DESIGN AND DEVELOPMENT OF TRUNNION HYDRAULIC FIXTURE FOR REDUCING COST AND MACHINING TIME OF BASE JAW

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ABSTRACT

A fixture is designed and built to hold, support and locate every component to ensure that it is machined with accuracy. The recent trends in the industry are towards adopting the hydraulic and pneumatic techniques because it saves time and machining cost gets reduced. By using computer-aided fixture design technique the designer creates a model of fixture and carried out finite element analysis on fixture model by considering given boundary condition before getting manufacture and can see deficiency and could make modification accordingly without getting it manufactures, which saves a great amount of money and time. In this project, the same methodology is adopted for designing analyzing the designed Trunnion hydraulic fixture. The Trunnion hydraulic fixture is designed for Master Jaw of the chuck to perform milling, undercut and drilling operations using Vertical machining centers. Computer-aided fixture design of fixture assembly is carried out using SOLIDWORKS 2017 software and Finite element analysis of fixture and cylinder block is carried out using ANSYS Static workbench software.

Keywords: hydraulic fixture, trunnion fixture, swing cylinder, base jaw, block cylinder, OK vise.

1. INTRODUCTION

The fixture is the basic tool for holding a workpiece during manufacturing. The fixture used to support and locate the workpiece as required. It also serves to reduce working time by allowing quick set-up, and by smoothing the transition from part to part. Reduces the complexity of a process, allowing for unskilled workers to perform it and effectively transferring the skill of the toolmaker to the unskilled worker. Fixtures also allow for a higher degree of operator safety by reducing the concentration and effort required to hold a piece steady.

1.1 LITERATURE REVIEW

Chetan M, Patel. *et al.*, [1] paper includes the unique aspect of designing and manufacturing a hydraulic fixture for machining earthing terminal block on CNC - VMC 430. It is an integrated approach of manufacturing to the design process of a hydraulic fixture. His design of fixture to accommodate 5 various types of strips of the same shape but of different sizes.

Harish P. Jorvekar. *et al.*, [2] has said the efficiency and reliability of the fixture design has been enhanced and a result of their fixture design made reasonably. A fixture was manufactured and resulted rate of production has increased. Human error and cycle time have been reduced by their fixture design.

Komal Barge. *et al.*, [3] has developed the fixture by considering to reduce the loading and unloading time. By his fixture, he reduces cycle time by 2min from 5min 10sec to 3min 30sec. Rejection rate has been minimized by 2%. 60 products are produced per shift on a manually operated fixture and 85 products are produced on the hydraulic fixture.

Malave. S.K. *et al.*, [4] fixture workpieces are clamped with same clamping force range which is 150 kN in every cycle. Hainbuch locator has facilitated greater vibration damping due to use of vulcanized rubber along with steel. Large clamping range and fast conversion time are achieved. Compared to existing old fixture, this newly proposed fixture is stable and capable. By this new fixture design, workpieces are clamped in the same direction every time so a correct location is achieved and eliminating the variability in workpiece deflection from clamping force.

Maniar N.P. *et al.,* [5] discussed that HMC is the best solution for the particular component but designer can’t ask industries to replace CNC with HMC because of the cost factor, as HMC cost more than CNC. With the help of creo element/ proe5.0, the unbalance mass and its location of C.G are found out and it is remarkably same as an experimental result on the dynamic balancing machine. So, Computer-aided mass balancing of quadrants is found more accurate to decrease in percentage error by almost 6%.

Nisarg Parmar. *et al*., [6] has reviewed an approach to reduce cycle time for loading and unloading of a part. To fulfill the multifunctional and high performance fixturing requirements optimum design approach can be used to provide comprehensive analyses and determine an overall optimal design. His aim is to formalize a methodology to facilitate the automation of such design process. The proposed methodology for fixture design process will fulfill researcher production target and enhanced the efficiency, Hydraulic fixture reduces operation time and increases productivity, high quality of operation, reduce accidents.

Sanket. *et al.,* [7] has designed fixture for component Body has been designed successfully in order to increase accuracy and productivity. The maximum cutting force, Value of stress and deformation was found in the drilling operation and checked they lie within the elastic limits by analytical & FEA methods. The same fixture can be used for all various strips with just a change of rest block; the clamps being the same. The same methodology of location and clamping are used for all 5 strips. The rejection rate is reduced to less than 1 % in a new set up in comparison to 15 % in an old traditional setup and productivity is increased by 25 %.

Shailesh S. Pachbhai *et al.,* [8] has proposed fixture will not only provides the repeatability and high productivity but also offers a solution, which reduces workpiece distortion due to clamping and machining forces. the values of deformation and von misses stress calculated with ANSYS software is comparatively lower than standard values and hence he concluded design is safe.

2. PROBLEM STATEMENT

In the company, currently the raw material(En-353) for the manufacturing part (Base jaw) is undergoing operations such as rough milling, finish Milling, undercut, drilling, chamfering, tapping are carried out in conventional machinery. These are time-consuming and sometimes not economical due to conventional. Maximum time of worker is used for setting of Fixture and its Handling. It is more hectic to the operator to load and unload. By observing these problems here, I came to know that there is need of designing a new fixture to increase productivity, reduce the rejection rate, reducing machining time and cycle time by making loading and unloading process simple.

Conventional Machines Includes
Machine 1: Radial Drilling Machine
Machine 2: Horizontal Milling Machine
Machine 3: Conventional Milling Machine

2.1 Objective

The objective of Trunnion Hydraulic fixture is to transfer the conventional machining operations to modern and high tech Vertical Milling Machine (VMC LMW JV55) to reduce Cycle time, Machining time, handling time and to complete set of operations in a single setup.

2.2 Component detail

A Power chuck is a specialized type of clamp. It is mounted on the lathe spindle used to hold an object with radial symmetry actuated by a cylinder. In drills and mills, it holds the rotating tool whereas in lathes, it holds the rotating workpiece. On a lathe the chuck is mounted on the spindle which rotates within the headstock.

A master jaw is been used in the chucks, which converts the one side axial linear motion to another side linear motion. The top clamping jaws are mounted on the Master jaws which are used to clamp the components.

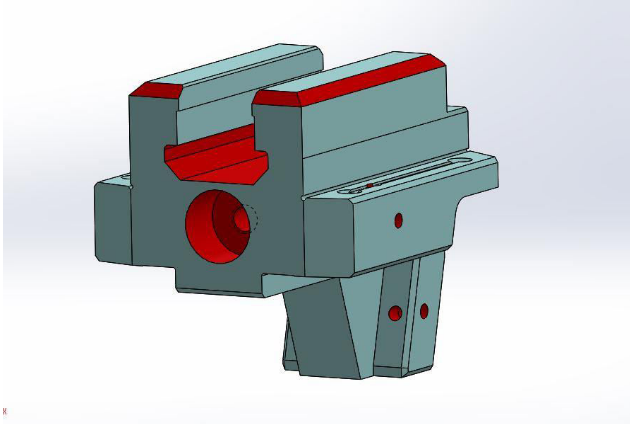

Figure-1. Base jaw.

3. FIXTURE DESIGN

The fixture is designed with UCAM rotary table which can be indexed to any degree as per the requirement. It is also implemented that most number of components should accommodate the fixture at a same time, so that handling time gets reduced. This fixture is designed which can accommodate eight master jaws at single loading and unloading. This saves time by eight times. Machine JV55 can accommodate 20 tools for operations so it is easier for accommodating a maximum number of operations in the single setup.

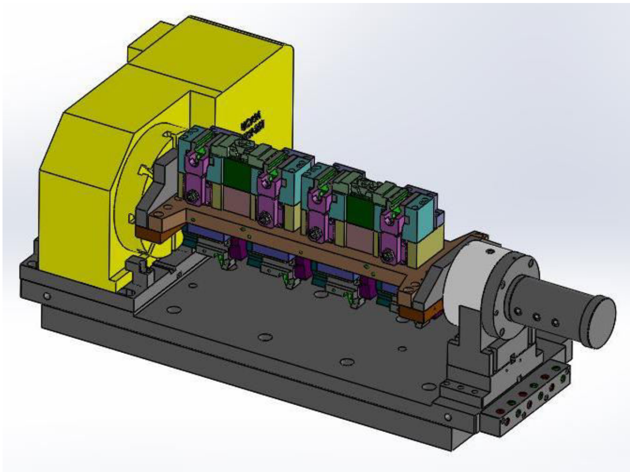

Figure-2. Trunnion fixture.

Table-1. Major parts of trunnion fixture.

S. No.	Part Name	Quantity
1	Base plate	1
2	UCAM	1
3	Distributor	1
4	Pedal Plate	1
5	Cylinder Rest Block	4
6	Block cylinder-1	4
7	OK-vise	2
8	Clamp -1	4
9	Block Cylinder-2	2
10	Clamp -2	4
11	Rest Block -2	4
12	Rest Block -1	4
13	Guide Block -1	4
14	Guide Block -2	4
15	Support Plate -1	2
16	Swing Cylinder	4

Load capacity
CNC Rotary table: URX - 250
Load capacity of Rotary table = 400kg
= 400x0.8 = 320kg
Weight of Fixture = 88kg
Fixture weight 88kg is less than the allowable load capacity of UCAM rotary table. Therefore condition is safe.

Work inertia
Allowable Work Inertia: 2.4kg.m^2
Inertia (I)
$= (m_1\times((4a_{12}+b_2)/12)) + (m_2\times((4a_{22}+b_2)/12))$
$=(29\times((4\times0.1312+0.1552)/12))+$
$(48\times((4\times0.152+0.1552)/12))$
$= (29\times((0.09266)/12)) + (48\times((0.114)/12))$
$= 0.2239+0.456$
$= 0.6799$ kg.m^2
Inertia of fixture is less than the allowable inertia of UCAM rotary table. Therefore condition is safe.

Driving Torque
Driving Torque of Table: 400 Nm
Torque $= I\times\omega\times2\pi/360$
$= 0.6799\times1000\times0.0175$
$= 11.8982$
Necessary Torque = T×1.5
$= 11.8982\times1.5$
$=17.8473$ Nm
Torque required for drive the fixture is 17.8473 which is lower than torque produced in rotary table.

Cutting forces

For roughing (milling)
Specific Cutting Force (K_c) = 1500 N/mm^2
Estimated Chip Thickness (ECT) = 0.4
Cutting Edge Length (CEL) = 5 mm
Area (A) = 0.4 × 5 = 2 mm^2
$F_C = K_C \times A$
$= 2 \times 1500$
$= 3000$ N
Resultant Force $F_H = 0.5 \times F_C$
$= 0.5 \times 3000$
$=1500$ N
Axial Cutting Force
$F_A = F_H \times \cos(CFA)$
$= 1500 \times \cos 30$
$= 1299$ N
Radial Cutting Force
$F_R = F_H \times \sin(CFA)$
$= 1500 \times \sin 30$
$= 750$ N

for finishing (milling)
Specific Cutting Force (Kc) = 1700 N/mm^2
Estimated Chip Thickness (ECT) = 0.2
Cutting Edge Length (CEL) = 2 mm
Area (A) = 0.2 × 2 = 0.4 mm^2
$F_C = K_C \times A$
$= 0.4 \times 1700$
$= 680$ N
Resultant Force $F_H = 0.35 \times Fc$
$= 0.35 \times 680$
$= 238$ N
Axial Cutting Force $F_A = F_H \times \cos(CFA)$
$= 238 \times \cos 60$
$= 199$ N
Radial Cutting Force $F_R = F_H \times \sin(CFA)$
$= 238 \times \sin 60$
$= 206$ N

drilling load
$T=(0.005\times K_d\times F_f\times F_t\times B\times W) +(0.004\times K_d\times D^2\times J\times W)$
$=(0.005\times24000\times0.133\times2.54\times1.2\times1.3)$
$+(0.007\times24000\times3^2\times0.006\times1.3)$
$=1575$ N
T=Thrust N
Kd =Work material factor
Ff =Feed factor
FT =Thrust factor for drill diameter
B=Chisel edge factor for thrust
W=Tool wear factor
D=Drill diameter mm
J=Chisel edge factor for thrust

OK VISE
The Model selected for the fixture is DK2-VT.
Max Force it can withstand is 65
Force created in Milling Operation - 1299 N
Since the force created is less than the allowable force, this OK vise can be used

VOL. 13, NO. 21, NOVEMBER 2018 ISSN 1819-6608
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Cylinder suitable for OK Vise:
Piston dia: Ø3cm
Area: 7.06cm^2
The Force created in cyl : 283 kgf
: 283 × 9.81
: 2776 N
Since 2776N is higher than the milling load, it can withstand the force formed during the milling operation.

Swing cylinder

The swing cylinder which can be used for clamping base jaw is Clasys 0301-0101. It's Area: 5cm^2 (from catalogue)
The force created in cyl : 200 kgf
: 200 × 9.81
: 1962 N

Since 1962N is higher than the milling load, it can withstand the force formed during milling operation; therefore this can be used for clamping.

Block cylinder

The block cylinder which can be used for clamping base jaw is 0105-0303
It's Area: 8.04cm^2 (from catalogue)
Force Created in Cyl: 322kgf
: 322 × 9.81
: 3158 N

Since 3158N is higher than the drilling load, it can withstand the force formed during milling operation; therefore this can be used for clamping.

4. ANALYSIS FOR CRITICAL PARTS

Table-2. Material properties.

Parts	Material	Poisson's ratio	Density (kg/m^3)	Young's Modulus (GPa)	Tensile strength (MPa)	Yield strength (MPa)
Pedal Plate	C45	0.29	7850	210	700	430
Rest Block 1	EN-19	0.28	7850	210	755	555
Guide Block 1	EN-353	0.28	7870	180	896	320
Clamp 1	EN-19	0.28	7850	210	755	555
Rest Block 2	EN-19	0.28	7850	210	755	555
Clamp 2	EN-19	0.28	7850	210	755	555

For Pedal Plate

Deflection analysis

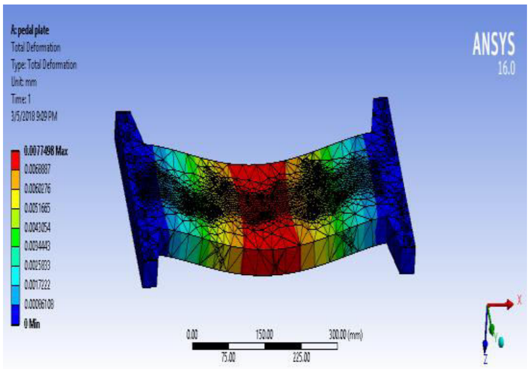

Figure-3. Deflection analysis of pedal plate.

Max deflection value is 0.00774mm
Allowable deflection = L/360
= 577/360
= 1.60mm
Therefore 0.00774 < 1.6mm
Deflection is under safe condition

Stress analysis

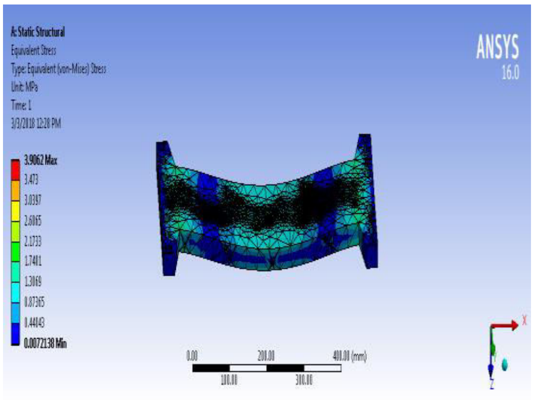

Figure-4. Stress analysis of pedal plate.

Max stress formed due to load is 3.9Mpa
Allowable Stress = Yield strength/FOS
= 430/1.5
= 286.6MPa
Stress formed 3.9 < 286.6 MPa
Stress is under safe condition

For Rest Block 1

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Deflection analysis

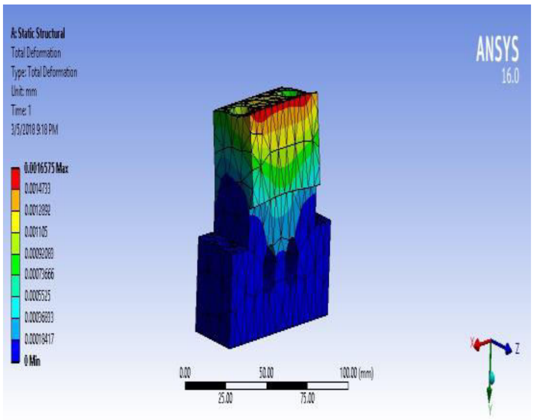

Figure-5. Deflection analysis of Rest Block 1.

Max deflection is 0.0016mm
Allowable deflection = L/360
= 58/360
= 0.161mm
Max deflection 0.0016 < 0.161 mm
Deflection is under safe condition

Stress analysis

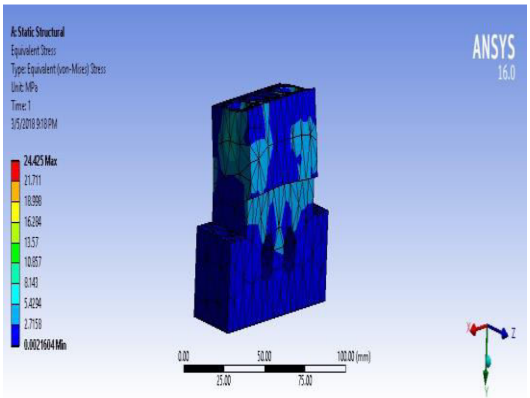

Figure-6. Stress analysis of Rest Block 1.

Max stress formed due to load is 24.5 Mpa
Allowable Stress = Yield strength/FOS
= 555/1.5
= 370MPa
Stress formed 24.5 < 370 MPa
Stress formed is under safe condition

For Guide Block 1

Deflection analysis

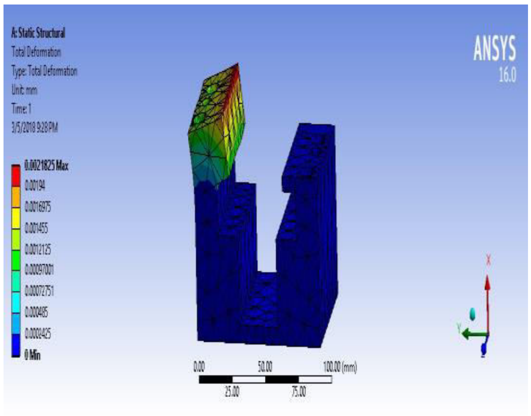

Figure-7. Deflection analysis of Guide Block 1.

Max deflection is 0.0021mm
Allowable deflection = L/360
= 72/360
= 0.257mm
Max deflection 0.0021 < 0.257 mm
Deflection is under safe condition

Stress analysis

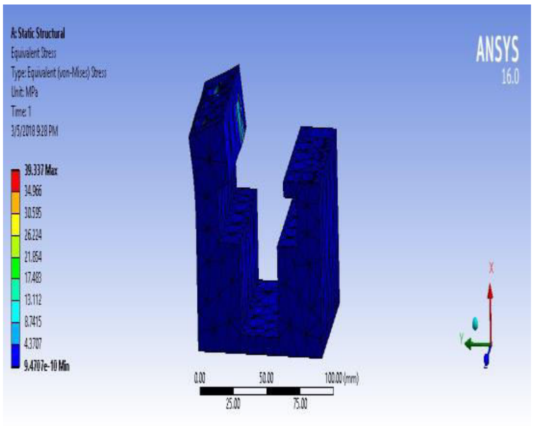

Figure-8. Stress analysis of Guide Block 1.

Max stress formed due to load is 39.3 Mpa
Allowable Stress = Yield strength/FOS
= 320/1.5
= 213.3MPa
Stress formed 39.3 < 213.3 MPa
Stress formed is under safe condition

For Clamp 1

Deflection analysis

VOL. 13, NO. 21, NOVEMBER 2018 ISSN 1819-6608
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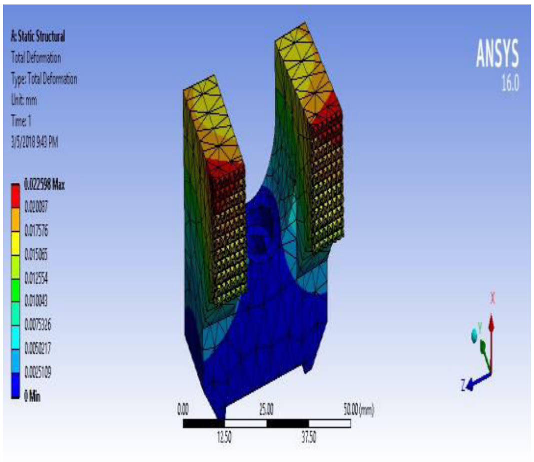

Figure-9. Deflection analysis of Clamp 1.

Max deflection is 0.02259mm
Allowable deflection = L/360
= 32/360
= 0.088mm
Max deflection 0.02259 < 0.088 mm
Deflection is under safe condition

Stress analysis

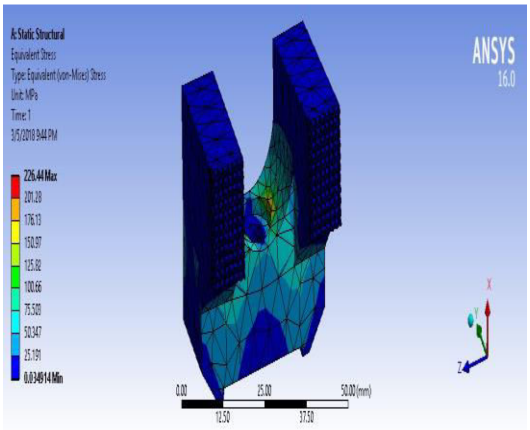

Figure-10. Stress analysis of Clamp 1.

Max stress formed due to load is 226.44 Mpa
Allowable Stress = Yield strength/FOS
= 555/1.5
= 370MPa
Stress formed 226.44 < 370 MPa
Stress formed is under safe condition

For Rest Block 2

Deflection analysis

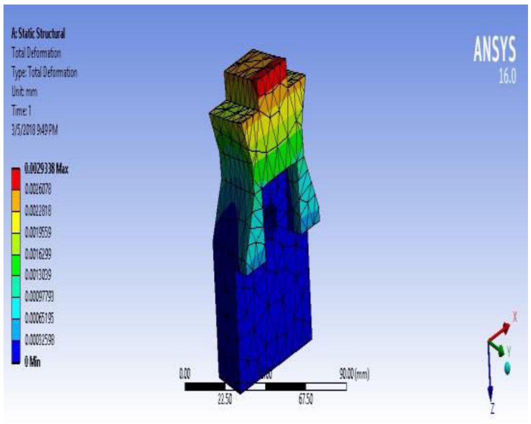

Figure-11. Deflection analysis of Rest Block 2.

Max deflection is 0.0029mm
Allowable deflection = L/360
= 73/360
= 0.202mm
Max deflection 0.0029 < 0.202 mm
Deflection is under safe condition

Stress analysis

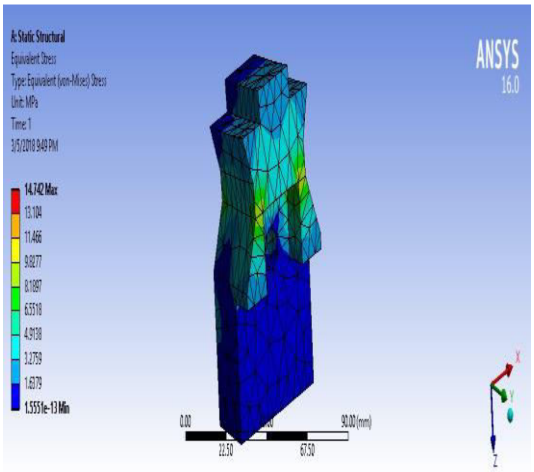

Figure-12. Stress analysis of Rest Block 2.

Max stress formed due to load is 14.74 Mpa
Allowable Stress = Yield strength/FOS
= 555/1.5
= 370MPa
Stress formed 14.74 < 370 MPa
Stress formed is under safe condition

For Clamp 2

Deflection analysis

VOL. 13, NO. 21, NOVEMBER 2018 ISSN 1819-6608
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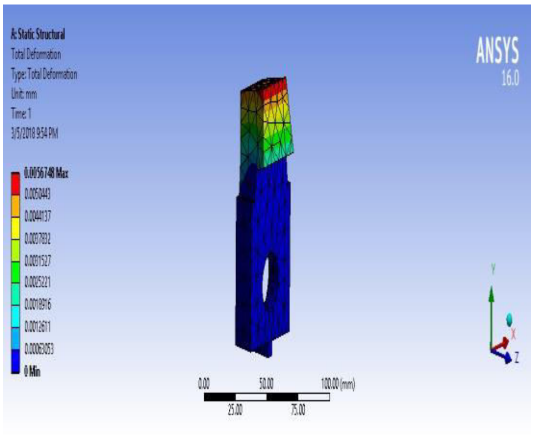

Figure-13. Deflection analysis of Clamp 2.

Max deflection is 0.0056mm
Allowable deflection = L/360
= 85/360
= 0.236mm
Max deflection 0.0056 < 0.236 mm
Deflection is under safe condition

Stress analysis

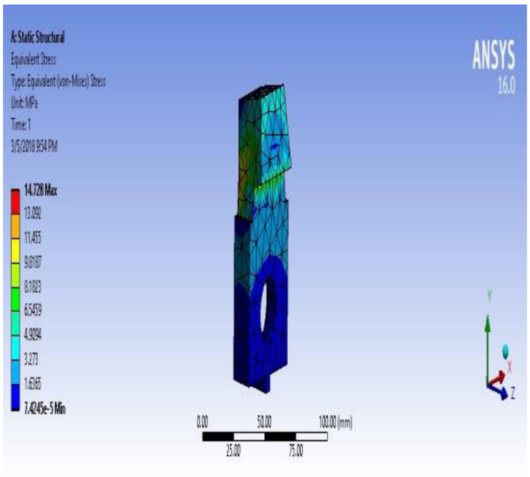

Figure-14. Deflection analysis of Clamp 2.

Max stress formed due to load is 14.728 Mpa
Allowable Stress = Yield strength/FOS
= 555/1.5
= 370MPa
Stress formed 14.728 < 370 MPa
Stress formed is under safe condition

5. COST WORKOUT FOR EXISTING FIXTURE

One key objective of cost engineering is to arrive at accurate cost estimates and schedules and to avoid cost overruns and schedule slips. Cost engineering goes beyond preparing cost estimates and schedules by helping manage resources and supporting assessment and decision making.

Table-3. Cost workout for existing fixture.

S. No.	Operation	T_S	T_H	T_M	H_R
1	T-Slot Milling	45	1.5	9.5	550
2	Undercut Milling	31.5	2.15	2.35	230
3	Marking	0	1.5	0	210
4	Drilling and Tapping	25	5	14	240

T_s - Setting Time
T_H - Handling Time
T_M - Machining Time
H_R - Hour Rate
Machining Cost:$(((T_S/\text{batch qty})+T_H+T_M) \times H_R)/60$
Batch Quantity: 1500nos
For T-slot Milling:
(((45/1500)+1.5+9.5) ×550)/60
= Rs.101.10
For Undercut Milling:
(((31.5/1500) + 2.15+2.35) ×230)/60
= Rs.17.33
For Marking:
(((0/1500) +1.5+0) ×210)/60
= Rs.5.25
For Drilling & Tapping:
(((25/1500) + 5+14) ×240)/60
= Rs.76.06

Total T_S = 101.5min
Total T_H = 10.15min
Total T_M = 25.85min
Total T_C = Rs.199.74

Table-4. Cost workout for existing fixture.

S. No	OPERATION	TS	TH	TM	HR
1	T-SLOT MILLING, Undercut Milling, Drilling and Tapping	25	0.3	10	550

Machining Cost: (((25/1500) +0.3+10) × 550)/60
= 94.5

6. RESULT AND DISCUSSIONS

From the analysis report, it may be concluded that the stress concentration factor is very less in all areas in the fixture and hence the deformation of all parts is under tolerable value.

Each operation can be done easily by indexing Trunnion fixture instead of manual setup.

Table-5. Comparative analysis.

S. No.	Parameters	Existing fixture	Trunnion fixture
1	Cost/Jaw	Rs.199.74	Rs.94.5
2	Loading/Unloading Time	10.15 min	0.3 min
3	Cycle Time	36min	10.3min
4	Jobs/Shift	13	46

By using this fixture the cost of manufacturing reduced from Rs199.74 to Rs94.5, which saves Rs105.24 per jaw

In the existing fixture, the loading and unloading time is 10.15min which has been reduced to 0.3min by this trunnion fixture.

By using this fixture cycle time reduces by 27.5 minutes. Cycle time in the manual fixture was 36min and on Trunnion fixture is 10.3min because of CNC and unloading and loading time has been reduced.

13 parts are produced per shift on the manually operated fixture and 46 parts are produced on Trunnion fixture. With the help of fixture extra 33 parts per shift are produced.

7. CONCLUSIONS

Thus design and analysis of Trunnion hydraulic fixture is carried out and verified that can obtain remarkably higher production rate than existing fixture.

Three setups of operation is converted into a single setup.

Implementation of this project eliminates the need of skilled human operator for clamping of base jaws.

8nos of Base Jaw will be completed in a single setting

It reduces the cycle time

It gives economically feasible design also ensures accurate and efficient clamping of parts.

The clamping systems are designed such a way that they withstand the huge retention forces applied from the machining operations onto the workpiece.

By using manual fixture production of base jaw is insufficient in industries; hence Trunnion hydraulic fixture is a good option to increase the production of base jaws

Machines freed by this fixture can be used for machining other workpiece.

Manpower is reduced from 3 persons to single person and also he can operate multiple machines at the same time.

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