Design and Analysis of Welding Fixture for Automotive Component using FEA

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ABSTRACT

In manufacturing industry, fixtures have a direct impact upon product manufacturing quality, productivity and cost. Welding fixtures are designed for the components which are difficult to weld in normal way or without any holding unit. The fixture is to be designed for the cab leg sub-assembly which is to be welded with its companion for its application. The investigation involves study of basics of fixture and welding, need of fixture, location principle. In this work, welding fixtures are designed considering all the welding factors like access to its welding area, cycle time, and availability of space for fixture. Materials are selected as per functional requirements and based on previous designs. The general arrangement is made and fixture is designed with the use of analytical method which includes pneumatic cylinder selection, L-shaped bracket design and positioning of units. Power clamps and LM guides are selected as per the fixture requirements. The design is verified with the use of FE analysis for strength criteria of material and is found under safety limits.

Keyword: - *Fixture, Welding Fixture, Bending Stress, FEA.*

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1. INTRODUCTION

An automobile consist of a suspension system and axle. Suspension is the system of tires, tire air, springs, shock absorbers and linkages that connects a vehicle to its wheels and allows relative motion between the two. An axle is a central shaft for a rotating wheel or gear. This both the systems nearby mounted on cab leg assembly. Cab leg assembly having parts on the basis of which suspension system are mounted on it. Cab Leg Assembly is very important element of an automobile as suspension mounting and axle mounting depends on it. Therefore, it is very essential to ensure the performance of cab leg assembly before they are installed to ensure the trouble free functioning of systems. It is very important to do proper welding of it all parts.

Welding is the important factor in assembly of automobile component so whenever there is need of welding its performance matters. If proper welding is not done it will directly affect the strength of the component. Manufacturer rely on product development to deliver products that add value to their portfolios. Efficient designs reduce material and manufacturing labor costs. In this we aim to design and analyze welding fixture for cab leg assembly in automobile system. The purpose of this welding fixture is to conduct proper welding of sub-component. This includes basic study of fixtures. Design of welding fixture as per component. Analysis of welding fixture and validation of results of analysis with respect to analytical calculation .In this detail understanding, design and analysis of welding fixture for cab leg component is carried out.

2. LITERATURE REVIEW

Following literature review is carried out for the basic study regarding the fixture design before going to actual design of welding fixture for cab assembly.

Hui Wang, Yiming (Kevin) Rong, Hua Li, Price Shaun [4] their work gives brief literature survey of computer aided fixture designing and improvements (automation) in fixture designing. They have suggested some future aspects regarding fixture. Fixture design still continues to be a major bottleneck in the promotion of current manufacturing, though numerous innovative CAFD techniques have been proposed.

S.S.Khodwe, S.S.Prabhune[5], In this work they have presented the design of a test bench for gear box to test a gearbox at the end of assembly line to check leakage, noise, gear shifting feeling and shift load in driving and dragging condition. They have included the design of fixture for gearbox, clamping arrangement, gear shifting arrangement, design of oil dispensing, extraction and filtration unit. They have done FEA of gear box fixture. They have concluded that their design of fixture is safe as error was within the acceptable limit.

NOMENCLATURE		
F	:	Force generated by cylinder (N)
P	:	Input Pressure (N/ m^2)
A	:	Area of cross-section (mm^2)
I	:	Moment of Inertia (mm^4)
w	:	Width of plate (mm)
t	:	Thickness of plate (mm)
X	:	Point load distance (mm)
M	:	Bending Moment (Nmm)
Y	:	Perpendicular distance to neutral axis (mm)
σ	:	Bending Stress (MPa)
D	:	Bore Diameter (mm)
S	:	Stroke of cylinder (mm)
L	:	Length of plate for uniform distribution of load (mm)
β	:	factor selected on the basis of ratio of a/b
y_{max}	:	maximum deflection, mm

Kalpesh Khetani, Jafar Shah, Vishal Patel, et. al.[6], In this paper they have design, analyse and optimize the welding fixture of the brake pedal of a tractor by using ANSYS Workbench 14.5. From results of the thermal analysis they have observed that the thermal stresses are distributed around the welding points and by the graph they found that the temperature variation with respect to time.

Y.J. Gene Liao, S. Jack Hu [7], their work explains importance of fixture designing and different forces that should be considered while designing a fixture. They have presented design and analysis technique for a fixture which is subjected to time varying loads. By combination FEA and nonlinear rigid body dynamics a flexible multi body dynamic model is formulated.

Jigar D Suthar, K.M .Patel, and Sanjay G Luhana [8], their work presents use of impeller structure as a fixture. Basically impeller is used in the exhaust system of drum mix plant to remove dust particles. During welding, fixture is needed to hold the different parts of impeller. In this paper they explained new method in which we can use impeller structure itself as a fixture. For designing a proper impeller as a fixture, proper selection of tolerance has been done. In design for reducing welding distortion they have provided intermittent slots rather than long slots. Analysis is done using ANSYS workbench. From CFD analysis of impeller they have conclude that improper streamline in impeller assembly design is generated due to improper pressure, improper design of casting and improper design of impeller blade.

3. FIXTURE DESIGN

Mass production aims at high productivity to reduce unit cost and interchangeability to facilitate easy assembly. This necessitates production devices to increase the rate of manufacturing and inspection devices to speed- up inspection procedure.

Generally, all the jigs and fixtures consist of [1]:

a) Locating Elements These position the workpiece accurately with to the tool guiding or setting elements in the fixture.

b) Clamping Elements These hold the workpiece securely in the located position during operation.

c) Tool Guiding Elements These aid guiding or setting of the tools in correct position with respect to the workpiece. Drill bushes guide the drills accurately to the workpiece. Milling fixtures use setting pieces for correct positioning of milling cutters with respect to the workpiece.

Every part has 6 degrees of Freedom (3 Linear + 3 Rotary) which need to be arrested to ensure proper location of the part in space. Fig. 1 shows the locating principles. The Location Principle used to achieve this is called the 3-2-1 Principle where:

- **d) 3 Stands for** - Minimum 3 Rests with clamps to establish a part plane thus restricting 1 Up-Down motion + 2 Rotary motions.
- **e) 2 Stands for** – A Round locating pin in a round hole that restricts motion in the 2 directions in the established plane.
- **f) 1 Stands for** - A Round locating pin in a slot that restricts the rotary motion in the established plane about the round pin.

Fixtures are made from a variety of materials, some of which can be hardened to resist wear. It is sometimes necessary to use nonferrous metals likes phosphor bronze to reduce wear of the mating parts or nylon or fibre to prevent damage to the workpiece. Given below are the materials HSS, OHNS i.e. 20MnCr5 and EN-24, MS which often used in fixture, press tolls, collets etc [1].

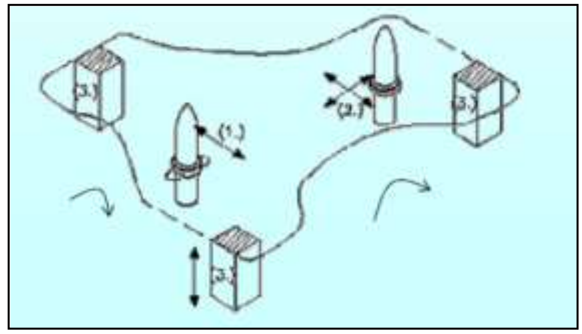

Fig. 1 Location Principle

High Speed Steels (HSS) these contain 18% (or 22%) tungsten for toughness and cutting strength, 4.3% chromium for better hardenability and wear resistance and 1% vanadium for retention of hardness at high temperature (red hardness) and impact resistance. HSS can be air or oil-hardened to RC 64-65 and are suitable for cutting tools such as drills, reamers and cutters [1].

Oil Hardening Non-Shrinking Tool Steels (OHNS) these contain 0.9-1.1% carbon, 0.5-2% tungsten and 0.45-1% carbon. These are used for fine parts such as taps, hand reamers, milling cutters, engraving tools an d intricate press tools, which cannot be ground after hardening (RC62) [1]. Mild Steel It is the cheapest and most widely used material in fixtures. It contain less than 0.3% carbon. It is economical to make parts that are not subjected too much wear and are not highly stressed from mild steel [1].

Fig. 2 shows the CAD model of Cab Leg assembly. Total 13 sub-component parts are there in cab leg assembly. Combination of 13 sub-component part makes main assembly which is called as cab leg assembly. These 13 parts are combined together with the help of welding. Cab leg assembly is used in front suspension assembly. There are two cab leg assembly used. One is LH cab leg assembly and another one is RH cab leg assembly. In this application cab leg assembly is above the chassis of vehicle system. Cross member cables is there to connect LH & RH cab leg assembly which is downside of front floor member. Cab leg assembly is above the anchorage bracket which is connected with the help of lever and anchorage bracket is connected to chassis, cab tilt mechanism. Chassis is connected to rear suspension. So from all the connection we can conclude that all assemblies are interrelated and they transfer their performance on each other.

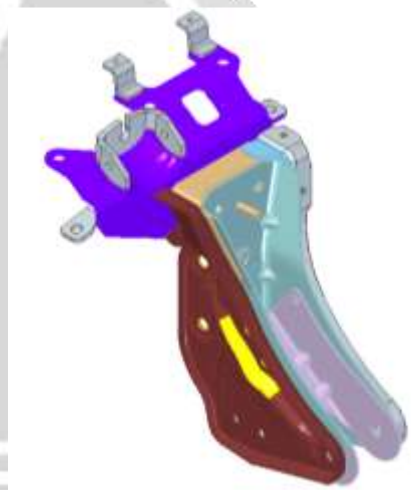

Fig. 2 Cab Leg assembly

In cab leg assembly we cannot assembled or weld all part at a one time. On the basis of previous experience we have divided full cab leg assembly in three stages. We have to repeat this three stage operation for both LH & RH cab leg assembly. In this fixture design we have considered the case of RH cab leg assembly. In which we have considered the only the first stage of RH cab leg assembly that is first Sub assembly of cab leg

In the fig. 3 first stage of RH cab leg assembly is shown. As shown in fig three different sub-component parts welds together to form a first cab leg sub-assembly. On first base bracket two brackets are welded. They cannot be assembled without help of welding. Their position face mating and location is very important to do proper welding of remaining parts in next stages.

Fig. 3 Cab Leg Sub-Assembly stage

Concept design process is basically the interaction of machine designer with end user of the machine. This process is carried out to ensure that end user will not face any problems while using the machine. In fig.4 concept design of fixture is shown which gives the basic idea about various units and their locations.

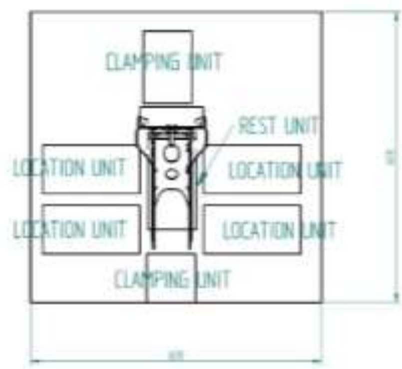

Fig. 4 Concept design

4. DESIGN AND ANALYSIS

The welding fixture is to be designed for welding a cab leg assembly; hence according to the requirement of welding, components of fixture are decided. Following are various components of the test bench.

1. Mechanical Structure and fixture - M.S. Fabricated Base plate.
2. Pneumatic Clamping Units.
3. Holding Blocks.
4. Location Units
5. Component Resting Blocks.

For giving movement to location pin and holding a pin on component face pneumatic cylinder is needed. If hydraulic cylinders used then they produce more force which is not needed.

The operating fluid is a gas, leakage from a pneumatic cylinder will not drip out and contaminate the surroundings, making pneumatics more desirable where cleanliness is a requirement. The cylinders are selected on the basis of force requirement.Here we required a force of 500-3000N which varies as per unit.

For selection of pneumatic cylinder first we need to find out the force generated by cylinder. Force generation depends on the bore size of cylinder also on the input pressure supplied from compressor. Industrial pneumatic pressure is between 4 to 6 bar. Here we have taken 5 bar as an input pressure. On the basis of that cylinder input parameters and selected cylinder model nos. are shown in table II. Cylinders are selected from SMC catalog [9].

Mounting Bracket Design

On the basis of mounting position of locating cylinder we have designed the bracket with L-shaped. L-shaped brackets are commonly used in most of the fixture arrangements due to its simplicity in design. The design factor in L-shaped brackets is only thickness of the plate from which it is going to be manufacture. Let's consider our case as a cantilever beam (though it is not a proper cantilever beam but for the initial analysis we are considering this as a cantilever beam) [2].

Table 1. INPUT PARAMETERS FOR CYLINDER SELECTION

	Cyl. 1 & 2	Cyl. 3 & 4	Cyl. 5	Cyl. 6
Required F (N)	750-1000	1500-1750	2500-2750	750-1000
D (mm)	50	63	80	50
P (N/m^2)	500000	500000	500000	500000
S (mm)	25	50	50	25
Cyl. Model No.	CD55B50-25M	MGPM63-50	CD55B80-50M	CD55B50-25M

Table 2. INPUT PARAMETERS FOR BENDING STRESS

	Cyl. 1 & 2	Cyl. 3 & 4	Cyl. 5	Cyl. 6
F (N)	981.25	1557.8	256	981.25
W (mm)	105	110	110	75
t (mm)	10	10	10	10
L (mm)	188.5	246	155	-
X (mm)	139.5	-	-	65
Y (mm)	5	5	5	5

- **Force:** It is the force generated by cylinder. F= P*A
- **Moment of Inertia:** I= $wt^3/12$
- **Maximum Moment for Cantilever beam with point load:** M= F*X
- **Maximum Moment for Cantilever beam with udl:** M= $wl^2/2$
- **Bending Stress:**
  It is the Bending Stress of Brackets.

$$\frac{\sigma}{Y} = \frac{M}{I}$$

Factor of Safety= $\frac{Max.allowable\ stress}{bending\ stress}$

Calculations:-

Table 2 shows the input parameters for calculating a bending stress value for L-Bracket as a cantilever beam.
For 1st and 2nd cylinder selection following calculations are shown

F= P*A= 500000 * 0.0019625 =981.25 N= 100 kg

Bending Stress Calculations for 1st & 2nd Cylinder Mounting Bracket

I= $wt^3/12$ = 105 * 10^3 / 12 = 8750 mm^4

M= F * X = 100 *139.5 = 136884.375 Nmm

σ =Bending Stress= 78 MPa

Factor of Safety = 3

Table 3 shows the analytical results of bending stress values for pneumatic cylinder mounting brackets. The modelling of welding fixture flange for cab leg is carried out in Solid Edge (Student Edition) and analysis done on Ansys. Pneumatic cylinders, mounting brackets opening on welding fixtures are important for illustration process.

Power Clamps are used for clamping purpose in this fixture design. Here we required a clamping moment of 350-400 Nm on the basis of that we have chosen power clamp from the TUNKER catalogue i.e. V631BR2ZA40 [10].

For load carrying and its moment purpose we need a LM Rail & Block. Here we required basic static load rating between 50-75 kN on the basis of that and available space we have chosen HGH-25-CA model of HIWIN make [11].

Table 3. Analytical Stress Table

Bracket No.	Analytical Bending Stress (MPa)
I & II	78
III & IV	105
V	106
VI	51

Design of base plate

Following formula is used, ref [3]

Table 4 shows the input parameters for base plate.

σ_{max} (bending stress) = $\frac{-\beta q b^2}{t_1^2}$ = 9.66 N/mm^2 OR MPa

Now, we will check the deflection of the plate, by following formula ref [3]

$y_{max} = \frac{\alpha q b^4}{E t_1^3}$ = 0.062 mm = 60 micron

Table 4. Input parameters for base plate

Parameter	Value	Unit
Thickness of Plate (t_1)	10	mm
Width of plate (b)	525	mm
Length of Plate (a)	625	mm
Load on the plate (F)	3000	N
UDL	0.0091	N/mm^2
Modulus of Elasticity (E)	210000	N/mm^2
B	0.3834	

Hence, deflection is very less, but still we cannot use this thickness of plate. As here we didn't consider fixture height also for calculating stress and deflection. For safety we will take thickness of plate as 20mm because it is available in standard size. . Also for flatness process for small thick plate having cost more as compared to 20 mm thickness plate. Considering 20 mm plate is good. For handling purpose also we need to consider 20 mm as a full fixture load is on it.

So now we calculate the deflection for 20 mm plate.

$y_{max} = \frac{\alpha q b^4}{E t_1^3}$ = 0.0072 mm = 07 micron

Hence, deflection is very less, so we have use this plate.

Structural Analysis

Traditionally, to determine the acceptability of the design, formulas and charts based on analytical solutions and empirical data have been used. This is today called as Design by Formula (DBF). In the 1960's an alternative to DBF was established known as Design by Analysis (DBA). It served as a complement for the design cases which were not covered by DBF, and was based on a method where stresses are classified into different categories. Formulas are not always applicable and therefore design by analysis serves as a complement.

The stress distribution of fixture mounting brackets is found out. For doing this analysis meshing and loading conditions on fixture are important. Here the meshing is done using solid tetrahedron elements. Fig. 5 shows the meshing of L-bracket. For better accuracy high mesh quality is used. Fig. 6 shows the boundary conditions applied i.e. force and fixed support on the L-Bracket. Von-Mises stress distribution on the bracket when it is fixed and weight of a cylinder is acting on bracket is as shown is fig. 7. By finite element analysis the maximum stress developed on the bracket is 69 MPa. Allowable Stress value is 250MPa. This stress value is lower than allowable, hence the design is safe. Fig. 8 shows the deflection of L- Bracket. Maximum deflection is just a 0.22 mm which is negligible.

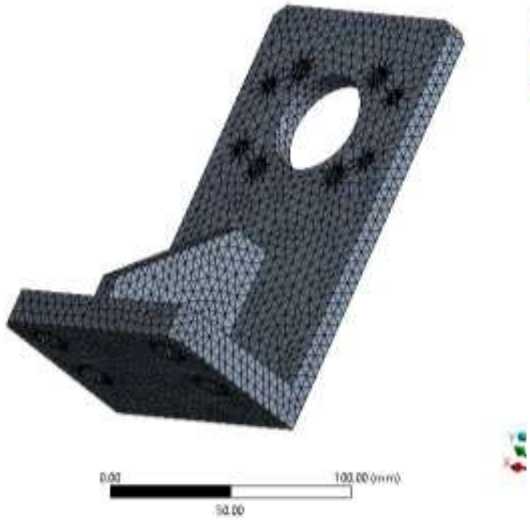

Fig. 5 Meshing

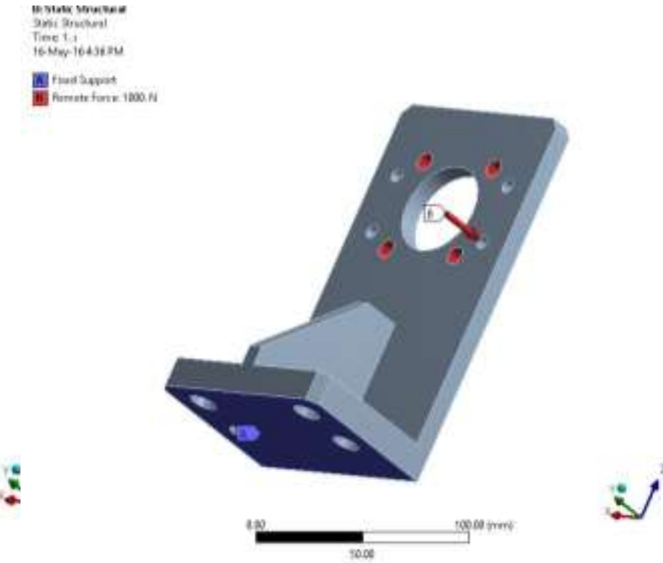

Fig. 6 Force Application

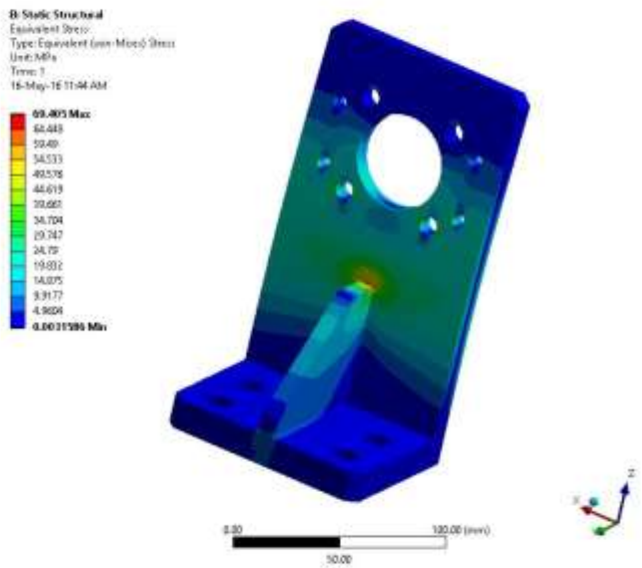

Fig. 7 Stress distribution

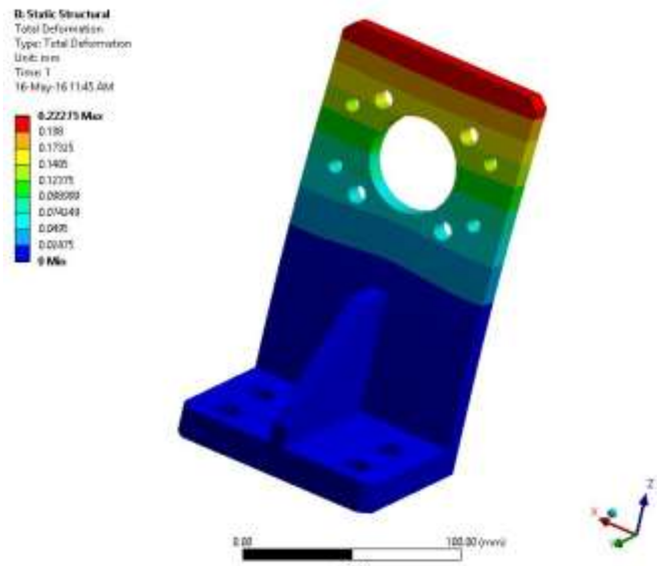

Fig. 8 Deflection

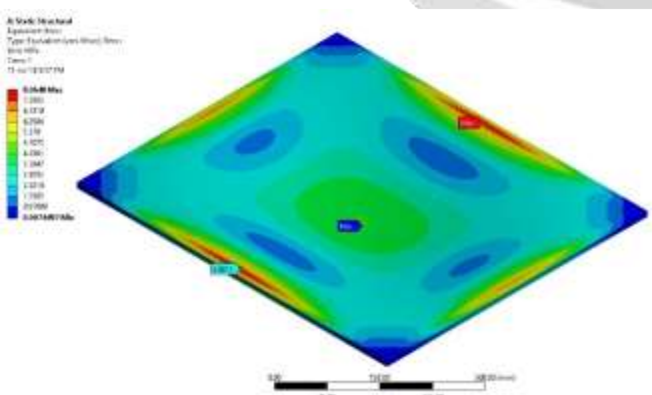

Figure 9. Stress on base plate

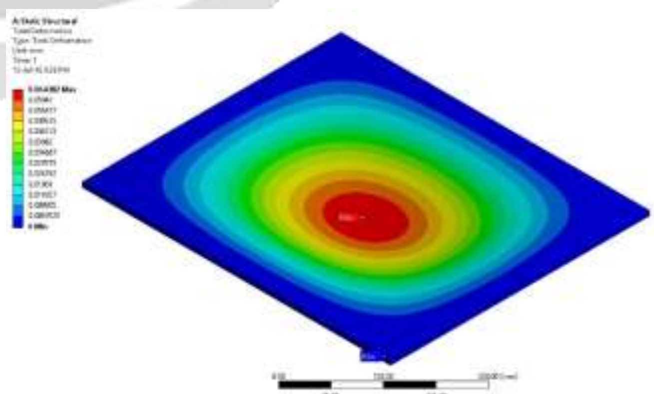

Figure 10. Deformation on base plate

By finite element analysis maximum torsional stress developed is 8.06 MPa. This value is lower than allowable, hence design is safe.
Table 5 & 6 shows the values of bending stress from analytical calculations and FEA. The percentage error has been calculated for bending stress values and are within acceptable limit. Deflection values are also shown in table for all mounting brackets based on FEA results. The analytical & FEA results of stress are compared in graphical form as shown in fig. 11.

Table 5. Result Table

Bracket No.	Analytical Bending Stress (MPa)	Bending Stress (MPa)	Deflection (mm)	% Error
I & II	78	69	0.22	11.5
III & IV	105	117	1.93	11.42
V	106	100	0.14	5.06
VI	51	47	0.14	7.84

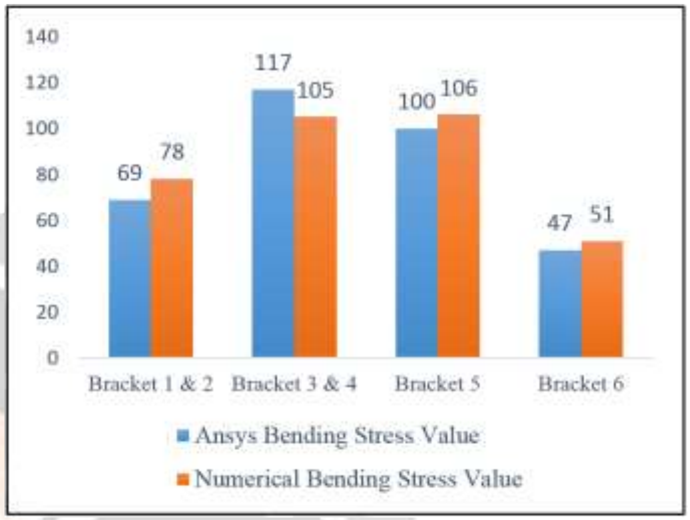

Fig. 11 Bending Stress Graph

Table 6. Result table for base plate

Analytical Bending Stress (MPa)	Bending Stress (MPa)	Analytical Deflection (mm)	Deflection (mm)	% Error for stress	% Error for deflection
9.66	8.06	0.062	0.064	11.5	3.2

Fig. 12 shows the full fixture design in which 1 to 8 nos. indicates all the cylinders and I to VI indicates all the cylinder mounting brackets.

5. CONCLUSIONS

The complete fixture for welding of cab leg assembly has been designed analytically as well as critical components of the fixture assembly are analysed using FEA for safety. The design is safe as per strength criteria as all the stress levels are below the allowable limit of stress. The percentage error values of analytical and FEA design varies within the range of 5% to 15%; which is acceptable. The fixture satisfies the functionality of the welding.

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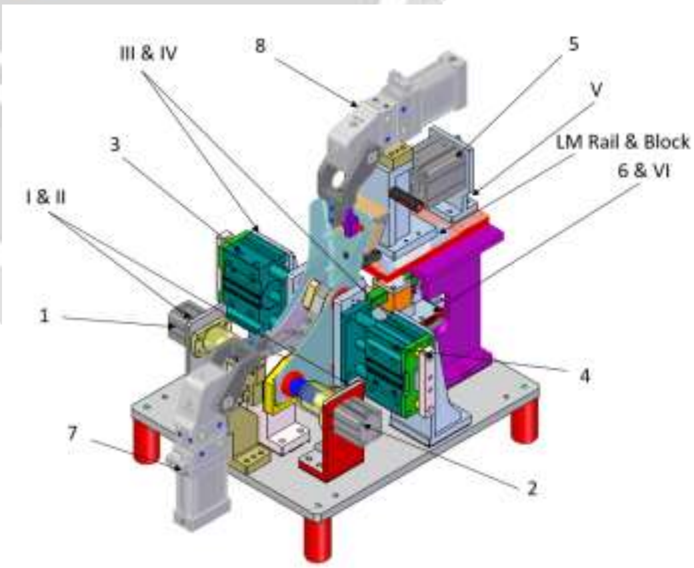

Fig. 12 Complete Fixture Design

REFERENCES

[1] P H Joshi, "Jigs and Fixtures", Third Edition, 2004, Tata McGraw Hill Publishing.
[2] V.B. Bhandari, "Design of Machine Elements", Third Edition, 1987, Tata-McGraw Hill Publication.
[3] Warren C. Young Richard G. Budynas, "Roark's Formulas for Stress and Strain", Seventh Edition, McGrwhill Publication.
[4] Hui Wang, Yiming (Kevin) Rong, Hua Li, Price Shaun, "Computer aided fixture design: Recent research and trends", Volume 42, Issue 12, December 2010, Pages 1085–1094.
[5] S. S. Khodwe, S. S. Prabhune, "Design and Analysis of Gearbox Test Bench to Test Shift Performance and Leakage" International Journal of Advance Research and Innovative Ideas in Education Volume 1 – issue2. (2015) Page 270-280.
[6] Kalpesh Khetani, Jafar Shah, Vishal Patel, Chintan Prajapati, Rohit V. Bhaskar, "Design and Thermal Stress Analysis of Welding Fixture of a Brake Pedal" International Journal on Recent Technologies in Mechanical and Electrical Engineering (IJRMEE) ISSN: 2349 -7947 Volume: 2 Issue: 5
[7] Y.J. Gene Liao, S. Jack Hu "Flexible multi body dynamics based fixture-work piece analysis model for fixturing stability" International Journal of Machine Tools Manufacture" 40, 2000.
[8] Jigar D Suthar, K.M .Patel, and Sanjay G Luhana, "Design and analysis of fixture for welding an exhaust impeller", Procedia Engineering 51 (2013) 514 – 519.
[9] SMC Catalog-2016.
[10] TUNKERS catalog-2016.
[11] HIWIN catalog-2016.