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Fixture Design for Rooftop of Metro

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Keywords: *welding, fixture, manipulators, solidworks, plc.*

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Fixture Design for Rooftop of Metro

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Abstract- Researching the possibilities for fixture design aided by computers has been in the sphere of interest of a number of authors worldwide for a longer period. Research results have led to the precise and systematised knowledge on the possibilities offered by computer application in fixture design process. The paper emphasises the importance of fixture design automation. It presents a general structure of the automated design system with a special highlight on the fixture design systems and their main characteristics. It also shows a structure and a part of output results of the automated modular fixture design system. Finally, the reached conclusions are presented with the expected directions of future researches. In industrial ergonomics a manipulator is a lift assist device used to help workers lift, maneuver and place articles in process that are too heavy, too hot, large or otherwise too difficult for a single worker to manually handle.

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1. INTRODUCTION

Fixture design is typically a setup cost function, making it very valuable in flow time and indirect cost calculations. Due to the rapid response required in many applications, the fixture design principles must be integrated and properly detailed so as to facilitate the fast design development of a fixture. Frequent checking, positioning, individual marking and non-uniform quality in manufacturing process are

eliminated by fixture. This increase productivity and reduce operation time. Welding fixtures are normally designed to hold and support the various components (workpieces) to be welded. Fixture is a device for locating, holding and supporting a work piece during a manufacturing industry [2]. It is necessary to support them in a proper location which is capable of preventing distortions in workpieces during welding. For this the locating elements need to be placed carefully, clamping has to be light but firm, placement of clamping elements has to be clear of the welding area and the fixture has to be quite stable and rigid to withstand the welding stresses. With the aid of manipulator the welding fixture on which the rooftop will be placed is rotated for welding purpose. After necessary welding operations being performed, the fixture is rotated back to its original position. Then the rooftop is unclamped and unscrewed from its fixture in order to get lifted by the crane to be placed on the train top. For carrying out these operations appropriate design and functioning of this mechanism is of prime concern. As a result of complex alignment and positioning equipment are important as they are required in nearly all research and manufacturing processes[1].



Figure 1 : Rooftop of railway

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Current production systems in manufacturing industry are characterized by product range extension, high frequency in changing production programs, demands for constant product quality improvement, shortenings in production time, constant need for increasing technological level of products and decreasing their manufacturing costs. In industries it is however, with the availability of 64 digit computers and refined FE tools, welding engineers around the world are

more biased towards the computer simulations of complex welding phenomenon instead of the conventional trial and error approach on the shop floor is the most common practice nowadays [5]. With such market demands, and intensive development of science, technique and information technologies, the level and the trend of further development of technological machining processes in metal manufacturing industry depend on all the composing factors, those being the following: type of blank, machining process, order of operations, machinery, operation and sequence concentration, tools, fixtures, measurements, etc

II. MATERIALS AND COMPONENTS

Out of many types of steel used for manufacturing we have chosen plain carbon steel while designing and manufacturing as it is robust, cheaper than other steels and easily available.

- i. The fabrication System mounted on the base is made up of mild steel.
- ii. For hard parts which are prone to inducing friction is made up of alloy steel grade EN-19 having high tensile strength, good ductility and shock resisting properties.
- iii. Pins are made up of 20MnCr5 which are toughened and case hardened for smooth operation.

Jigs and Fixtures are made of variety of materials, some of which can be hardened to resist wear. Materials generally used: -

- High speed Steel: Cutting tools like drills, reamers and milling cutters.
- Carbon steels: Used for standard cutting tools.
- Non shrinking tool steels: High carbon or high chromium.
 - Very little distortion during heat treatment.
 - Used widely for fine, intricate press tools.
- Nickel chrome steels: Used for gears.
- High tensile steels: Used for fasteners like high tensile screws
- Mild steel: Used in most part of Jigs and Fixtures Cheapest material contains less than 0.3% carbon
- Cast Iron: Used for odd shapes to some machining and laborious fabrication
 - CI usage requires a pattern for casting.
 - Contains more than 2% carbon.
 - Has self-lubricating properties.

Our finalized design is a product of the several different ideas and components originally created in the design phase.

a) *Manipulator*:- In industrial ergonomics a manipulator is a lift assist device used to help workers lift, maneuver and place articles in process that are too

heavy, too hot, too large or otherwise too difficult for a single worker to manually handle. As opposed to simply vertical lift assists (cranes, hoists, etc.) manipulators have the ability to reach in to tight spaces and remove workpieces.



Figure 2 : Manipulator

- b) *Gears*:- Gears used are spur gears or straight-cut gears are the simplest type of gear. They consist of a cylinder or disk with the teeth projecting radially, and although they are not straight-sided in form (they are usually of special form to achieve constant drive ratio, mainly involute), the edge of each tooth is straight and aligned parallel to the axis of rotation. These gears can be meshed together correctly only if they are fitted to parallel shafts.



Figure 3 : Spur Gear

- c) *Brake Motor*:- A Motor is a device that creates motion. It usually refers to an engine of some kind. It may also specifically refer to Electric motor, a machine that converts electricity into a mechanical motion. Brake motor consists of an induction motor coupled to a disk brake, forming an integrated compact and robust unit. The brake used is sturdy with few moving parts and minimum of maintenance. This type of motor is mainly used in applications requiring quick stop and positive action and stand still like conveyors, gear reducers, machine tools etc. The motor used in our project is

1.5 HP with a rotational speed of 0.5 rpm as per our application.

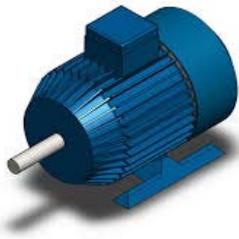


Figure 4 : Brake Motor

d) **Gear Box**:-The gear box used in our project work is a BOX type 5 inch worm and worm wheel gear box. It comprises of series of worm gear units made with die cast aluminium housing from size 25 upto 90 and cast iron for the size 110, 130, & 150. Two taper roller bearings are mounted on the worm shaft improving the mechanical resistance to the axial thrust generated by the worm wheel. The housing has been designed using parametric 3-D CAD software supported by symmetric analysis of the thermal dissipation capacity and structural resistance to deformation under the effect of working loads. The housing has been optimized to maximize the draining of water or liquid in the event of gear box being subjected to splashing or washing, thanks to the adoption of auto lubricated bearings on the output gear.

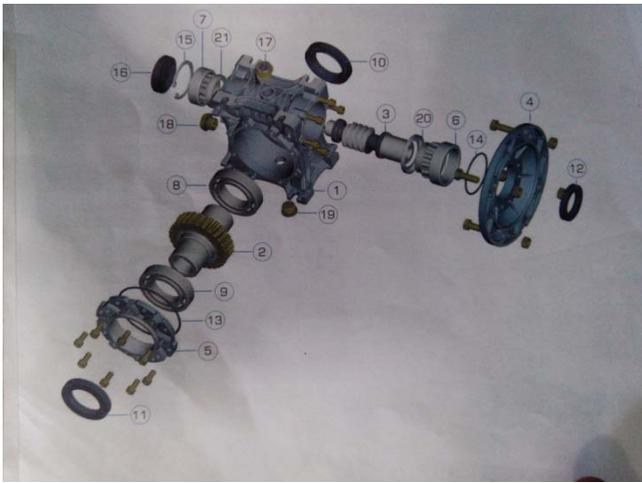


Figure 5 : Exploded view of Gear Box

e) **Bearing** :- Bearing is a machine element that constraints relative motion and reduces friction between moving parts to only the design motion. The design of bearing provides free linear of the moving part or free rotation around the fixed axis. Bearing used in our project is single deep groove bearing no. 6206 having a basic static capacity of 1000 Kgf and basic dynamic capacity of 1.30 Kgf. The maximum rotational speed for the bearing is 13000 rpm.

f) **PLC** :- The main concept of this research is implementation of a control system, by using an intelligent device, which controls the fixture so that manipulation of job becomes easy. A Programmable Logic Controller, PLC, is an electronic device used for Automation of industrial processes, control of machines and automation of factory assembly lines implying that PLC is an industrial computer which has multi-purpose use in order to handle complex parts and processes safely [3].

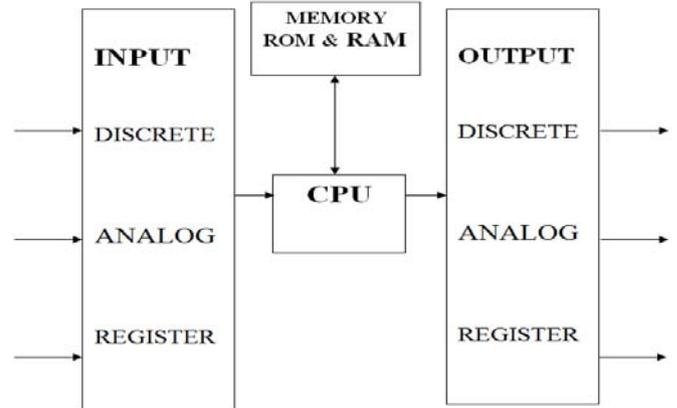


Figure 6: PLC

g) **Drive unit**:- The entire unit including the gear box, brake motor, shaft and the bearing mounting with the shaft is called drive unit. This entire unit is used to rotate the shaft with the help of gear mechanism according to our requirements. In order to improve the efficiency of the drive it needs to be regularly maintained.



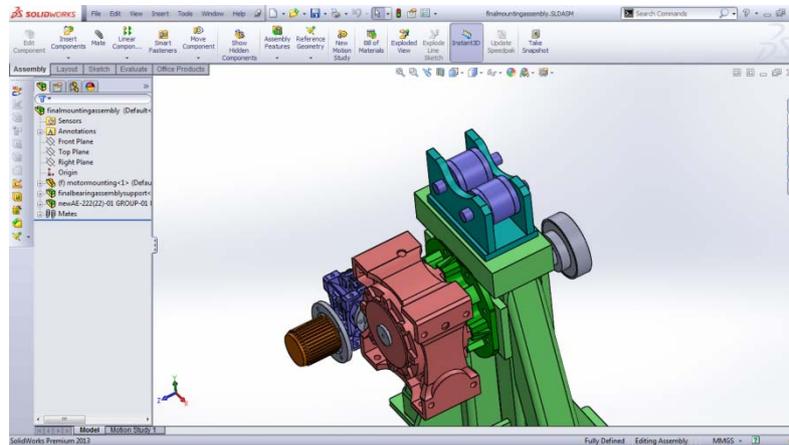


Figure 7 : Drive Unit

f) *Motor mounting:* - The entire drive unit is placed on this mounting. Its unique design plays a crucial role in reducing the weight of entire assembly. The roller

support is mounted on the mounting assembly and the drive unit is attached to its side.

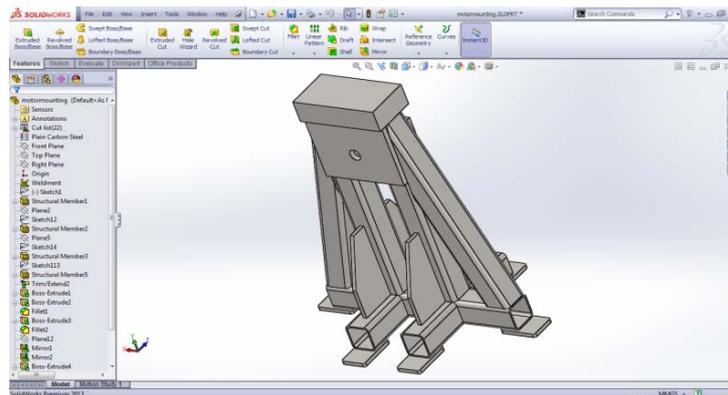


Figure 8 : CAD Model of Motor mounting



Figure 9 : Motor mounting

g) *Shaft support:* - For frictionless shaft rotation there is a specially designed shaft support. It mainly consists of use of bearings. This results into point contact between the shaft and the bearings, thus

maintaining a firm support for the shaft movement. Mostly, temporary support is not adopted, while in others it becomes essential to protect the crew and equipment from any side fall.

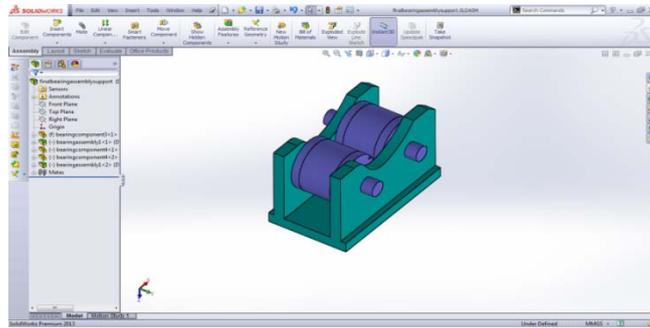


Figure 10 : Shaft Support

h) *Duct*: - In order to carry the electrical wires and other appliances for purposes of lighting specially designed pair of duct is used as a protective

covering. The duct size is 300x200x6 mm which is assembled four in a number.

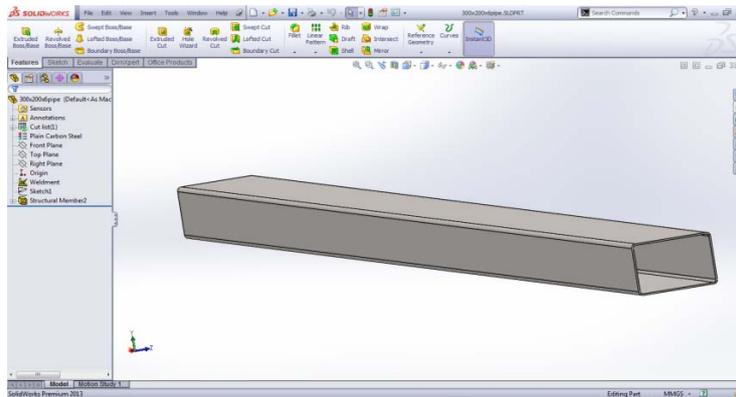


Figure 11 : Duct

i) *Supporting Components*: - These components are not considered as the main parts of the design but still they play a very important role in avoiding the falling of the main component that is the rooftop.

When the entire assembly is turned by the manipulator, the rooftop is supported by these components so that welding operation can be carried out easily and safely.

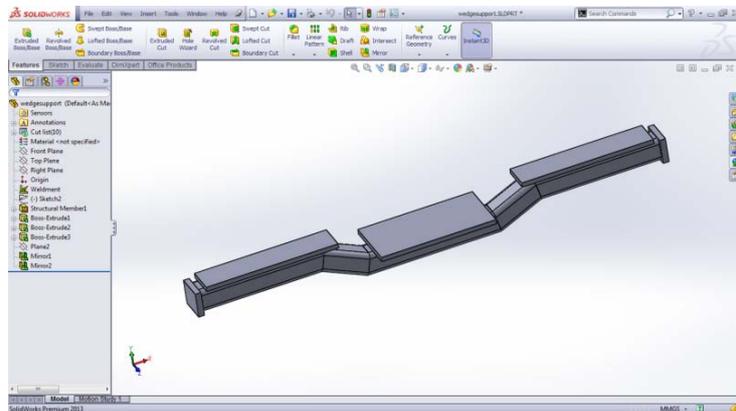


Figure 12 : Duct Supporting Component

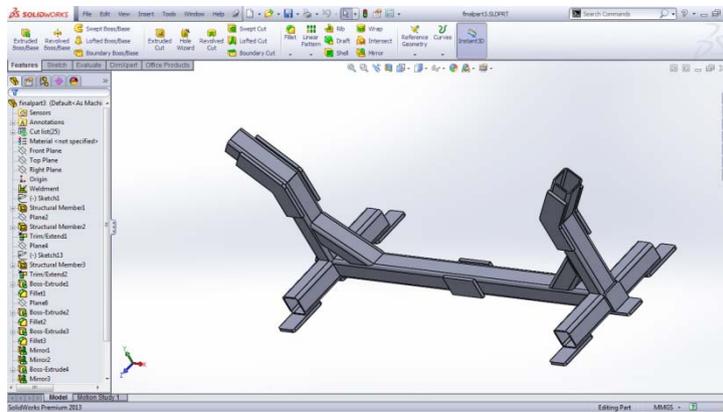


Figure 13 : Duct Supporting Assembly

j) *Actual rooftop:* - It basically consists of four components each having a specific dimension which is altogether assembled as one part of the entire rooftop assembly. Another pair of the rooftop

is similar but having different dimensions. Though the design is complicated, error while manufacturing will not be tolerated.

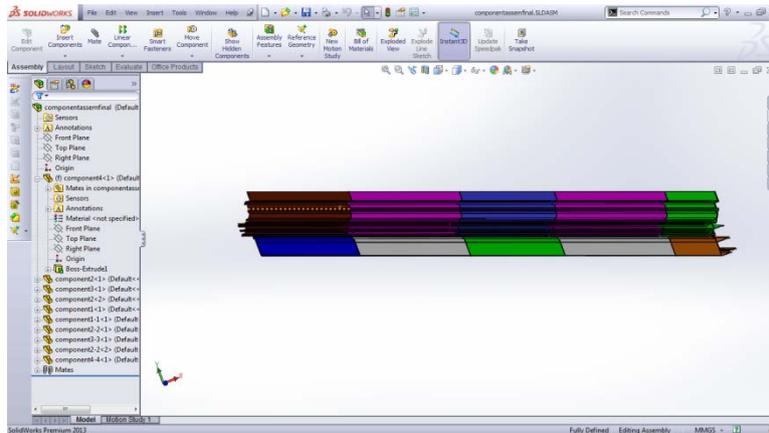


Figure 14 : CAD Model of a Rooftop

k) *Final Assembly:* - Based on the above design of the components, various components are assembled together in order to design the entire assembly which is further used for manufacturing.

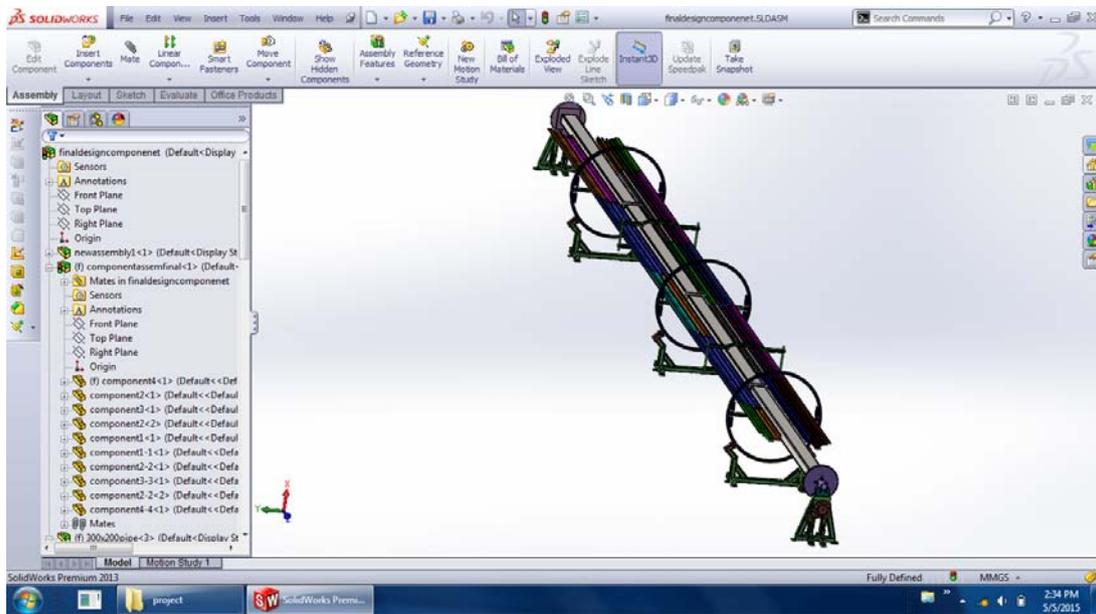


Figure 15 : CAD Model of assembly

III. DESIGN PROCEDURE

Before starting with the designing of the component there are rules which we followed which are:-

1. Compare the cost of production of work with present tools with the expected cost of production, using the tool to be made and see that the cost of buildings is not in excess of expected gain.
2. Decide upon locating points and outline clamping arrangement Make all clamping and binding devices as quick acting as possible
3. Make the jig fool proof Make some locating points adjustable Avoid complicated clamping arrangements
4. Round all corners
5. Provide handles wherever these will make handling easy
6. Provide abundant clearance
7. Provide holes on escapes for chips Locate clamps so that they will be in best position to resist the pressure of the cutting tool when at work
8. Place all clamps as nearly as possible opposite some bearing point of the work to avoid springing action Before using in the shop, test all jigs as soon as made

The complete planning, design and documentation process for a fixture can be carried out systematically in 3 phases based on application which are design pre planning, fixture design, and design approval[4].

The steps considered during designing are as follows:-

- Analytical design for fixture.

- 3 - D Modeling in SOLIDWORKS Wildfire 5.0
- Fixture assembly.

a) Analytical design for fixture

It includes the design of base plate, base vblock, threaded block, supporting v-block, clamp, hexagonal bolt with washer, supporting pin.

b) 3D Modelling in SOLIDWORDS

It includes generation of 3D models of all part details of the fixture like base plate, blade, shim, spacer, bolts, riser, etc.

c) Fixture assembly

It includes assembly of all the parts of the fixture step by step.

IV. DESIGN CALCULATIONS

a) Theoretical design calculation of duct

To calculate deflection of duct having rectangular cross section when subjected to full loading condition :

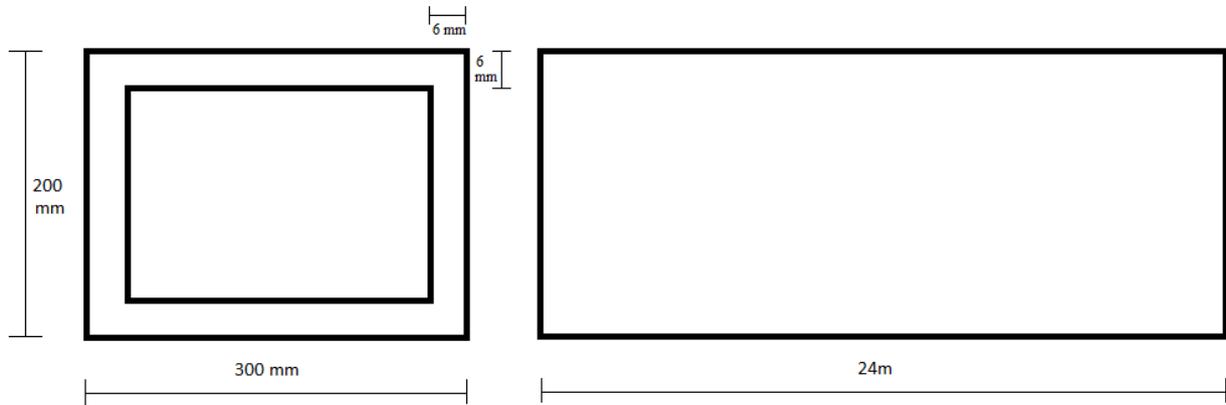


Figure 16 : Rectangular Cross Section of duct

For Figure 24, Moment of Inertia can be determined by,

$$I_{yy} = (b_1 h_1^3 - b_2 h_2^3) / 12$$

From Figure 24,

$$b_1 = 200 \text{ mm} \quad ; \quad h_1 = 300 \text{ mm}$$

$$b_2 = (200 - 12) = 188 \text{ mm} \quad ; \quad h_2 = (300 - 12) = 288 \text{ mm}$$

Substituting above values in moment of inertia formula,

$$\begin{aligned} I_{yy} &= [b_1 h_1^3 - b_2 h_2^3] / 12 \\ &= [(200 * 300^3) - (188 * 288^3)] / 12 \\ &= 75756672 \text{ mm}^4 \\ &= 7.57 * 10^5 \text{ m}^4 \end{aligned}$$

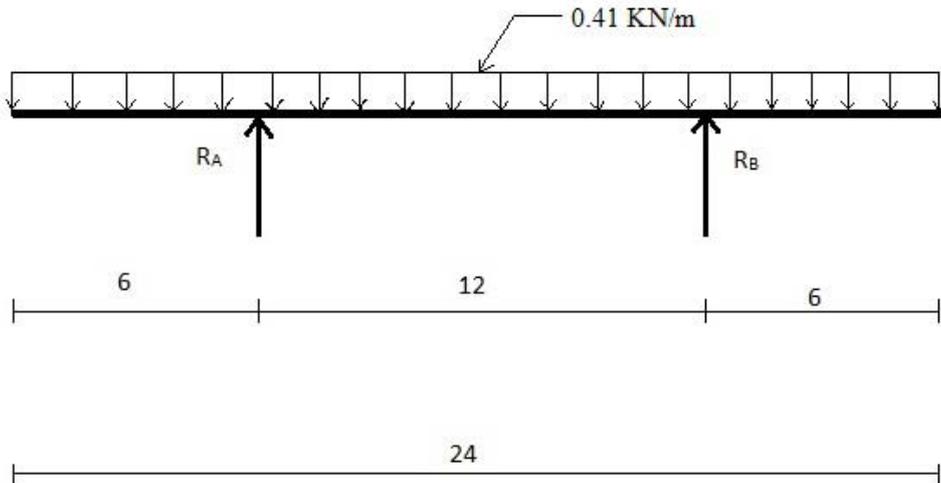


Figure 17 : FBD of Duct of 24 m

Total weight on the duct = 1000 kg = 1000 * 9.81 = 9810 N

Considering it as UDL over the span of 24 m length = 9810 / 24 = 0.41 kN/m

From Figure 25,

Considering Forces in x and y directions, we get,

$$R_A = R_B = 9.81/2 = 4.9 \text{ kN}$$

By Macaulay's method,

$$M = EI D^2y/Dx^2$$

$$\Rightarrow EI D^2y/Dx^2 = 4.9 (x) - 0.41 (x) (x/2)$$

Integrating and solving the equation, we get,

$$EI y = 4.9 (x^3/6) - 0.41 (x^4/24) + C_1x + C_2$$

Boundary Conditions,

$$\text{At } x = 0 \quad ; \quad y = 0$$

$$x = 12 \quad ; \quad y = 0$$

Now Substituting the following boundary conditions in the above equation and solving it, we get,

$$C_1 = -88.08 \quad ; \quad C_2 = 0$$

So, the final equation becomes,

$$EI y = 0.8166 x^3 - 0.017 x^4 - 88.08 x$$

Where, $E = 210 * 10^9 \text{ N/m}^2$
 $I = 7.57 * 10^{-5} \text{ m}^4$

calculated is finalized or changed based on the difference between two values. Two conditions are considered based on which analysis is done which are:-

Therefore,

Deflection, $y = 23.5 \text{ mm}$ (downward)

b) *Verification of calculation in Ansys*

In order to verify the calculations, analysis of duct is carried out in Ansys so that the deflection

i. *Undeformed condition*

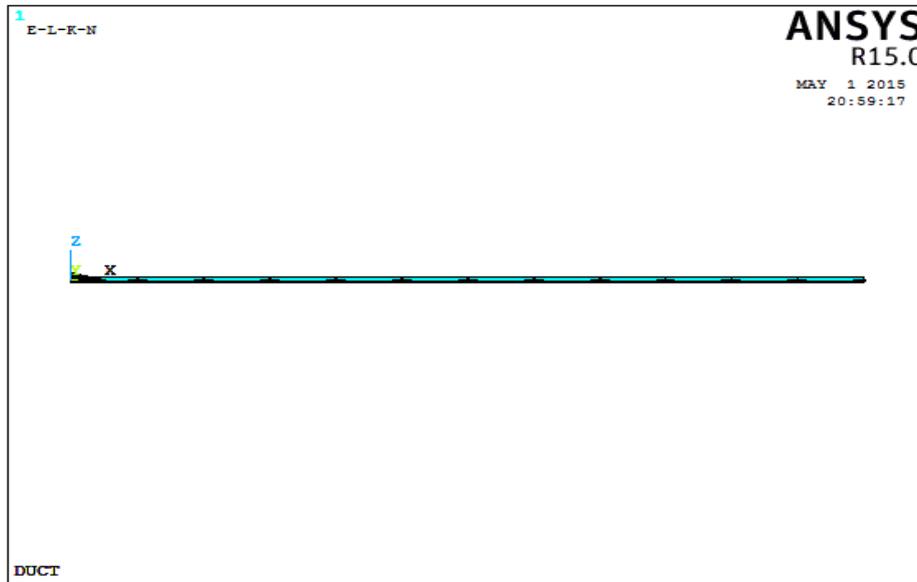


Figure 18 : Undeformed Duct without forces

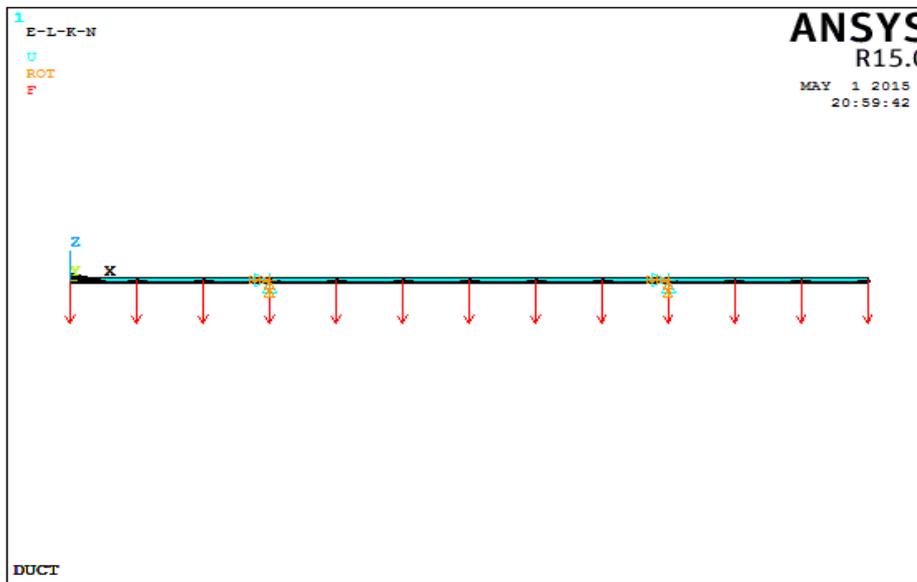


Figure 19 : Undeformed Duct with forces

ii. Deformed Condition

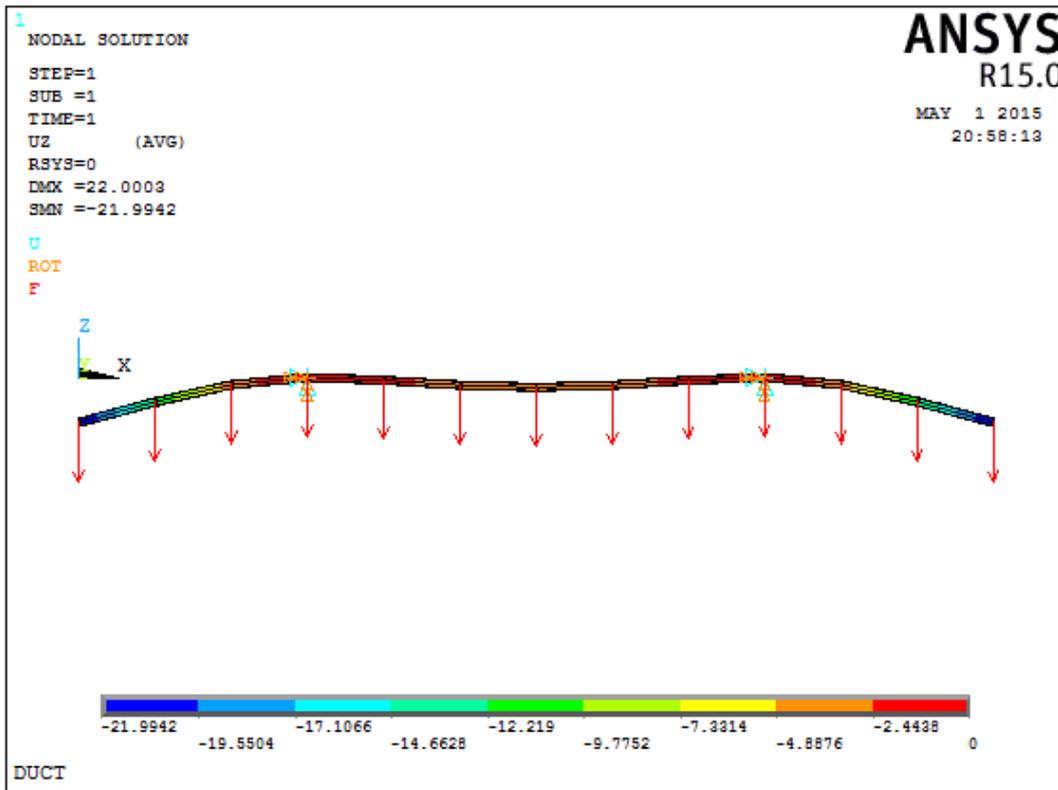


Figure 20 : Deformed Duct

Maximum deflection of duct = 21.9942 (Downward)

c) Calculations of Spur gear

For the given pair of spur gear,
 Pitch Circle Diameter (P.C.D.) of pinion, $d_p = 150\text{mm}$
 Pitch Circle Diameter (P.C.D.) of gear, $d_g = 700\text{mm}$

Based on standard selections, Standard Module, $m = 6\text{mm}$ for gear pair
 From the above information we can calculate the following parameters :-

- 1) Width (b) = 10m = $10 * 6 = 60\text{mm}$
- 2) Teeth of pinion (Z_p) = $d_p / m = 150 / 6 = 25$
- 3) Teeth of gear (Z_g) = $d_g / m = 700 / 6 = 117$
- 4) Center distance (C.D) = $(d_p + d_g) / 2 = (700 + 150) / 2 = 425\text{mm}$
- 5) Addendum (h_a) = 1m = $1 * 6 = 6\text{mm}$
- 6) Dedendum (h_i) = 1.25m = $1.25 * 6 = 7.5\text{mm}$

Now, Check whether Pinion or Gear is weaker
 Ultimate tensile strength for Pinion, $(S_{ut})_p = 600\text{ MPa}$
 for Gear, $(S_{ut})_g = 300\text{ MPa}$

Deformation Factor (c) = 11000 N/mm^2 ;
 Power P = 7.5 KW;
 Factor of safety, FOS = 2.5;
 Sum of errors between meshing teeth (e) = 7.3 microns;
 Velocity factor = $6 / (6 + V)$; Lewis factor = $0.484 - 2.87 / z$;
 Thus,
 $(\sigma_b)_p = (S_{ut})_p / 3 = 600 / 3 = 200\text{ MPa}$

$$(\sigma_b)_g = (S_{ut})_g / 3 = 300 / 3 = 100 \text{ MPa}$$

Lewis form factor is

$$Y_p = 0.484 - 2.87 / 25 = 0.3692$$

$$Y_g = 0.484 - 2.87 / 117 = 0.46$$

Now,

$$(\sigma_b)_p * Y_p = 200 * 0.3692 = 73.84 \text{ MPa}$$

$$(\sigma_b)_g * Y_g = 100 * 0.46 = 46 \text{ MPa}$$

As $(\sigma_b)_p * Y_p < (\sigma_b)_g * Y_g$, gear is weaker than pinion in bending. So, the design is required based on gear.

$$\text{Beam Strength of gear, } F_b = (\sigma_b)_g * Y_g * b * m = 46 * 60 * 6 = 16560 \text{ N}$$

$$\text{Effective load on gear pair, } F_{\text{eff}} = (K_a * K_m * F_t) / K_v$$

$$\text{As } V = \pi d_p N_p / 60 = (\pi * m * Z_p * N_p) / 60$$

$$= (3.14 * 6 * 25 * 1440) / (60 * 10^3)$$

$$= 11.304 \text{ m/sec}$$

$$\text{Tensile Force, } F_t = P / V = 7500 / 11.304 = 663.48 \text{ N}$$

$$K_v = 6 / (6 + V) = 6 / (6 + 11.304) = 0.3467$$

$$K_a = 1.56 \text{ and } K_m = 1 \text{ (assume)}$$

Therefore,

$$F_{\text{eff}} = (K_a * K_m * F_t) / K_v = (1.56 * 1 * 663.48) / 0.3467 = 2985.373 \text{ N}$$

Dynamic Load by Buckingham's Equation :-

$$F_d = [21V(\text{Ceb} + F_t)] / [21V + (\text{Ceb} + F_t)^{(1/2)}]$$

$$\Rightarrow F_d = [21 * 11.304(11000 * 7.3 * 10^{-3} * 60 + 663.48)] / [21 * 11.304 + (11000 * 7.3 * 10^{-3} * 60 + 663.48)^{(1/2)}]$$

$$\Rightarrow F_d = 3631.97 \text{ N}$$

Design safety :-

$$F_{\text{eff}} = (F_t)_{\text{max}} + F_d = K_a * K_m * F_t + F_d$$

$$\Rightarrow F_{\text{eff}} = 1.56 * 1 * 663.48 + 3631.97$$

$$\Rightarrow F_{\text{eff}} = 4667 \text{ N}$$

$$\text{Therefore, FOS} = F_b / F_{\text{eff}} = 16560 / 4667 = 3.5483$$

As available FOS of gear pair is higher than the required FOS; Design of gear pair is safe.

$$\text{Surface Hardness, } F_w = d_p * b * Q * K$$

$$\text{But, } d_p = 150 \text{ mm ; } b = 60 \text{ mm}$$

$$Q = 2Zg / (Z_g + Z_p) = (2 * 117) / (25 + 117) = 1.648$$

$$\text{Assume, } K = 0.16 * (\text{BHN} / 100)^2$$

$$F_w = 150 * 60 * 1.648 * 0.16 * (\text{BHN} / 100)^2$$

$$\text{But, } F_w = \text{FOS} * F_{\text{eff}}$$

$$\text{Hence, } 2373.12 * (\text{BHN} / 100)^2 = 2.5 * 4667$$

$$\text{BHN} = 221.7322$$

V. VARIOUS PROCESSES AND MACHINES USED FOR OUR COMPONENT

- Gas cutting:** - Oxy-fuel cutting is a process that uses fuel gases and oxygen to weld and cut metals, respectively. Pure oxygen, instead of air, is used to increase the flame temperature to allow localized melting of the workpiece material (e.g. steel) in a room environment. A common propane/air flame burns at about 2,000 °C (3,630 °F), a propane/oxygen flame burns at about 2,500 °C (4,530 °F), and an acetylene/oxygen flame burns at about 3,500 °C (6,330 °F).

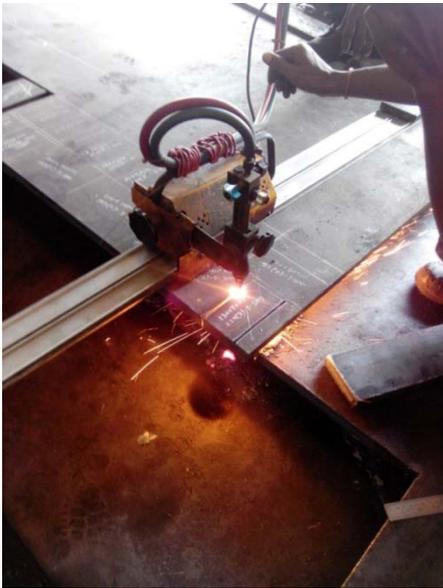


Figure 21 : Gas Cutting Process

- **Arc welding:** -Arc welding is a type of welding that uses a welding power supply to create an electric arc between an electrode and the base material to melt the metals at the welding point. They can use either direct (DC) or alternating (AC) current, and consumable or non-consumable electrodes. Each weld on any component is welded using a specific welding process with the aid of highly focused electrode shielding gas, largedegree of control the welder has over the heat intensity leads to production of very strong and consistent welds [6].
- **Special purpose machine:** -Special purpose machines are designed to perform some specific applications which cannot be carried out using conventional machines. In our company the SPM is of the company SCHARMANN is used mainly for job setting and machining the components using operations like sizing, drilling, rimming, boring, finishing etc.



Figure 22 : Special Purpose Machine

- **Vertical machining center:** - VMC used in our company is of the Hartford Company. It is very costly but serves its purpose to the fullest. Being economical it is widely used for large scale production of components. It is basically constituted of three components- the monitor where program is fed, keypad for feeding the program and the control panel for controlling the feed rate, RPM, start and stop of machine. For the machining purpose following are the codes which are written:-

a) Drilling



Figure 23 : G-code for Drilling

b) Interpolation



Figure 24 : G-code for Interpolation

c) Milling



Figure 25 : G-code for Milling

VI. MANUFACTURING PROCEDURE

The actual manufacturing phase which plays a very important role is mainly classified into three categories:-

- **Fabrication:** Metal fabrication is the building of metal structures by cutting, bending, and assembling processes. This stage plays a very simple but a crucial role. Fabrication shops and machine shops have overlapping capabilities, but fabrication shops generally concentrate on metal preparation and assembly as described above. By comparison, machine shops also cut metal, but they are more concerned with the machining of parts on machine tools.
- **Machining:** Machining is any of various processes in which a piece of raw material is cut into a desired final shape and size by a controlled material-removal process. The three principal machining processes are classified as turning, drilling and milling. Other operations falling into miscellaneous categories include shaping, planing, boring, broaching and sawing
- **Assembly:** Component or end item comprising of a number of parts or subassemblies put together to perform a specific function, and capable of disassembly without destruction. It is the last stage of manufacturing but very difficult requiring high precision and accuracy. Successful fixture designs begin with a logical and systematic plan. With a complete analysis of the fixture's functional requirements, very few design problems occur. When they do, chances are some design requirements were forgotten or underestimated. The workpiece, processing, tooling and available machine tools may affect the extent of planning

needed. Preliminary analysis may take from a few hours up to several days for more complicated fixture designs. Fixture design is a five step problem-solving process.

The manufacturing process which we selected must be an economical balance of materials, manpower, product design, tooling and manpower, plant space, and many other equipment factors influencing cost and practicality.

a) *Our Basic Aim for Manufacturing the Assigned Fixture was*

1. Using Materials More Economically
2. Eliminating Operations
3. Selection of Proper Tooling
4. Minimum Cost Analysis

In minimum cost studies, it is found that when changes occur in a common variable (In this case it is operational speed), the change may modify other cost aspects of the problem in such a way that the combined problem effect produces a minimum value.



Figure 26 : Milling Machine

b) *Component Fabrication*

Precision cutting and forming of sheet metal is utilised for manufacture of superstructures including drivers cab engine hoods, and compartments for housing electrical equipment. All activities connected with pipes like pickling, bending, cutting, forming and threading of pipes of various sizes are undertaken in another well-equipped work area.

All electrical equipment is assembled in the fabricated control compartments and driver's control stands are done in another work area.

c) *Under frame Fabrication*

Under frames are fabricated with due care to ensure designed weld strength. Requisite camber to the under frame is provided during fabrication itself. Critical welds are tested radio-graphically. Welder training and their technical competence are periodically reviewed.

High Horse Power (HHP) under frame is fabricated using heavy fixtures, positioners to ensure down hand welding.

VII. RESULTS

From the above design calculations the type of gear which we have chosen is spur gear because it has proportional Brinell hardness number, high power transmission efficiency, highly reliable and unlike belt drives have no slip condition.

From the above bending condition the design of duct is not suitable, so it is required to take a plain rectangular duct with square cross section in order to reduce the bending below 10mm. By changing the

cross section the inertia will change leading to decrease in the deflection. Thus it is advisable to design a duct 100*100mm with 8mm thickness and 6mm chamfer.

Bearing selection also plays a very important role and based on our application it is highly recommended to select single row deep groove ball bearing as they can sustain some axial load in either direction as well as radial loads, and the two raceway cross-sections are simple circular arcs which can be very precisely finished so that the bearings have low friction and very little noise or vibration. Several different cage designs are available with different characteristics and the choice depends upon the individual application.

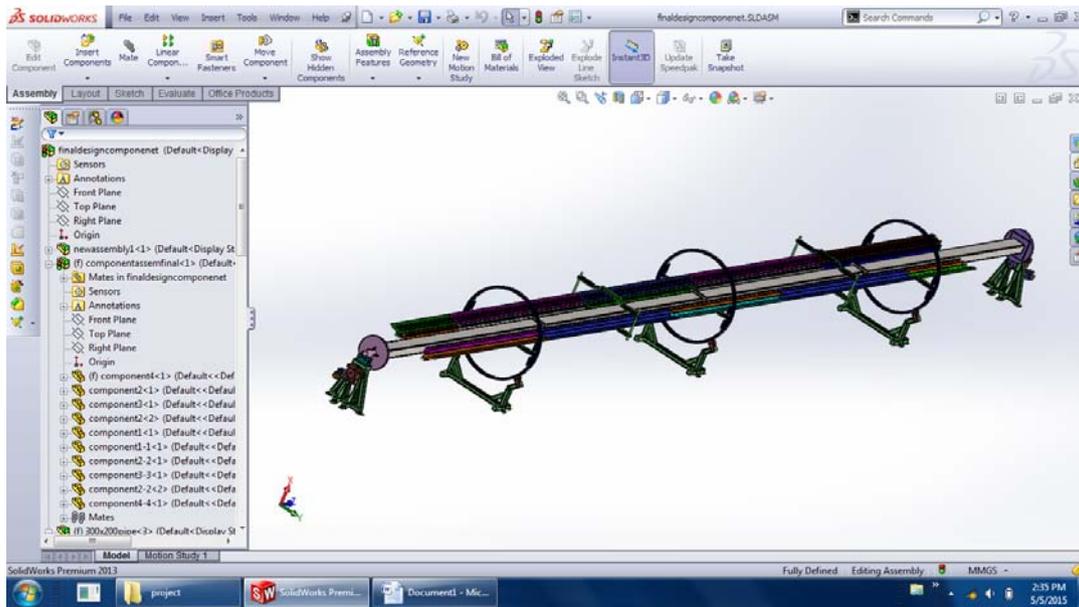


Figure 27 : Final assembly of fixture

VIII. ACKNOWLEDGEMENT

Inspiration and guidance are invaluable in every aspects of life, especially in the fields of academics, which we have received from our company. We would like to thank them as they are responsible for the complete presentation of our project and also for the endless contribution of time, effort valuable guidance and encouragement given by professor S.N.Shindeto project work.

IX. CONCLUSION

Conclusion is drawn on the basis of the information collected on each aspect of our project. It leads to a belief that if applied will create an even better machine than we have designed. The process of conducting operations related to welding fixtures and positioners helps in gaining a deeper understanding as well as effective project process. From finding a resource for research material to design updates of the

part causes the task of accurately prototyping the real design difficult. It is important that the design satisfies all of the functional requirements and design parameters which were outlined at the start of the project. In order to meet the requirements of the fixture customization is done by making the clamping system very practical for various sizes and geometries. By also knowing the material selection a cost benefit analysis could be conducted to determine how cost effective the product is.

Design data handbooks detail mechanical component design analysis with sufficient information provided regarding material specification, properties, requirements for design, etc. This facilitates designers to apply their exact requirements and choose from available resources. Also, verification with the design data books allows one to confirm that correct procedures are being followed. Similarly, the idea behind the preparation of a guide for fixturing as undertaken in this project is to develop a guide that

could be used as a ready reference while designing jigs and fixtures. This project represents the first phase of designing a comprehensive roadmap for fixture design, to assist Tinker Engineers, designers and shop supervisors alike, as well as sub-contractors.

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