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Development of JOLIS GC3000 Gas Cutter Joint Ordinate Linear Interpolation System CNC Machine

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***Abstract*—JOINT ORDINATE LINEAR INTERPOLATION SYSTEM is an automation solution that improves the speed, accuracy and cost effectiveness of the traditional system. The basic concepts of Oxyacetylene cutting is still preserved, but operation is optimized with a motion-controlled system. JOLIS-GC-3000 is a 2 $\frac{1}{2}$ axes system that provides the torch freedom to be interpolated in various profiles. JOLIS is a controller independent system that allows the integration of PLC, PCI based, or Micro controller based Controllers. It is portable, accurate to 0.1mm, user friendly and extremely cost effective, hence suitable for all fabrication and production oriented businesses.**

***Index Terms*—CNC, Motion Control, Gas Cutter**

I. INTRODUCTION

The design of JOLIS was developed on the basis of problems and issues that were faced by medium scale industries which use manual hand-operated gas cutting tool. It incorporates a cantilever frame structure unlike the gantry style which is preferred in CNC machines. As the structure of the gantry system would be sturdy and bulky,but the system had to be compact, portable, accurate and fast thus the design of the system was based on a cantilever system. JOLIS has a wide range of cuts spans that maybe incorporated depending on customer needs. Unlike other portable CNC systems, JOLIS need not be dismantled to be transported. It is mobile and can be swiveled for easy storage when not in use. JOLIS system is completely independent of the type of controller (PLC, Micro controller, PCI port, etc.) hence accuracy and cost can be adjusted as per customer requirements. It is extremely user-friendly especially when interfaced with a controller, which has its own library of predetermined shapes that the user could use. Hence, operators do not require extensive training or experience in operating a CNC or G and M code programming knowledge.

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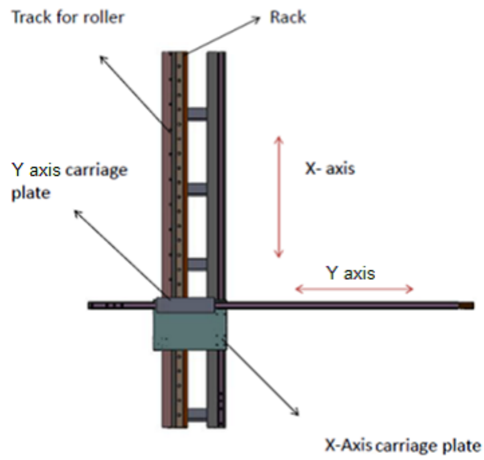

Fig. 1. Basic design of JOLIS system

II. DETERMINATION OF FRAME DIMENSIONS

JOINT ORDINATE LINEAR INTERPOLATION SYSTEM (JOLIS) suggests the system works on the principle of producing the desired tool motion by the simultaneous fluctuations in both the X and Y-axis. The JOLIS GC 3000 is an economical solution to automation of small and medium scale industries, reducing effort and time required for production. Its high accuracy and high-speed performance ensures high productivity and quality.

A. *Determination of Y Axis Beam*

While calculating the dimension of the Y-axis slide, it is important that the system is designed for the worst possible scenario, which is when the slide is extended to its extreme length. In that case, the system will behave like a Cantilever system.

Let us consider a composite beam made of Aluminum and Mild Steel that has been bolted together to form a single beam. Now as the dimension of the Aluminum beam is fixed, the mild steel bars can be machined onto it.

The objective it to calculate the dimension of the steel beam required to keep the deflection of the entire system below 0.1mm.

$$\delta_T = \delta_W + \delta_L$$

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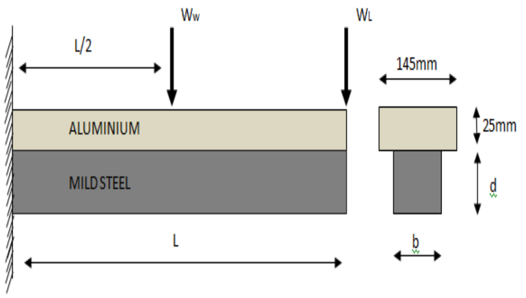

Fig. 2. Composite beam

$\delta_W = \frac{W_W l^2}{6EI}\frac{5l}{2}$

$\delta_L = \frac{W_L l^3}{6EI}$

Where:W=Weight,L=Length.

Assume the maximum deflection to be 0.1mm, therefore:

$\delta_T = \frac{W_W l^2}{6EI}\frac{5l}{2} + \frac{W_L l^3}{3EI}$

$= \frac{l^3}{3EI}\frac{5W_W + W_L}{4}$

$0.0001 = \frac{2.3^3}{3EI}\frac{5W_W + 58.84}{4}$

Now as the two beams are stacked one on top of the other, and the forces are acting perpendicular to both of them, the Effective Young's Modulus is given by:

$\sum_{i=1}^{n}\frac{V_i}{E_i} = \frac{V_{MS}}{E_{MS}} + \frac{V_{Al}}{E_{Al}}$

where MS= mild steel and AL= Aluminium

$E = b \times d \times 1.15 \times 10^{-11} + 1.21 \times 10^{-12}$

$= \frac{b \times d \times 2.3}{200 \times 10^9} + \frac{0.145 \times 0.25 \times 2.3}{69 \times 10^9}$

Now the total weight of the entire beam system, W_w is given by:

$W_w = [(b_{Al} \times d_{Al} - 2\pi r^2) \times \rho_{Al} + 2\pi r^2 \times \rho_{MS} + b_{MS} \times d_{MS} \times \rho_{MS}] \times L$

where:
$b_{AL} = 0.145m$
$d_{AL} = 0.025m$
$\rho_{AL} = 2700kg/m^3$
$\rho_{MS} = 7750kg/m^3$
$r = 0.022m$

$W_w = [(0.145 \times 0.025 - 2\pi(0.022)^2) \times 2700 + 2\pi(0.022)^2 \times 7750 + b_{MS} \times d_{MS} \times 7750] \times 2.3$

$W_w = [7.735 + 5.892 + 7750 \times b_{MS} \times d_{MS}] \times 2.3$

$W_w = [31.342 + 17.825 \times 10^3 \times b \times d]$

Moment of Inertia of system is calculated by the derivation:

$I_X = \int y^2 dA$

Now calculate the moment of inertia of the composite system , use parallel axis theorem:

$I_x = (\overline{I_x} + d^2 A)_{AL} + (\overline{I_x} + d^2 A)_{MS}$

$\overline{y} = \frac{(b \times d \times y)_{AL} + (b \times d \times y)_{MS}}{(b \times d)_{AL} + (b \times d)_{MS}}$

$= \frac{(0.145 \times 0.025 \times (d + 0.0125)) + (b \times d \times \frac{d}{2})}{(0.145 \times 0.025) + (b \times d)}$

$\overline{y} = \frac{\frac{b \times d^2}{2} + 3.265 \times 10^{-3}(d + 0.0125)}{3.265 \times 10^{-3} + bd}$

Now for the simplification of calculation, assume that:

$b = d$

$\overline{y} = \frac{\frac{d^2}{2} + 3.265 \times 10^{-3}(d + 0.0125)}{3.265 \times 10^{-3} + d^2}$

The Moment of Inertia is:
$I_x = (\overline{I_x} + d^2 A)_{AL} + (\overline{I_x} + d^2 A)_{MS}$

$I_x = [\frac{0.145 \times 0.025^3}{12} + 0.145 \times 0.025(d + 0.0125 - \overline{y})] + [\frac{d^4}{12} + d^2(\overline{y} - \frac{d}{2})]$

Now substituting $\overline{y}$ and differentiate I_x with respect to d, we get:

$\frac{d(I_x)}{d(d)} = A' + B' + C'$

where
$A = \frac{0.145 \times 0.025^3}{12} + 0.145 \times 0.025(d + 0.0125 - \overline{y})$
$B = \frac{d^4}{12}$ and $C = d^2(\overline{y} - \frac{d}{2})$

Thus the resultant equation is:
$d^4 + 3.66 \times 10^{-3} d^2 - 1.83 \times 10^{-4} d + 2.62 \times 10^{-5}$

Now equating it to zero, as this would give the maximum value of I_x , which would give the least amount of material required to keep the deflection below 0.1 mm.

$d^4 + 3.66 \times 10^{-3} d^2 - 1.83 \times 10^{-4} d + 2.62 \times 10^{-5} = 0$

The above expression is derivated w.r.t d and equated to zero to find optimized value of d. Thus, the real solution obtained is d=0.03637 m
Compare this result with various cross-sections in regard with the moment of inertia equivalent with the study carried out on FEA Software it was determined that rectangular cross-section provides the best alternative, requiring least material

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for equivalent deflection.
Hence,MS 60 x 40 x 2.6 beams are selected.

B. *MOTOR SELECTION*

Now the Rack and Pinion system that has been recommended for the high precision solutions such as a CNC machine is:

Rack:
Material: Stainless Steel,Grade 416
Treatment: Hardened to 35-45 HRc
Pressure Angle: 20

Pinion:
Material: Stainless Steel,Grade 17-4 PH
Treatment: Hardened 36/40 HRc
Pressure Angle: 20

Load Torque Calculation:
$F = F_A + mg(\sin\theta + \mu\cos\theta)$
Where:
F:Force of moving direction.
F_A:External Force.
m:Total mass of table and load.
θ:Tilt angle in degree.
g:gravitational acceleration.

Where μ between stainless steel-stainless steel is (0.5-0.8)
Now calculating for the worst possible scenario, consider μ = 0.8
$T_L = \frac{F}{2\pi\eta} \times \frac{\pi D}{i} \times \frac{FD}{2\eta i}$

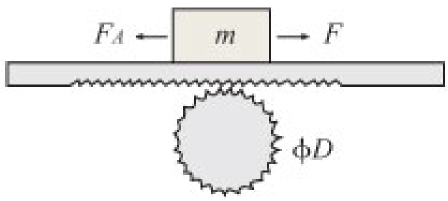

Fig. 3. Rack and pinion for Y-axis beam

Where:
F=Force of moving direction.
μ^0=Internal Friction coefficient of preload nut(0.1$\sim$ 0.3)
i=Gear Ratio(This is the gear ratio of mechanism)
P_B=Ball screw lead.
F_A=External Force.
m=Total mass of the table and load.
μ=Friction coefficient of sliding surface(0.05).
θ=Tilt angle(Degree).
D=Final Pulley Diameter.
g=Gravitational Acceleration.

C. *Dimensions of X axis Beam*

Load Torque Calculation:
$F = 0 + 23.88 \times 9.81 \times 0.8 = 187.41N$
$T_L = \frac{187.41 \times 0.047}{2 \times 0.85 \times 1} = 5.181Nm$

Therefore the required torque for X axis system is: 5.181 N-m

X axis slide system:

Now the total weight of the carriage and X slide system is:
W = Y beam + Torch mounting + Y motor
$= 36.37^2 \times 2300 \times 0.00785g/mm^3 + 6kg + 5.4kg$
$= 35.28Kg$

Load Torque calculation:
$F = 0 + 35.28 \times 9.81 \times 0.8 = 276.90N$
$T_L = \frac{276.90 \times 0.047}{2 \times 0.85 \times 1} = 7.655Nm$

Motor selection:
As the maximum desired Torque is 7.65 N-m, 8.7 N-m Bipolar Stepper Motor is selected. Thus the motor selected is
Model : 34H-155-50-4A
Type : Bipolar

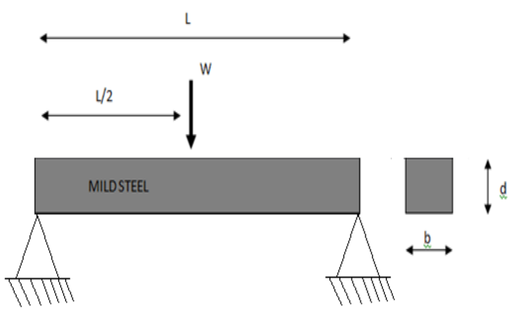

Fig. 4. Simply Supported Beam

W = Y beam + Torch mounting + Carriage + X motor + Y motor
=23.88kg + 6kg + 20kg + 5.4kg + 5.4kg
= 60.68kg
Assume that various components (i.e. welds, nut and bolts, etc.) add up to this weight. Thus W $\approx$70kg .
The maximum deflection of a simply supported beam is at its mid-point:
$\delta = \frac{-Wl^3}{48EI}$

Equating it to 0.1mm and by assuming that

b = d,

Therefore symbol

$$0.0001 = \frac{(27475d^2+343.23)3.5^3)}{48\times210\times10^9\,\frac{d^4}{12}}$$

Reducing the above equation and solving:

$1.96 \times 10^5 d^4 + 27475 d^2 + 343.23 = 0$

d = 0.117 m

Compare this result with various cross-sections in regard with the Moment of Inertia equivalent; find the best alternative with least material consumption.

Hence from the study carried out on FEA Software it was determined that rectangular cross section provides the best alternative, requiring least material for equivalent deflection.

Hence, MS 80 x 40 x 4.8 beams are selected.

D. *Selection of Optimum Beam Cross-section using FEA Software*

FEA Software is used for analyzing various cross-sections. These can be used as an alternative for the calculated square beams. This is done by finding the dimensions required to sustain a maximum deflection of 0.1 mm.

Weight of Material required = (Area) x L X Density of Mild

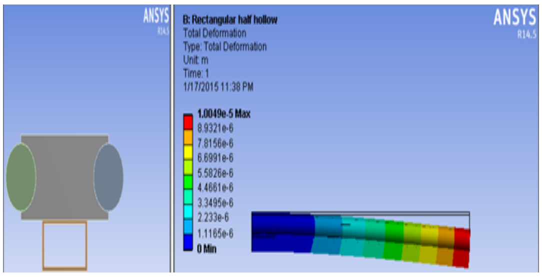

Fig. 5. FEA Analysis

Steel = 28.893024 kg

Tabulating the results,

TABLE I
COMPARISON BETWEEN VARIOUS CROSS-SECTIONS

Type of C/S	Volume ($10^4 mm^3$)	Weight (kg)	Deflection (10^{-3}mm)	Stress (Mpa)	Rating Factor 10^{-3}
Rect- -angular Hollow	0.6582	51.6687	5.81	0.1532	3.826
Half Rect Hollow	0.3680	28.8930	10.04	0.22115	3.698
H Flat Plate	0.36	28.26	15.044	0.17343	5.415
C section	0.4	31.4	10.21	0.2841	4.087
V Flat Plate	0.48	37.68	10.01	0.29395	4.806

Comparing the results on the basis of deflection to weight proportion, the Rating Factor was devised, which is basically the product of volume and deflection. Lower the Rating factor, better the alternative solution. From the table it is clear that the half rectangular pipe beam provides the best

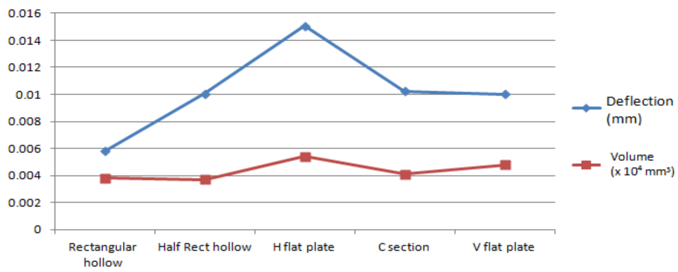

Fig. 6. Plot of the values of various cross-sections

solution. Hence, rectangular pipe beam ofMS 60 x 40 x 2.6 is selected.

III. CONCLUSION

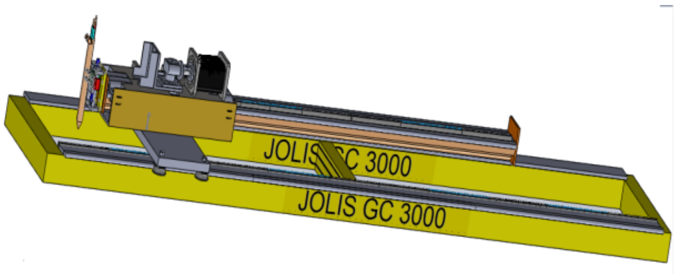

Fig. 7. Final Design of JOLIS GC 3000

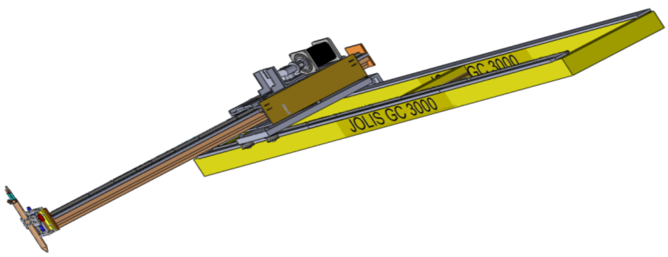

Fig. 8. Final Design of JOLIS GC 3000

As the structure of the JOLIS GC 3000 is designed and analyzed with the help of FEA Software, the deflections due to static loading are less than 0.1mm. These deflections were measured with the help of laser calibrators. Successful trial runs of the system were done by triggering the X and Y slide motors, initially with the help of a PLC system. This trial run proved that the system was as designed and all loading conditions were met. ANSYS simulations results were seen to be identical, implying that the models were accurate. The completion of the project entails the calibration of the Controller, Gas torch and Z-axis motor. Till now, the project seems to be running smoothly and on time. Recent tests that were conducted resulted in an accuracy of ± 1mm. The JOLIS GC 3000 was able to produce a variety of simple and complicated shapes that were available in the controller's library. Further, all the initial desired key features are incorporated and functioning as desired. Future improvements such as weight reduction, introducing sensors and height compensation to provide a closed loop, complicated controls modeled by better mathematical formulations like NURBS can be implemented. JOLIS GC 3000 provides an easy, fast, reliable and accurate automation solution for Gas Cutting.

Fig. 9. Final Build

Fig. 10. Prep for First cut

Fig. 11. First cut of JOLIS GC 3000

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