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DESIGN AND FABRICATION OF AUTOMATED 2-AXIS WELDING MACHINE

Seayon S. Dmello
U.G. Student, Mechanical Engineering, VCET, Vasai (West), India

Jebin Biju
U.G. Student, Mechanical Engineering, VCET, Vasai (West), India

Shashank S. Hegde
U.G. Student, Mechanical Engineering, VCET, Vasai (West), India

Anand V. Ganoo
U.G. Student, Mechanical Engineering, VCET, Vasai (West), India

ABSTRACT

CNC automated welding is the most preferred welding technique when it comes to construction of onshore and offshore transmission pipelines of various diameters. Automatic welding allows creating and maintaining a quality welding workflow, ensuring flexibility, high efficiency and high output rates. The MIG welding machine has a relay switch to control ON/OFF operation of welding torch. The essential feature of the process is the small diameter electrode wire, which is fed continuously into the arc from a coil. The base metal used for welding is carbon steel. Through this report our effort will be to completely eliminate human contact during welding which will no doubt be safer but will also be more efficient. The machine is used to weld work pieces in flat position since higher deposition rates are achieved in this position and is a convenient approach. The project will be able to weld any contour in 2D profile that is generated over a graphic user interface in addition to butt, edge, and lap joints. Electronic devices such as stepper motors and driver board are interfaced with microcontroller board. The microcontroller Arduino Uno at mega 328 is used to signal the stepper motors to rotate while deciphering the G-code. GRBL version 8.0 is used to transform "arduino uno" into G code interpreter.

In this report, the emphasis is given on design calculation and structural analysis. The analysis of L section base frame and bridge of material AISI 1020 is done considering the weight of 18kgs. Setup makes use of three stepper motors of 10 kg-cm capacity for efficient movements in three axes. MIG welding is used in the process in order to attain proper trade-off between quality of welding and the price. The report gives step wise development and analysis of the entire designing process for automatic welding equipment.

Key words: CNC, arduino uno, Welding machine, Fabrication

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1. INTRODUCTION

1.1. Motivation

The idea behind fabrication of low cost Automatic welding machine is to full fill the demand of CNC welding machines for small scale to large scale industries with optimized low cost. In addition to that the quality of the weld is also quite paramount therefore using an optimisation technique we try to optimise the different weld parameters and get a good quality of weld. We aim to develop a prototype 3-axis CNC Welding machine using Arduino-based control system is desired to have following specifications:

- Low cost
- Easily operable
- Easy interface
- Flexible
- Low power consumption

1.2. Problem Definition

The current state in small scale industries is that they still resort to manual welding and machining methods due to lack of economic resources and infrastructure. In addition to that the uniformity and quality of the weld cannot be ensured, not to mention the work hours put in and the expenditure spent on the labours. Also there is a persistent risk of causing hazards to the operator through fumes, fires, spatter flying off those machines.

1.3. Outline of the Paper

It gives brief idea about the papers published regarding the topic and the concepts that are learnt and applied in the process. It gives information about theoretical evaluation of the equipment. This involves in depth idea of design calculations of all structural members like main frame, bridge, lead screw, guide rails and electric components like stepper motor, etc. It also sheds light on the engineering aspects learned and applied in the process.

2. THEORETICAL EVALUATION

2.1. Main Frame

In order to reduce the weight of the frame and have efficient trade-off between the weight, strength and the price we select L section over the complete square cross section.

Material Selection: For having material with good strength, low density and lesser price we select alloy steel that is AISI 1020.

Table 1 Material properties for AISI 1020[12]

Properties	Metric
Tensile strength	420 MPa
Yield strength	350 MPa
Modulus of elasticity	205 GPa
Shear modulus (typical for steel)	80 GPa

Factor of safety (F.O.S): As the base frame does not go under any heavy dynamic load vibrations or dynamic forces during the process, let us assume the F.O.S as 4.

Hence $\sigma_{\ allowable} = \frac{350}{4}$

$= 87.5\ \frac{N}{mm^2}$

As per availability in standard sections we select cross section for L section as given below

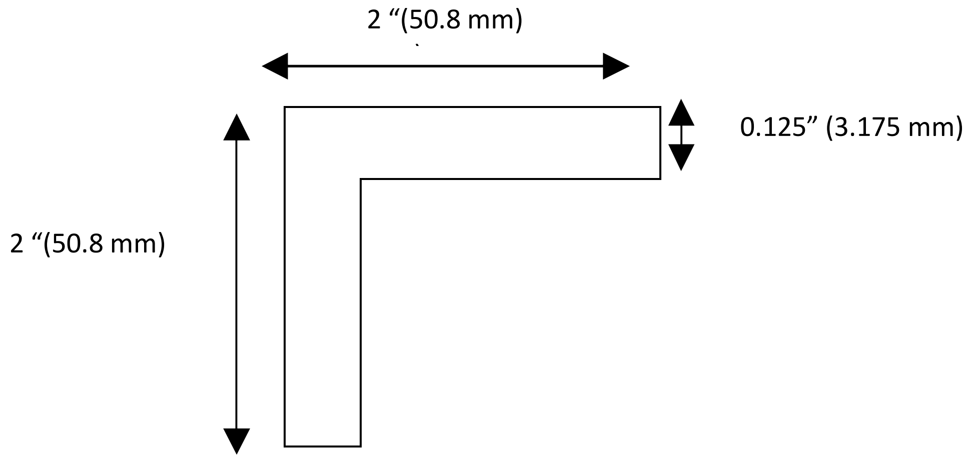

Figure 2 L cross section

As per the design considerations, area on which force acts will be projected area of circular section.

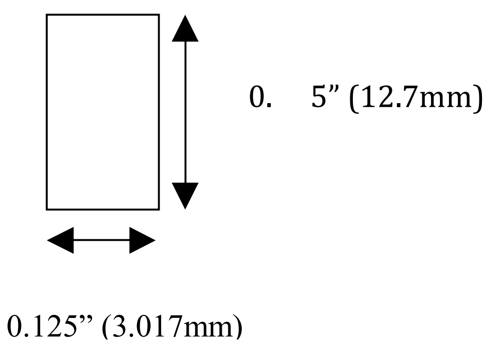

Figure 3 Projected area of circular cross section

Hence area under compression, $A = 3.017 \times 12.7$
$= 40.3225 mm^2$
Let us assume the weight of moving frame and all the elements supported by the base frame be 18 Kg.
Total Force exerted on base frame $F = m \times g$ (1)
$= 20 \times 10$... (Assuming g as 10 m/s^2)
$= 200\,N$
But as per the design this weight gets distributed over six different points
Force exerted on a single point, $F' = \frac{200}{6} = 33.33N$
Compressive stress,
$$\sigma_c = \frac{33.33}{40.3225}$$
$= 0.82\ N/mm^2$
As $\sigma_c < \sigma_{allowable}$
Hence, design safe.

2.2. Guide Rail

Material Selection:
We select case hardened material that is normally used for gears couplings etc for guide rail.
Material thus selected is En36A
Yield strength, $\sigma_y = 540 \frac{N}{mm^2}$
Taking factor of safety as 3,
$$\sigma_{allowable} = \frac{540}{3}$$
$$= 180 \frac{N}{mm^2}$$
Considering shear for Guide Rail,
$Area = \pi r^2$ (2)
$= \pi \times 12.72^2$
$= 253.35 mm^2$
$\therefore$ Shear stress, $\tau = \frac{F}{A_s}$ (3)
$$= \frac{33.33}{253.35}$$
$$= 0.13 \frac{N}{mm^2}$$
As force acting and area under compression is same, the direct stress will be same as that of the direct stress on frame.
$$\therefore \sigma_c = 0.82 \frac{N}{mm^2}$$
$$Moment\ of\ inertia = \frac{\pi \times d^4}{64}$$
$$= 1276.982 mm^4$$

Bending stress, $\sigma_b = \frac{M \times y}{I}$. (4)

$= \frac{66.66 \times 457.2 \times 6.35}{1276.928}$

$= 151.415 \frac{N}{mm^2}$

Total max stress,

$\sigma = \sigma_b + \sigma_c$ (5)

$= 151.415 + 0.82$

$= 152.23 \frac{N}{mm^2}$

Since $\sigma < \sigma_{allowable}$

∴ Design safe

Maximum deflection,

$y_{max} = \frac{P \times L^3}{48 \times E \times I}$ (6)

Where,

P = load acting on midpoint of beam

L = total length of the beam

E = Young's modulus of the material

I = second moment of inertia

$\therefore\ y_{max} = \frac{66.66 \times 914.4^3}{48 \times 200 \times 10^9}$

$y_{max} = 4.157 \times 10^{-6}\, mm$

2.3. Lead Screw

Selecting standard lead screw of 12mm diameter

Hence dimensions of lead screw are:

d = 12mm

Pitch, p = 3mm

Core diameter, d_c = 9mm

Mean diameter, $d_m = \frac{d + d_c}{2} = 10.5mm$

For Trapezoidal thread,

$2\theta = 30^\circ$

$tan\ \alpha = \frac{P_B}{\pi \times d_m}$ (7)

where P_B = lead

For the double start screw lead, $P_B = 2 \times p$

$\therefore tan\ \alpha = \frac{2 \times p}{\pi \times 10.5} = \frac{2 \times 3}{\pi \times 10.5}$

$tan\ \alpha = 0.1818$

$\mu = 0.15$, for steel and cast iron combination

Now, for trapezoidal threads,

$M_t = \frac{w \times d_m \times (\mu \sec\theta + tan\ \alpha)}{2 \times (1 - \mu \sec\theta\ tan\alpha)}$ (8)

$$= \frac{100 \times 10.5}{2} \times \frac{(0.15sec\,15 + 0.1818\,)}{(1 - 0.15sec\,15 \times 0.1818\,)}$$

$= 182.11\ Nmm$

$= 0.1821\ Nm$

Now, efficiency of the thread

$\eta = \frac{M_t}{[M_t]}$ (9)

Also, $\eta = tan\ \alpha \times \frac{1-\mu sec\ \alpha \times tan\ \alpha}{\mu sec\ \alpha + tan\ \alpha}$

$$= 0.1818 \times \frac{1 - 0.15\ sec15\ \times 0.1818}{0.15sec\ 15 + 0.1818}$$

$= 0.524$

$$\therefore\ [M_t] = \frac{M_t}{\eta} = \frac{0.1821}{0.524} = 0.2026\ Nm$$

2.4. Selection of Bearing

Referring the standard material selection, Screw is made of hardened steel 30C8. Nut is made of cast iron.

Bearing area,

$$A_b = \frac{\pi}{4} \times (d^2 - {d_c}^2) = \frac{\pi}{4} \times (12^2 - 9^2) = 49.48mm^2$$

Bearing pressure,

$P_b = \frac{W}{A_b \times z}$ (10)

$$= \frac{100}{49.48 \times z}$$

Assuming z = 4

$$P_b = \frac{100}{49.48 \times z} = 0.5052\ \frac{N}{mm^2}$$

Maximum pressure for steel – cast iron combination is 1 N/mm^2

Since 0.5052 N/mm^2 < 1 N/mm^2

Hence, design safe

We select deep groove ball bearing as it is standard for power transmitting screws.

D =12 mm..... (As d_c = 9 mm)

Series 60.... (PSG 4.12 [12])

Bearing 6000

Static capacity, C_0 = 190 kgf

Dynamic capacity, C = 360 kgf

Series 62..... (PSG 4.13 [12])

Bearing 6200

Static capacity, C_0 = 324 kgf

Dynamic capacity, C = 400 kgf

2.5. Bridge

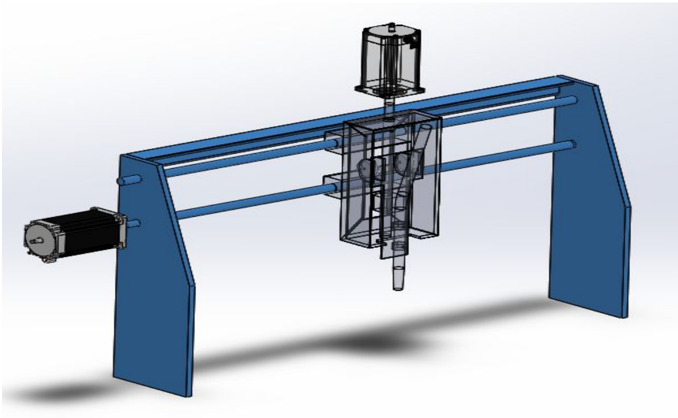

Figure 4 Bridge

Material Selection:

For having material with good strength, low density and lesser price we select alloy steel that is AISI 1020.

Material properties for AISI 1020:

Properties	Metric
Tensile strength	420 MPa
Yield strength	350 MPa
Modulus of elasticity	205 GPa
Shear modulus (typical for steel)	80 GPa

Assumptions:

Weight of tool holder = 10kg (actual weight will be less than 5kg)

All load acts on the lead screw

Consider shear failure

Let, $d = dia\ of\ lead\ screw = 12$

$W = load\ acting = m \times g = 10 \times 10 = 100N$

$\sigma_y = 350\ MPa$

$$[\tau] = \frac{350}{2 \times FOS} = \frac{350}{2 \times 5} = 35MPa$$

$$\tau = \frac{Force}{Area} = \frac{\frac{W}{2}}{d \times t} \quad (11)$$

$$t = \frac{50}{35 \times 0.5 \times 25.4}$$

$t = 0.112\ mm$

Let $t = 0.31'' = 0.31 \times 25.4 = 7.874mm$

$$\tau = \frac{w}{d \times t}$$

$W = \tau \times d \times t = 35 \times 0.5 \times 25.4 \times 7.874$

$W = 3500N$ i.e. 350kg, which is way above the weight of tool holder.

Hence design safe.

2.6. Selection of Stepper Motor

Load and Linear guide:
Mass of load and Table = 10kg
Friction coefficient of guide = 0.092
Lead screw specifications:
Diameter, D_B = 12mm
Length, L_B = 900mm
Pitch = 3mm
No. of starts = 2
Lead, P_B = 6mm
Efficiency, η = 52.4%
Material = Steel
Density, ρ = 7900kg/m^3
Breakaway torque of screw, T_B = 0.3475N-m
External Force, F_A = 1N
Operating conditions:
V_1 = 0 mm/s
V_2 = 50 mm/s
Stopping Accuracy
Δl = 0.01mm
Factor of safety = 1.25
Load Inertia (J):

$$J = J_w + J_s \tag{12}$$

Where, J_w = Inertia due to mass of table,
J_s = Screw inertia

$$J_w = m \times [\frac{P_B \times 10^{-3}}{2\pi}]^2 . \tag{13}$$

$$\therefore\ J_w = 10 \times [\frac{6 \times 10^{-3}}{2\pi}]^2$$

$$\therefore\ J_w = 9.1189 \times 10^{-6} kgm^2$$

$$J_s = \frac{\pi}{32} \times \rho\ \times (L_B \times 10^{-3})(D_B \times 10^{-3})^4$$

$$\therefore\ J_s = \frac{\pi}{32} \times 7900\ \times (900 \times 10^{-3})(12 \times 10^{-3})^4$$

$$\therefore\ J_s = 1.4474 \times 10^{-5} kgm^2$$

$$J = J_w + J_s$$

$$\therefore\ J = 2.36 \times 10^{-5}\ kgm^2$$

Required Speed:

$$V_{m1} = V_1 \times \frac{60}{P_B} \tag{14}$$

$$\therefore\ V_{m1} = 0 \times \frac{60}{6} = 3500N$$

$$V_{m2} = V_2 \times \frac{60}{P_B}$$

$$\therefore V_{m2} = 50 \times \frac{60}{6} = 500\ rpm$$

Load Torque (T_L):

$$F = F_A + m \times g \times \mu \qquad (15)$$

$$\therefore F = 1 + 10 \times 10 \times 0.092$$

$$\therefore F = 10.2N$$

$$T_L = [\frac{F \times P_B \times 10^{-3}}{2\pi} \times 1.1 + T_B] \times \frac{1}{0.01 \times \eta}$$

$$\therefore T_L = [\frac{10.2 \times 6 \times 10^{-3}}{2\pi} \times 1.1 + 0.3475] \times \frac{1}{0.01 \times 52.4}$$

$$\therefore T_L = 0.6836\ Nm$$

$$\therefore T_L = 6.836\ Kgcm$$

$$Required\ torque\ [T_L] = 1.25 \times 6.836 = 8.545\ Kgcm$$

3. CONCLUSION

Automatic welding machine was successfully designed. The design can be implemented to manufacturing working model. Knowledge of various fields of engineering such as strength of material machine design was applied to carry out efficient designing. While designing manufacturability of the design was considered. Simplicity of the design was maintained to its best in order to achieve the objective of designing cost efficient automatic welding machine.

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