Design and Analysis of Drill Jig for Head and Cover Part of the Actuator

Shivanand Vathare[1], Shrinivas L Gombi[2], Darshan M Katgeri[3]
Department of Mechanical Engineering,
KLS Gogte Institute of Technology, Udyambag, Belgaum,
Karnataka.

Abstract— The manufacturing industry mainly small scale and medium scale provides wide range of products to fulfil the market needs. To face the many challenges of market these industries should increase their production rate with good quality and accuracy. Hence, the time required for the production should be decreased to as small as possible. As per the company's present requirement they need such a technique for drilling operation which can be efficiently used to reduce the cost of production, improve the quality of the product, increase the production rate and reduce the operation time. Therefore, this study aims to design a drill jig. The main purpose of making this drill jig is to perform drilling operation without any need of shifting the job regularly. The objective of this project work is to design a drill jig for head and cover part of the cylinder actuator. The SolidEdge V19 software is used to model the drill jig, and analysis work is carried out on clamp plates to determine the stress, strain and deformation by using SolidWork and ANSYS Workbench. Based on design model of the drill jig, the design drawings of each part are created by using AutoCad software. According to the dimension, all parts are manufactured and assembled to test its performance.

Keywords—Design, Analysis, Drill jig, ANSYS.

1. INTRODUCTION

Today's present status of the small scale industry is to increase the demand of the product and increase the mass production. In order to meet these challenges it has become necessary for companies to increase the production rate. A mass production method requires a fast and easy method of positioning workpart for accurate operations on it.
Over the past few centuries it can be seen that the manufacturing sectors increasing gradually and increasing the productivity also the main cause for these issue is using jigs and fixtures. Jigs and fixtures are production tools used for manufacturing of duplicate and interchangeable parts with great accuracy. Jigs and fixtures are specially designed in order to machine a large numbers of components or assembled identically, and for easy interchangeability of components.
Jigs and fixtures are special purpose tools which are used to facilitate production when work pieces are to be produce on a mass scale. They provide a means of manufacturing interchangeable parts since they establish a relation, with predetermined tolerance, between the work and the cutting tool. Once the jig or fixture is properly set up, any number of duplicate parts may be readily produced without requiring any additional set up. Mass production target is to increase the productivity and increase the accuracy by reducing the setup time, labour cost and manual operations.
Jig can be defined as a workpart holding and locating device that positions and guides or controls the cutting tool during machining. Drill jig increases productivity and eliminates individual marking, positioning and repetitive checking. Interchangeability is one of the advantages of jigs. A jig minimizes the repetitive nature of work required for drilling a hole, as the locating, clamping and guiding are done by jig itself. The tool-guiding element helps to set a tool in correct position. Hence, skilled workers are not required. Compare to conventional hand methods drill jig helps in drilling, reaming and tapping holes at higher speed with great accuracy. The jig take care of accurate hole location.

2. PROBLEM STATEMENT

As per the companies present requirement they need such a technique for drilling operation which can be efficiently used to reduce the cost of production, improve the quality of the product, increase the production rate and reduce the operation time.

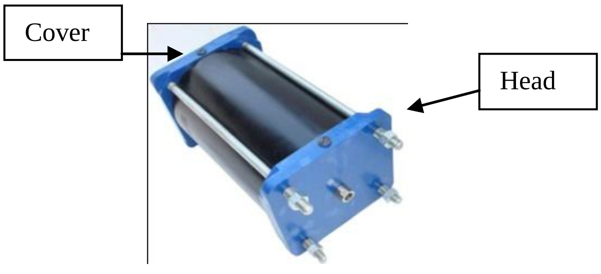


Fig 2.1: Pneumatic cylinder actuator

Fig 2.1 shows pneumatic cylinder actuator. There are two main components of the pneumatic cylinder actuator are having drilling operation, one is head part and another one is cover part. After detailed study of these components here providing drilling jig for these two components of the cylinder actuator is the best way to increase the productivity. Therefore, this study aims to design a drill jig.

Design drawings of the components:

Cover part:

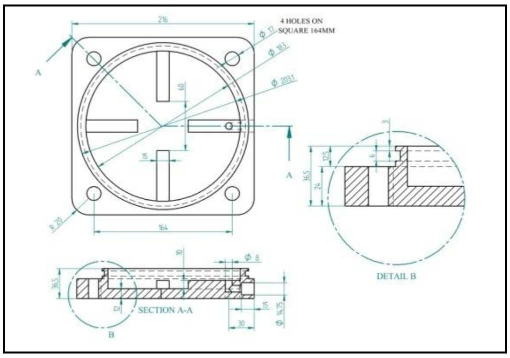


Fig 2.2: a) Drawing and specifications of cylinder cover part

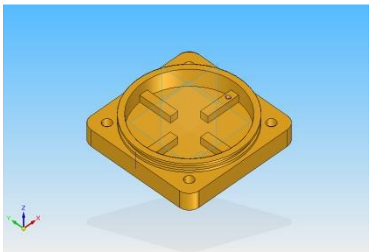


Fig 2.2: b) CAD model of the cylinder cover Part

Head part:

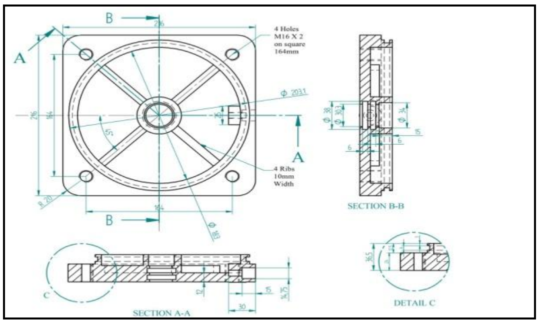


Fig 2.3: a) Drawing and specifications of cylinder head part

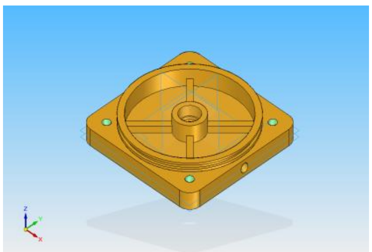


Fig 2.3: b) CAD model of the cylinder head Part

3. METHODOLOGY

The main objective of the study is to provide a suitable locating and clamping method for a drill jig. There are two main components of the cylinder actuator one is cover part and another one is head part, both the components having spigot and cross ribs. Here we have to drill total six holes on cover part and five holes on head part.

For Cover Part:

a) Four holes of diameter $17^{+0.1}$ mm and depth is 24mm on square of 164mm on spigot face of the workpart.
b) One hole of diameter $8^{+0.1}$ mm and depth is 14mm on specified rib face.
c) One hole of diameter $8^{+0.1}$ mm and depth is 30mm, and counter bore diameter 14.5mm and depth is 15mm on specified side face.

For Head Part:

a) Four holes of diameter $17^{+0.1}$ mm and depth is 24mm on square of 164mm on spigot face of the workpart.
b) One hole of diameter $8^{+0.1}$ mm and depth is 30mm, and counter bore diameter 14.5mm and depth is 15mm on specified side face.

The method used while designing a drill jig is given below;

1) The study starts with observation of shape and dimensions of the components.
2) Based on shape and dimensions of the components suitable location and clamping devices are provided.

Location method:

a) Here spigot location is taken. According to the dimension of the spigot the jig plate is machined. Here workpart resting pads are provided for maintaining clearance between bottom of the bushings and workpart face. This clearance gives the easy removal of chips from the material. Due to spigot location and workpart resting pads the part cannot move/rotate with respect to x-y direction. Hence four degrees of freedom (translator motions) and four degrees of freedom (rotational motions) are arrested. In z-direction, downward motion is arrested. But still the part rotating with respect to z-axis.
b) The locating pin is used to maintain the proper alignment on jig plate. The main purpose of providing locating pin is to arrest the rotation motion with respect to z-axis. Hence here two degrees of freedom (clockwise and anticlockwise rotational motions) are arrested.
c) Remaining two degrees of freedoms are left free for loading and unloading purpose. During machining operation these degrees of freedoms can be arrested by using suitable clamping devices.

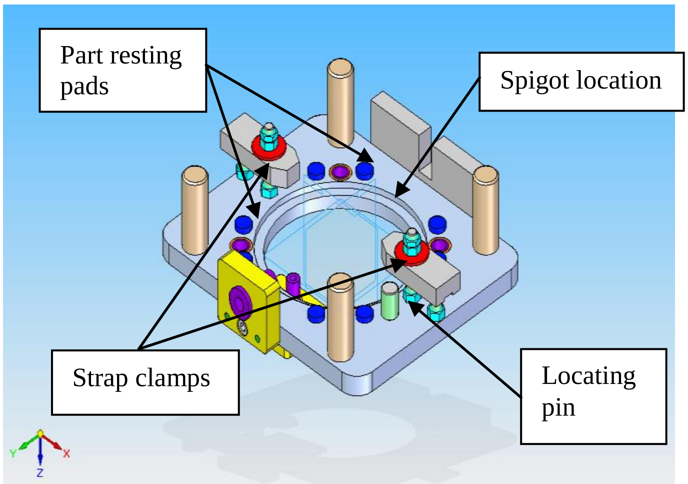


Fig 3.1: Location and clamping system used in drill jig

Clamping system:

a) Here strap clamp is used. Strap clamps are provided to hold the work part rigidly on the jig plate. In this system clamp is supported by a heel pin. This clamp is rotated about the stud axis to remove the workpart and held against the rotational forces by the heel pin engaged in the plate. Locating and clamping systems used in drill jig is shown in fig 3.1.

3) The liners and bushes are located on jig plate. Here the bushes are provided for tool guiding purpose.

4) For specified side face and rib face hole, here provided separate plates with bush and liner arrangement and these plates are fastened on jig plate with the help of M10X1.25 hexagonal socket head cap screws. Dowel pins are used to restrict the rotational motion of each plate while fastening on jig plate.

5) Now the jig plate is fastened on four solid pads (feet or legs) with the help M10X1.25 hexagonal socket head cap screws.

4. DESIGN

Cutting conditions selected for drilling operation:

The suitable cutting conditions are selected during drilling operation are given in table 4.1 and 4.2. Suitable factors have to be used depending on the nature of the surface condition of job, depth of hole, cutting fluid used, rigidity of the drilling machine and jigs, etc. Generally, torque, thrust, and the power values are of interest in selecting suitable cutting conditions, depending on the power of the machine.[5]

Table 4.1: Typical cutting speed and material factor in drilling

Work material	Cutting speed, in m/min		Material factor 'K'
	Drilling	Reaming	
Cast iron: Grey, ductile, and malleable	20-23	12-17	1

Table 4.2: Typical feed rates in Drilling and Reaming

Hole diameter, mm	Feed, mm/rev	
	Drilling	Reaming
6-8.5	0.10-0.18	0.20-0.40
12-14.5	0.15-0.25	0.41-0.61
15-18	0.18-0.28	0.46-0.66

Table 4.3: Power and Force requirements in Drilling

Dia "D" in mm	Spindle Speed "N" in rpm	Power at the spindle "P" in KW	Torque "T_s"	Axial thrust "T_{th}"
			N-m	N
8	875.35	0.1862	2.035	857.78
14.5	482.95	0.4518	8.949	2105.57
16	437.67	0.5616	12.273	2616.47
17	411.93	0.5967	13.856	2779.99

The power and force requirements in drilling are given in Table 4.3. The main cutting forces of drilling operation are torque and thrust. Here torque is a rotational force and thrust is an axial force.

For cover part: The maximum thrust force act on the workpart is, 2779.99N and the maximum torque is developed during cutting operation is 13.856N-m.

For head part: The maximum thrust force act on the workpart is, 2616.47N and the maximum torque is developed during cutting operation is 12.2735N-m.

Design model of the drill jig:

The design model of the drill jig is created by using Solid Edge V19 software.

Drill jig consist of following elements.

1) **Jig plate:** Jig plate is the major structural element of the drill jig. During drilling operation the work part is located on jig plate itself.
2) **Locating pin:** A locating pin is a fixed component of a drill jig. It is used to maintain the position of a workpart in the drill jig by constraining the movement of the part.
3) **Clamps:** A clamp is a force actuating mechanism of a drill jig. The forces exerted by the clamps hold a part securely in the jig plate against all other external forces acting on the components. Here used strap clamps for holding the workpart rigidly on the jig plate.

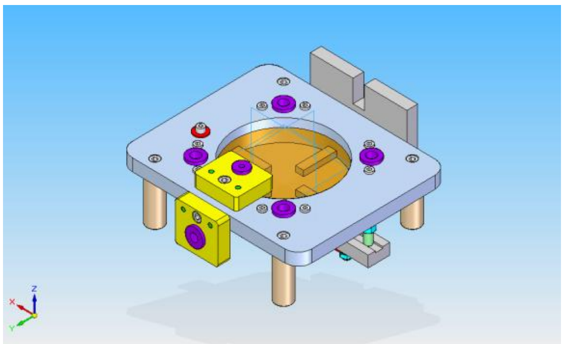


Fig 4.1: Assembly model of drill jig

4) Jig plate rest pads or legs: A drill jig should stand on four legs instead of flat surface. If the jig stands on flat surface, chips will get under flat surface and imbalance the jig. To avoid imbalance, jigs stand on four legs.

Clamping system:

Strap clamp:

These are made of rectangular plates and act like levers. In its simplest form, the clamp is tightened by rotating a hexagonal nut on a clamping screw. One end of the clamp presses against the workpart and the other on the heel pin, thus, loading the lamp like simply supported beam.

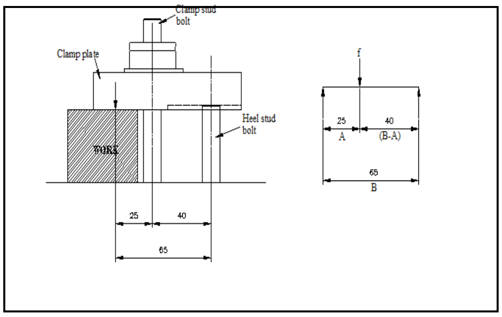


Fig 4.2: strap clamp

Strap clamps are usually made to at least the same width as the washers under the head of the bolt used to tighten the clamp. The slots are made approximately $1/16^{th}$ of an inch wider than the diameter of the bolt. The width, w, of the clamp, may be calculated as

$$w=2.3d+0.062 \text{ inch.}$$
$$w=2.3d+1.5625 \text{ mm}$$

The thickness, t, of the clamp for a bolt diameter d is given by the equation

$$t=\sqrt{0.85dA\left(1-\frac{A}{B}\right)}$$

Where, d=bolt diameter
A=distance, pivot-to-bolt
B=span, pivot-to-workpart
w=width of clamp
t=thickness of clamp

Clamp stud bolt selection:

Total axial load applied on the bolt is, F = 3000N
Here the bolt material is, Plain carbon steel (Mild steel)
Now ultimate strength of the Plain carbon steel is 400N/mm^2.
Considering factor of safety is 5.

$$\text{Now, working stress} = \frac{\text{Ultimate Stress}}{\text{FOS}}$$
$$= \frac{400}{5} = 80 \text{ N/mm}^2$$

$$\text{Now,} \quad \sigma_t = \frac{F}{A}$$

$$80 = \frac{3000}{\frac{\Pi}{4}d^2}$$
$$d^2 = 47.7465$$
$$d = 6.9099\text{mm}$$

Now, considering standard threaded bolt size is, M10 and M12.Here M12 bolt is selected.

Clamp plate selection:

Here M12 bolt is used for strap clamps.

a) The width of the clamp should be,

$$w = 2.3d +1.5625$$
$$= (2.3X12) +1.5625$$
$$= 29.1625\text{mm.}$$

Here taken w = 40mm for factor of safety.

b) The thickness of the clamp should be,

$$t=\sqrt{0.85dA\left(1-\frac{A}{B}\right)}$$
$$t=\sqrt{0.85X12X40\left(1-\frac{40}{65}\right)} = 12.5269\text{mm}$$

Here taken t = 20mm for factor of safety

5. ANALYSIS

5.1 Theoretical analysis

During drilling operation the maximum cutting force or pressure is acted on clamp plate itself. Here most critical part of the drill jig is clamp plates. The clamps are holds the workpart from the bottom side. Therefore, the theoretical analysis is done on clamp plates to analyze its strength.

Forces on clamp plates:

Now considering, force acting on each strap clamp is 3000N.

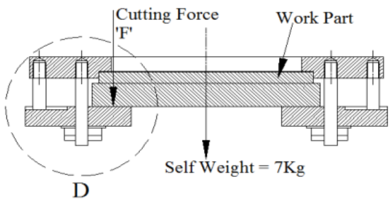


Fig 5.1: Force acting on the clamp plate

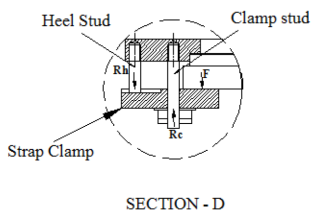


Fig 5.2: Reaction forces on clamp plate

Where, R_h = Reaction force because of heel stud bolt.
R_c = Reaction force because of clamp stud bolts.
F= Applied force

The contact surface between the clamp plate and workpart is shown in figure 5.3.

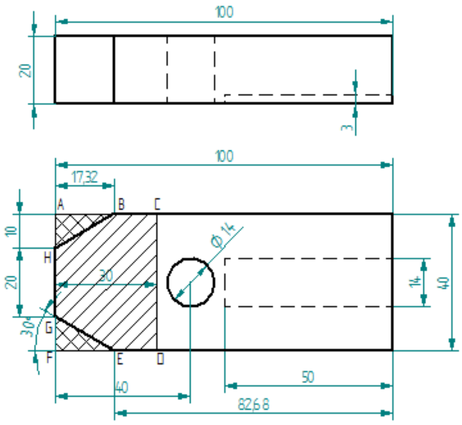


Fig 5.3: Contact surface between the clamp plate and workpart

Now, Area of the rectangle "ACDF" is,

A_1 = Base X Height

= 30X40 =1200mm^2

Area of the triangle "ABH" is,

$$A_2 = \frac{1}{2} \text{ X Base X Height}$$

$$= \frac{1}{2} \text{ X } 10 \text{ X } 17.32$$

= 86.6 mm^2

Similarly, Area of the triangle "EFG" = A_3 = 86.6 mm^2

Now, Area where the force will be act on the clamp plate is,

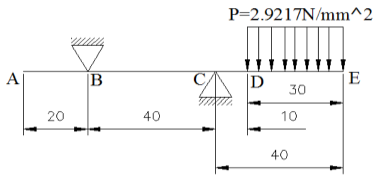
A = A_1 - A_2 - A_3 = 1200 - 86.6 - 86.6 =1026.8mm^2

Now considering,

The total force acting on the clamping plate is, F = 3000N

Now, Pressure on the clamp plate is,

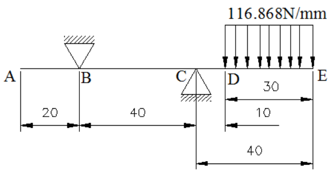
$$P = \frac{F}{A} = \frac{3000}{1026.8} = 2.9217 \text{ N/mm}^2$$



Now, Pressure is converted into UDL is,

UDL= P X Width

=2.9217X40=116.868 N/mm



Now, Taking moment about B,

R_c X 40 = (116.868 X 30) (15+10+40)

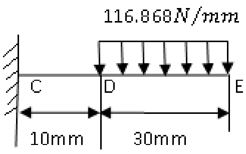
R_c = 5697.315N

Now, Taking moment about C,

R_b X 40 = (116.868 X 30 X 25)

R_b = 2191.275N

Now, considering CD and DE portion



Shear Force Diagram:

Portion DE, F_E = 0 N

F_D = 116.868 X 30 = 3506.037 N

Portion CD, F_C = 116.868 X 30 = 3506.037 N

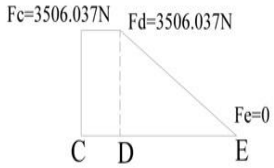


Fig 5.4: Shear Force Diagram

Bending Moment Diagram:

Potion DE, M_E = 0

$$M_D = 116.868 \text{ X } 30 \text{ X } \frac{30}{2} = 52590.6 \text{ N-mm}$$

$$\text{Potion CD, } M_C = 116.868\text{X}30\text{X } (10\text{X}\frac{30}{2})$$

= 87650.925 N-mm

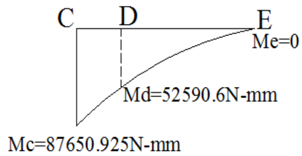
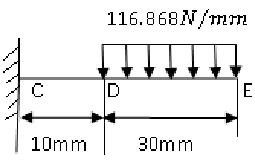
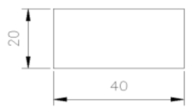


Fig 5.5: Bending Moment Diagram

Bending stress and deflection in clamp plates:

Bending stress in clamp plate:





$$\text{Moment of inertia 'I'} = \frac{bh^3}{12}$$

$$= \frac{40 \text{ X } 20^3}{12}$$

= 26666.667 mm^4

Distance of extreme fiber from the neutral axis.

$$y = \frac{h}{2} = \frac{20}{2} = 10\text{mm}$$

Bending moment at the fixed end is,

M_C = 87650.925 N-mm

$$\text{Now, bending stress is, } \frac{\sigma_b}{y} = \frac{M}{I}$$

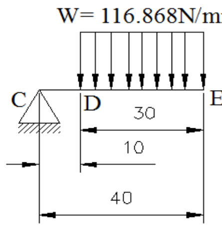
$$\sigma_b = \frac{87650.925 X 10}{266666.667} = 32.869 \text{ N/mm}^2$$

Now, E = stress/strain

Strain = stress/E

$= 32.869/210000 = 1.56519X10^{-4}$

Deflection at E:



$$\text{Deflection} = \frac{wl^4}{8EI} - \left[\frac{w(l-a)^4}{8EI} + \frac{w(l-a)^3}{6EI} \right]$$

$$= \frac{116.868}{210X10^3 X266666.667} \left[\frac{40^4}{8} - \frac{(40-30)^4}{8} - \frac{(40-30)^3}{6} X30 \right]$$

= 0.00655mm

The theoretical calculation gives the following results,

Bending stress in the clamp plate is 32.869 N/mm^2

Deflection in clamp plate is 0.00655mm.

Here concluded that the stress and deformation in clamp plate during drilling operation is within the allowable limit, Hence failure due to static loads is not possible.

5.2 Steps to be followed in ANSYS Workbench

Import geometry:

Design model of clamp, stud bolts, nuts and washers are created and assembled in Solid Edge V19 software and the file was saved in ".stp" format. Now SolidWorks software is used to split the clamp surface into two surfaces, because it is easy to apply total pressure on a region where the clamp plate and workpart mate each other.

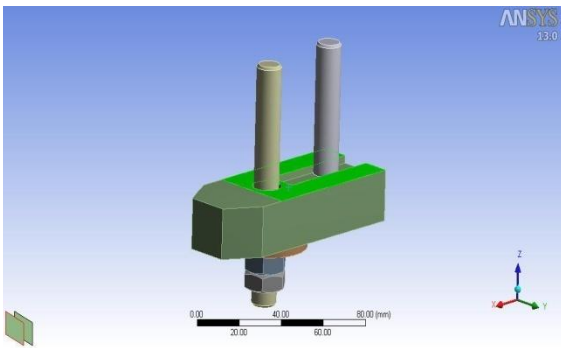


Fig 5.6: Design model of clamp and stud bolt assembly

The steps to split clamp surface in SolidWorks software is explained below,

File - Open the geometry (clamp and stud bolt assembly) - Select clamp plate - Right click – Open – Features - Reference geometry – Plane (Select a plane perpendicular to the surface to be split) – Select side face of the clamp - Give distance to create a plane – Ok – And go to Curves - Split line – Intersection – Select created plane - Select clamp face for split - Ok

After splitting the clamp surface again save the file in ".stp" format. Now ".stp" file was imported in ANSYS Workbench.

Assign engineering data:

Material used and engineering data for clamp plates, bolts, nuts and washers are given below,

1) **Clamp plates:** Mild Steel
2) **Nuts, bolts and washer :** Plain carbon steel or Mild steel

Table.5.1: Physical Constants of Material

MATERIAL	Young's Modulus "E"	Poisson's Ratio "μ"	Density " ρ" Kg/m^3
Mild Steel	210X10^{3}MPa	0.3	7850

Mesh generation:

Once the model is imported next step is to carry the meshing of the model. We have different approaches for creating mesh as mapped meshing and free (automatic) meshing. In this method free meshing method is adopted. The meshing is done by using SOLID187 element. Now identify the contact pairs and define target and contact surface and also define the type of contact region is bonded.

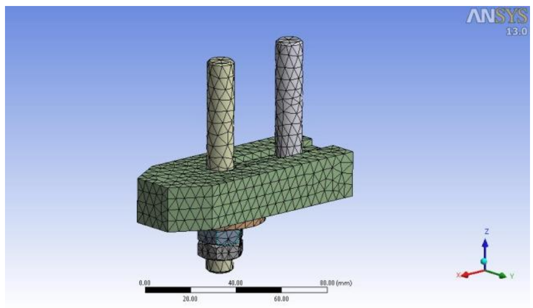


Fig 5.7: Meshed model of clamp and stud bolt assembly

Table 5.2: Mesh information of clamp and stud bolt assembly

Element	Solid 187
No. of Elements	8335
No. of Nodes	14380

Applying boundary conditions:

Table 5.3: Boundary conditions

Fixed support	Fix the bolts from upper side
Displacements	Displacements is given to the bolts X=free,Y=free, Z=0
Pressure	Pressure is applied to the region where the clamp plate and workpart will mate. Pressure = 2.9012MPa

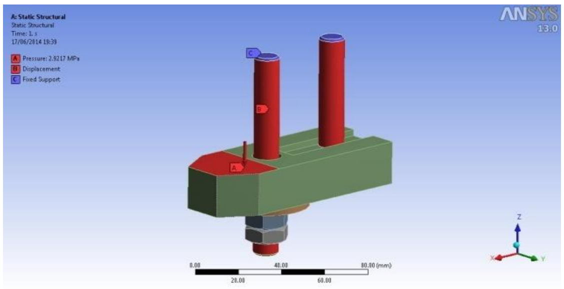


Fig 5.8: Boundary conditions applied on clamp plate

Solution of the problem:
After performing all the above steps the next step is to solve the problem and evaluate the results.

RESULTS:
The result will be displayed graphically.

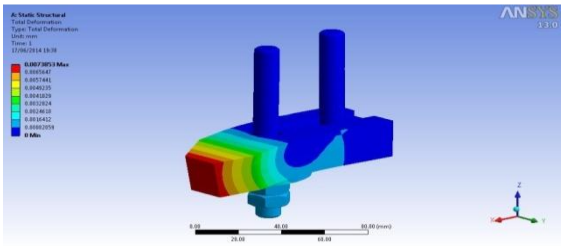


Fig 5.9: Total deformation in clamp and stud bolt assembly
The maximum deformation value (shown in Fig 5.9) of around 0.0074 mm with pressure exerted on the clamp plates while drilling operation.

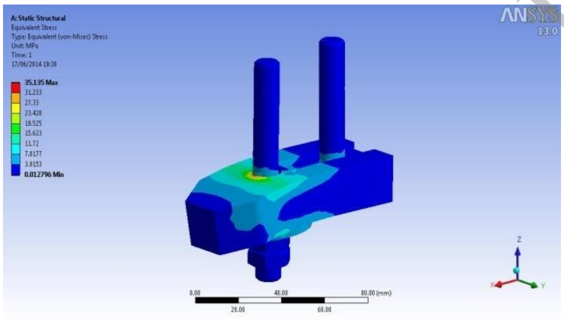


Fig 5.10: Von-Mises stress in clamp and stud bolt assembly
The maximum stress (shown in Fig 5.10) is very less compared to the yield stress of the material (250 MPa).

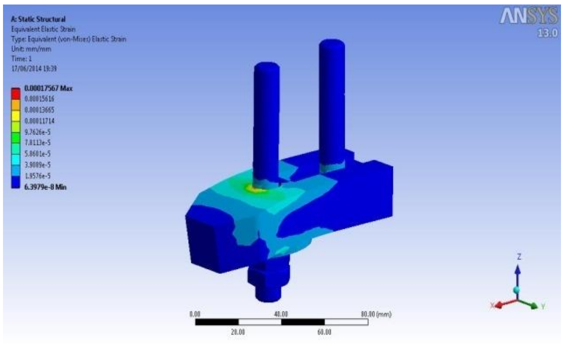


Fig 5.11: Von-mises strain in clamp and stud bolt assembly
The maximum strain (shown in Fig 5.11) is very less of around 0.0001756 with pressure exerted on the clamp plates while drilling operation.

5.3 Validation of results with theoretical calculations
Table 5.4: Analysis Result

	Stress MPa	Deformation 'mm'	Strain
ANSYS result	35.135	0.0073853	0.00017567
Theoretical result	32.869	0.00655	0.0001565

The stress, strain and deformation of clamp plate and stud bolt assembly are well below the allowable limits; hence failure due to static loads is not possible. Hence design is safe.

6. CONCLUSION

In this project work the drill jig is successfully designed for cylinder head and cover part of the actuator. The drill jig was modeled by using Solid Edge V19 software. The drill jig provides interchangeability to head and cover parts. The critical part of the drill is the clamping system. Here analysis is done on clamp plates by using SolidWork and ANSYS 13.0 software. The stress, strain and deformation of clamp plates are well below the allowable limits.

ACKNOWLEDGEMENT

I would like to thanks my guide **Dr. S. L. Gombi,** Head of the Mechanical Department, KLS's Gogte Institute of Technology, Udyambag, Belgaum for his valuable guidance and encouragement and also I would like to thank **Dr. M. S. Patil** and **Prof. S. C. Kulkarni,** Mechanical Department, KLS's Gogte Institute of Technology, Udyambag, Belgaum for their valuable guidance and design support of drill jig.

REFERENCES

[1] P.H.Joshi, "Jigs and fixtures", 3rd edition, Pg.No: 9-69, 85-91.
[2] Cyril Donaldson, G. H. LeCain, V.C. Goold, "Tool Design", 3rd edition, Pg.No: 493-535, 540-565.
[3] Edward G. Hoffman, "Jig and fixture design", 5th edition, Pg.No: 8-13, 21-32.
[4] Production engineering by K.C.Jain, A.K.Chitale P.No: 579
[5] "Production technology" by HMT, P.No: 140-143
[6] Machine tool design handbook 'CMTI', Pg.No: 83-84, 489-491, 640.
[7] Herman W. Pollack, "Tool Design", Pg.No: 240-244.
[8] S.S.Ratan, "Strength of Material", Pg.No:94-95, 214-222.
[9] H.V.Lakshminarayana, "Finite Element Analysis: Procedures in engineering", Pg.No. 4-6
[10] http://www.supriyaprototech.com/pneumatic-actuators-and-cylinders.html