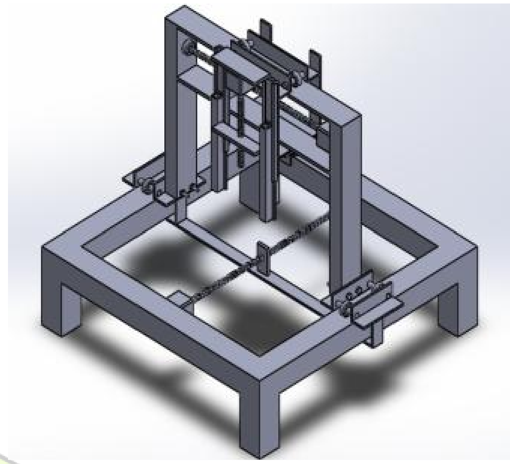
T_R = 93.66 Nmm

$$T_L = \frac{Fdm}{2}\left[\frac{-l+\pi f dm \sec\alpha}{\pi dm + fl \sec\alpha}\right]$$

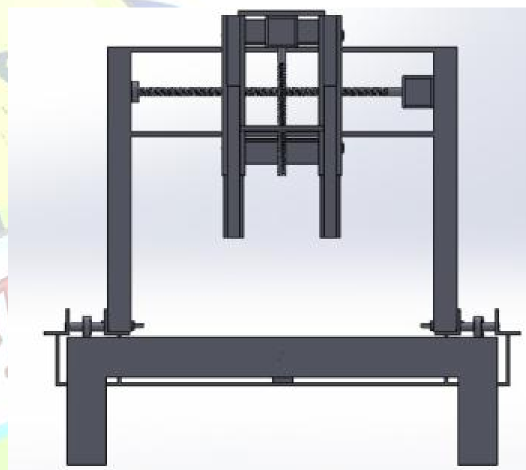
$$T_L = \frac{(78.48\times10)}{2}\left[\frac{[-1+(3.14\times0.2\times10\times sec14.5)]}{[(3.14\times10)+(0.2\times1\times sec14.5)]}\right]$$

T_L = 68.117 Nmm

SOLIDWORKS 3D MODELLING



Isometric View



Front View

SOLIDWORKS ANALYSIS

Name	Type	Min	Max
Stress1	VON: von Mises Stress	12.1054 N/m^2 Node: 14475	625261 N/m^2 Node: 11061

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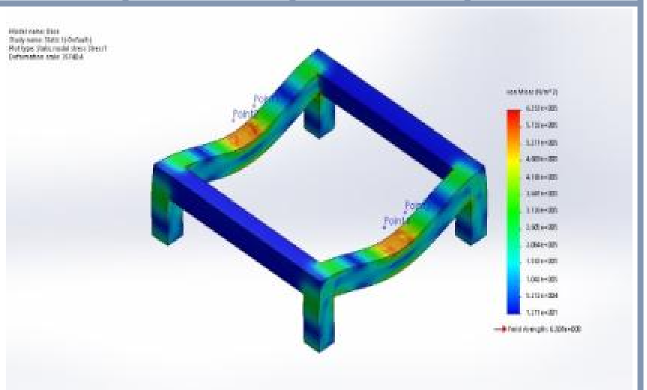
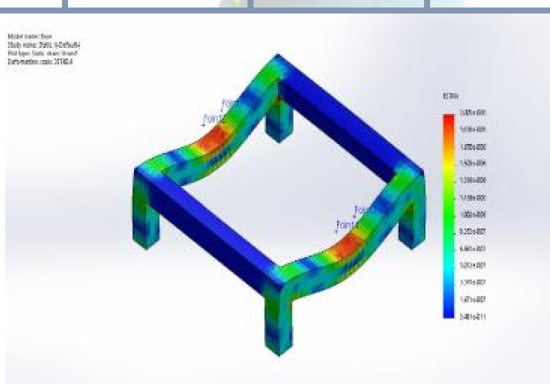
Name	Type	Min	Max



Base-Static 1-Stress

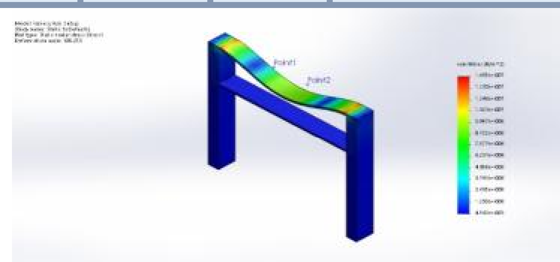
Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	3.48116e-011 Element: 4776	2.00457e-006 Element: 5177



Base-Static 1-Strain

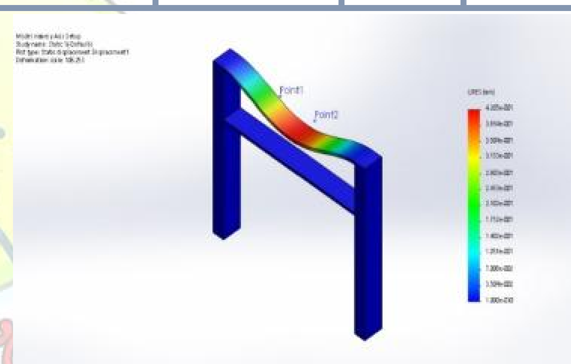
Name	Type	Min	Max
Stress1	VON: von Mises Stress	4542.58 N/m^2 Node: 25887	1.49486e+007 N/m^2 Node: 23426

Name	Type	Min	Max



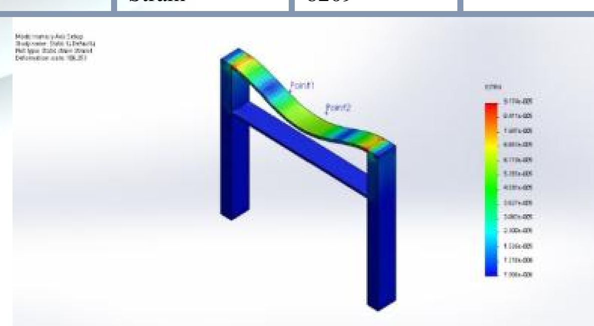
y Axis Setup-Static 1-Stress

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 1	0.42046 mm Node: 772



y Axis Setup-Static 1-Displacement

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	7.93773e-008 Element: 8209	9.1745e-005 Element: 11138



y Axis Setup-Static 1-Strain

VI. CONCLUSION

From the project Automatic Profile Cutting Machine the flowing conclusions have been made,

i. Taking this design and fabrication into account, the construction of the automatic profile cutting machine is relatively cheap and can use as an attractive productive for the small-scale industries, compared to the current market available machines.

ii. This automatic profile-cutting machine is easy to use, and require a less knowledge.

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