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Stress Analysis and Topology Optimization of Air Compressor Connecting Rod

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***Abstract*— The main aim of the paper is to optimize the shank of the connecting rod. The weight of connecting rod is optimized which can withstand when the load is acting on the connecting rod due to compression of gases. The connecting rod is used to translate the electric motor's rotating motion into the piston's oscillating motion. The rod is subject to high compression and tension cyclic loads. With reduced weight, the optimized connecting rod results in reduced system inertial forces. The objective is to design and analysis the structural stress distribution of connecting rod at the real time condition during process. Once the connecting rod is designed, FE analysis is performed depending on the connecting rod's loading condition. Based on gas pressure and compressor specification, the loading of the connecting rod is calculated. CAD modeling of the connecting rod is done on Catia V5 and analysis work is done on ANSYS. The parameters were obtained from ANSYS software like Von-mises stress, principle strain and deformation which shows reduction in weight and improvement in strength. The analytical method and UTM machine also validate the overall results of the analysis. Thus, the process leads to the optimized and efficient connecting rod.**

Key Words*— *Stress analysis. Strain gauging, Connecting rod

I. INTRODUCTION

The reciprocating compressor uses a piston, which moves inside a cylinder, to compress the air. When the piston moves down, air is drawn in. When the piston moves up, the air is compressed. Two sets of valves take care of the air intake and exhaust. The function of connecting rod in compressors is to transmit the power to compress the air from the crankshaft to the piston. The role of connecting rod is converting rotational movement into reciprocal movement. The lighter connecting rod and piston, the higher the compression and the lower the vibration due to the lower in weight. Steel and aluminum are the most common types of connecting rod material. Casting, forging and powdered metallurgy are the most common types of production processes.

When the maximum stress of the structure is less than ultimate strength and it is said to be safe, at that time critical buckling load becomes design driver i.e. if the applied load is greater than the critical buckling load, the structure will fail even though it is designed with respect to its strength. The ratio of critical buckling load to applied load is called as Buckling Factor (B.F) which is used to know whether the structure is buckled or not. Consumers search for the best from the best every day. That's why optimizing materials in industry is important. Material optimization is to make the less time to produce the stronger, lighter, and lower cost product. The connecting rod's design and weight influence performance. Pressure produces tensile and compressive stresses, and centrifugal effect & eccentricity produces bending stresses. The connecting rods are generally I-section designed to ensure maximum stiffness with minimum weight. Changes in structural design and material will result in significant weight and performance increases.

There is many work has been done on IC engine connecting rod but connecting rod of reciprocating compressor is grey out area. The main objective of the paper is to determine Von Misses stresses, Total deformation, Principle elastic strain and material optimization in the existing connecting rod by topology optimization. The comparison results between the FEA and experimental testing of Aluminum Alloy connecting rod. The connecting rod's static FEA is performed using Ansys software. Comparative analysis between FEA & Experimental results.

D.Gopinath et al. [1] The research's main goal was to explore weight reduction opportunities for forged steel, aluminum and titanium connecting rods to be produced. This study therefore deals with two topics: first, the static load stress analysis of the connecting rod for three materials, and second, the weight optimization of the connecting rod forged steel. Xiaolei Zhu. [2] Complex dynamic loads are subjected to connecting rod cap and connecting bolts of a reciprocating compressor. To determine the connecting system's failure mechanism and to identify which of the connecting rod cap and connecting bolts was first broken, the material characterization and numerical analysis of the connecting rod and connecting bolts are performed. J.Chaoe [3] The researcher's main goal was to identify different failures modes occurs due to different forces acting on connecting rod. In a medium-speed gas engine at a cogeneration plant, paper analyses the failure of an oblique split connecting rod with serrated joint faces. The analysis focused on the connecting rod in which fatigue characteristics were observed on the fracture surface. Mohamed Haneef [4] This study is focuses on the fatigue life due to concentrated load and cosine type load distribution on the bigger end. Connecting rods are subjected to forces resulting from the combustion of mass and fuel. Connecting rod is based on CATIA software and FE is analysed using ANSYS software.

S.V.Uma Maheswara Rao[5]. The aim of paper is chances of fatigue failure in the connecting rod are higher when alternative compressive and tensile stresses are present in the engine cycle. More is also subjected to buckling stress over the connecting rod as it acts as a column. K. Bari [6] In this

Work, root cause and possible mechanisms leading to its premature failure, a failed connecting rod from a motorcycle engine was investigated in the present work. Besides finding the root cause, this study expected that existing designs or practices could be improved to avoid similar failures in the future.

II. METHODOLOGY

To carry out analysis modelling of current connecting rod done by reverse engineering in CATIA V5 and analyse for stresses and deformation in CAE. Topology optimization on existing model by creating elliptical hole and side shank optimization in CAD. Analyse for stresses and deformation on optimized model. Machining the existing connecting rod as per optimization result. Finding high strain portion from CAE software. Prepare fixtures to hold connecting rod for experimental testing and mount strain gauge on high strain portion. Correlating results of both CAE and experimental results.

A. Specification of Compressor

Company of Compressor = Speed
Type = Single Stage Single Cylinder Reciprocating Compressor
H.P. = 7.5
RPM = 640
Tank in Size = 21*52 (In Inch) = 290 PSI
Working Pressure = 145 PSI = 1MPa
Bore*Stroke = 70*70 (In mm)
Piston Displacement = 27mm

B. Geometry of Model

The modeling of existing connecting rod is generated in CATIA software. Using reverse engineering dimensions of connecting rod is obtained from reciprocating compressor.

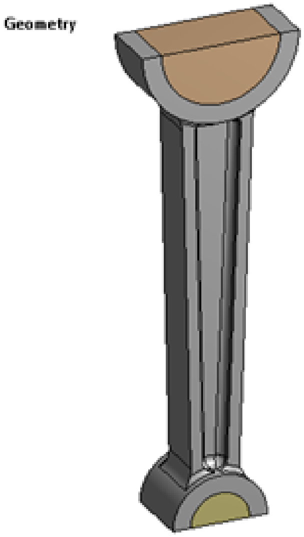

Fig. 1 Aluminum Connecting Rod

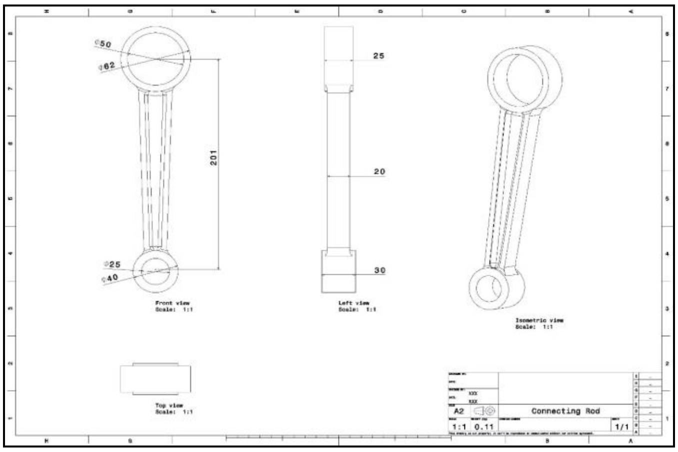

Fig. 2 CAD drawing of Aluminum Connecting Rod

C. Calculations

For finding out the force acting on connecting rod Diameter and width of connecting rod taken from CAD drawing which is nothing but the 62 mm and 25 mm respectively.

From above values area can be calculated

Area = *l x b* -------(1)

= 1550 mm2

Compressor pressure is 1Mpa with mass (mR) is 0.534 kg, radius of crank is 0.035 m, ratio of connecting rod with the crack radius (n) is 5.742, length of connecting rod is 0.201 m and Revolution of crank per minute is 640. By substituting this value in below equation, we get

Pressure = *Gas Force / Area* -------(2)

Gas Force = 1550 N.

Inertia force (FI) due to connecting rod

FI = *Mass x Acceleration*

$$F_I = m_R \times \omega^2 \times r \left(Cos\,\Theta + \frac{Cos\,2\Theta}{n}\right) \quad \text{------(3)}$$

$$\omega = 2\pi \left(\frac{RPM}{60}\right) \quad \text{-------(4)}$$

ω = 67.02 rad/sec

For Angle Θ = 0 substitute in equation 3 we get,

Inertia force (FI) = 100.41 N

Total Force = *Gas Force + Inertia Force* (F_I) -------(5)

= 1550 + 100.41

Total Force = 1650.41 N

Similarly, Using equation 3 for Angle Θ = 0 to 360.

Table I - Total force on connecting rod at different angle

Θ	Gas Force	Inertia Force	Total Force
0	1550	100.41	1650.41
30	1550	81.5	1631.5
60	1550	35.31	1585.31
90	1550	-14.89	1535.1
120	1550	-50.2	1499.79
150	1550	-66.61	1483.38
180	1550	-70.62	1479.37
210	1550	-66.61	1483.38
240	1550	-50.2	1499.79
270	1550	-14.89	1535.1
300	1550	35.31	1585.31
330	1550	81.5	1631.5
360	1550	100.41	1650.41

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D. Finite Element Analysis

The three basic FEA process are

i) Pre-processing phase

ii) Processing or solution phase

iii) Post processing phase

Properties of material is as follows,

Properties of Outline Row 3: Aluminum Alloy NL

	A	B	C
1	Property	Value	Unit
2	Density	2770	kg m^-3
3	Isotropic Elasticity		
4	Derive from	Young's Modulus...	
5	Young's Modulus	7.1E+10	Pa
6	Poisson's Ratio	0.33	
7	Bulk Modulus	6.9608E+10	Pa
8	Shear Modulus	2.6692E+10	Pa
9	Bilinear Isotropic Hardening		
10	Yield Strength	2.8E+08	Pa
11	Tangent Modulus	5E+08	Pa

Fig. 4 Aluminum Material Properties

a) Meshing

ANSYS Meshing is a high-performance automated product that is generally usable and insightful. It produces the most suitable mesh for precise, efficient solutions in metaphysics. For all parts of a model, a mesh well suited for analysis can be developed with a simple mouse click. Total controls are available for the expert user who wants to fine-tune it to the options used to create the mesh. The power of parallel processing reduces the time you have to wait for mesh generation automatically. From the meshing of existing connecting rod nodes & elements are 26502 & 14415 respectively.

Fig. 5 Meshing of Existing Connecting Rod

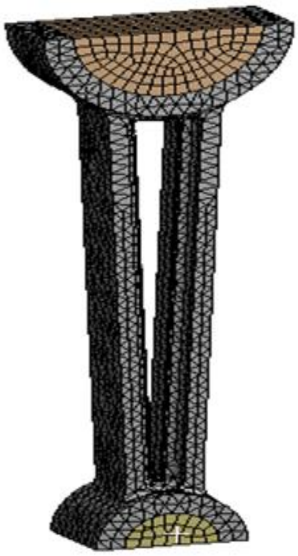

Fig. 6 Meshing of Connecting Rod having Elliptical Hole

For meshing of connecting rod having Elliptical hole & Side Shank optimization nodes & elements are 23531 & 11856 respectively.

b) Boundary Conditions

Boundary condition for connecting rod we applied 1650 N force from top side of connecting rod. Fix support are given to bottom of geometry.

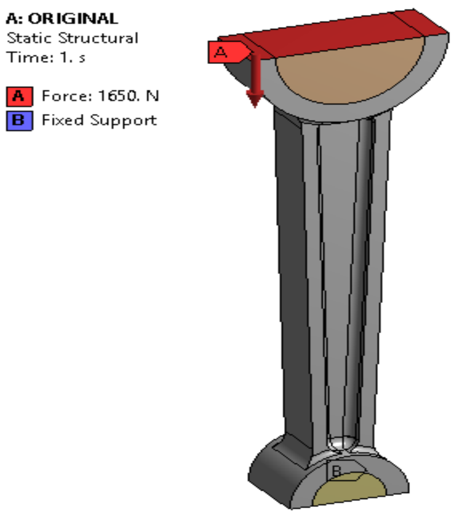

Fig.7 Boundary Condition on Existing Connecting Rod

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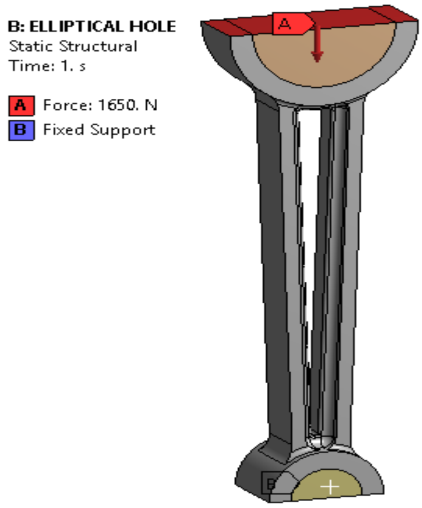

Fig. 8 Boundary Condition of Connecting rod having Elliptical Hole

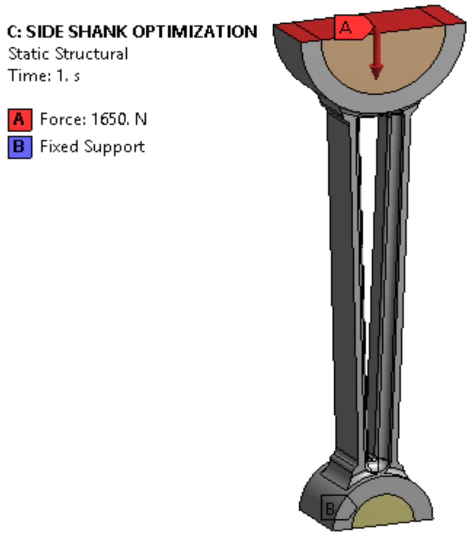

Fig. 9 Boundary condition of Connecting rod having Elliptical Hole & Side shank optimization

c) Total Deformation

The total deformation & directional deformation are general terms in finite element methods irrespective of software being used. Directional deformation can be put as the displacement of the system in a particular axis or user defined direction. Total deformation for different 3 cases are as follows.

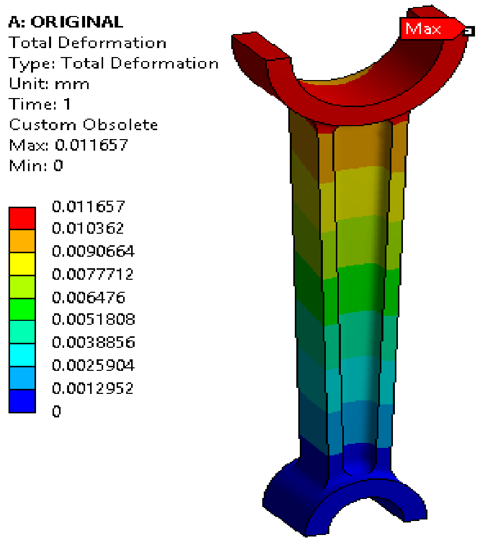

Fig.10 Total Deformation of Existing Connecting Rod

Above diagram shows total deformation of existing connecting rod. Maximum deformation is 0.011657 at bigger end.

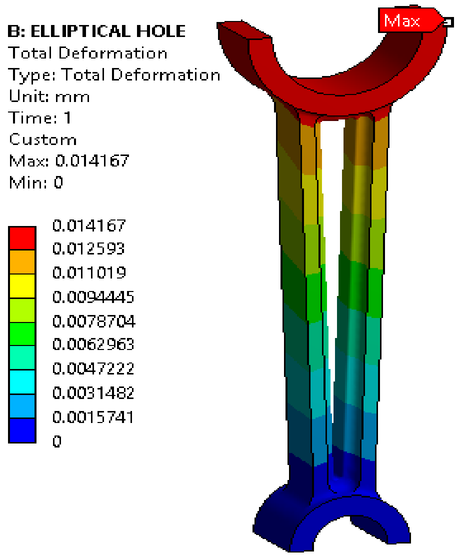

Fig. 11 Total deformation of Elliptical Hole Connecting rod

Above diagram shows total deformation of elliptical hole connecting rod. Maximum deformation is 0.014167 at bigger end.

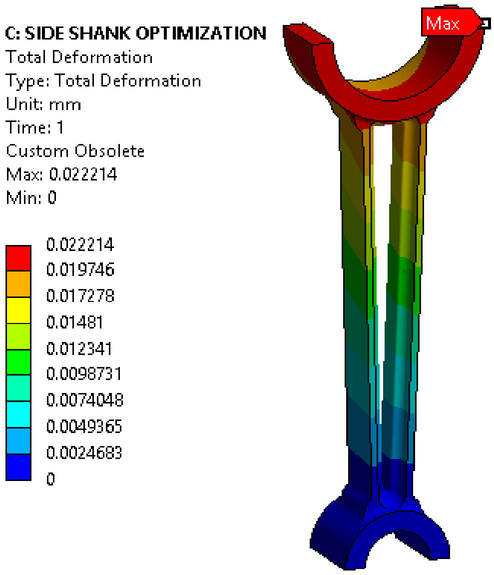

Fig. 12 Total Deformation of Connecting Rod having Elliptical Hole & Side Shank optimization

Above diagram shows total deformation of elliptical hole & side shank optimization connecting rod. Maximum deformation is 0.022214 at bigger end.

d) Equivalent Stress

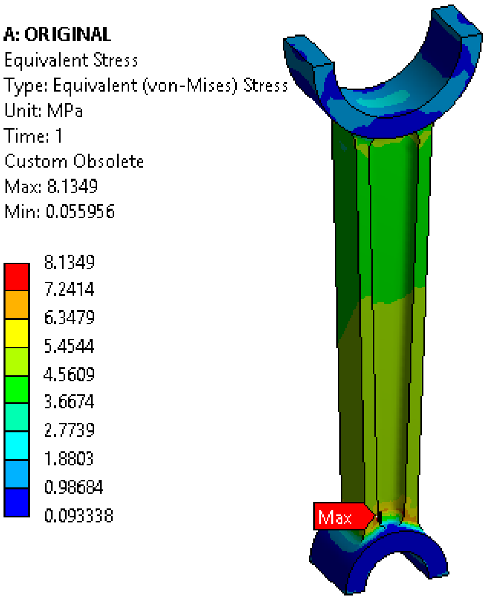

Fig. 13 Equivalent Stress of Existing Connecting Rod

Above diagram shows total equivalent stress of existing connecting rod. Maximum equivalent stress is 8.1349 MPa at lower end & Min 0.055956

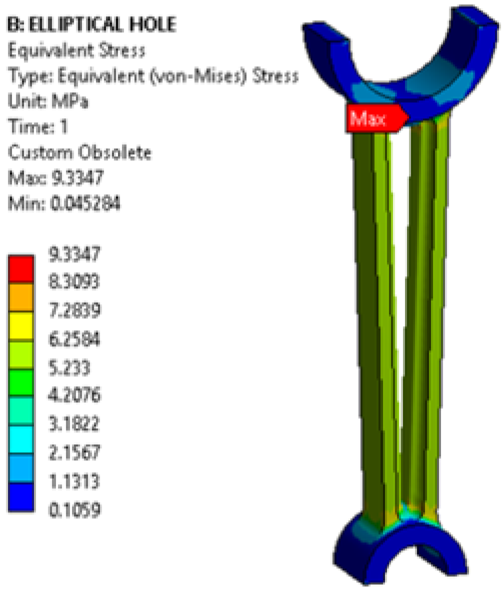

Fig. 14 Equivalent Stress of Connecting rod having Elliptical Hole.

Above diagram shows total equivalent stress of elliptical hole connecting rod. Maximum equivalent stress is 9.3347 MPa at bigger end & Min 0.045284.

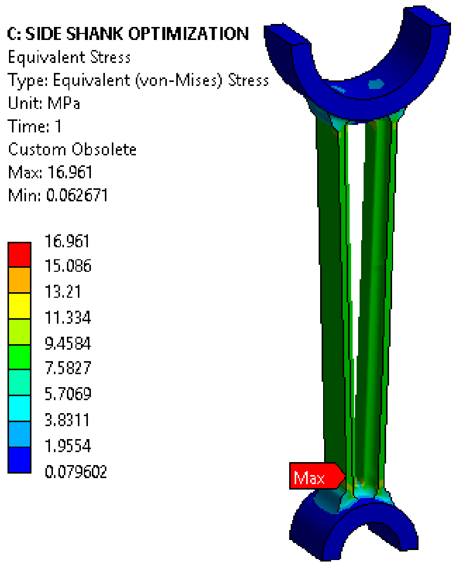

Fig. 15 Equivalent Stress of Connecting Rod having Elliptical Hole & side shank optimization

Above diagram shows total equivalent stress of elliptical hole & side shank optimization connecting rod. Maximum equivalent stress is 16.961 MPa at smaller end & Min 0.062671.

e) Maximum principal strain

This theory states that failure in any material occurs when the principal stress in that material due to any loading exceeds the principal stress at which failure occurs in the dimensional loading test.

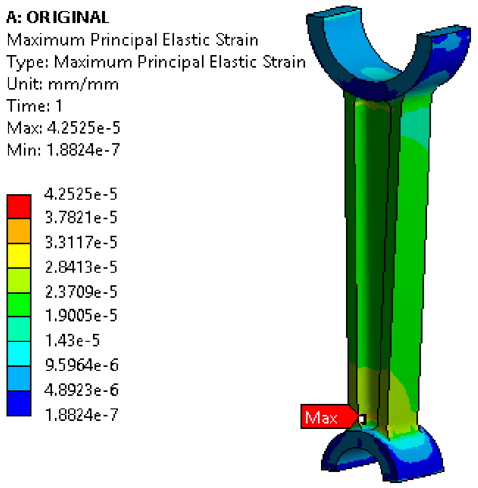

Fig. 16 Maximum Principle Strain of Existing Connecting rod

Above diagram shows Maximum Principle Strain of existing connecting rod. Maximum Principle Strain is 4.2525x10^{-5} at lower end & Min 1.8824x10^{-7}.

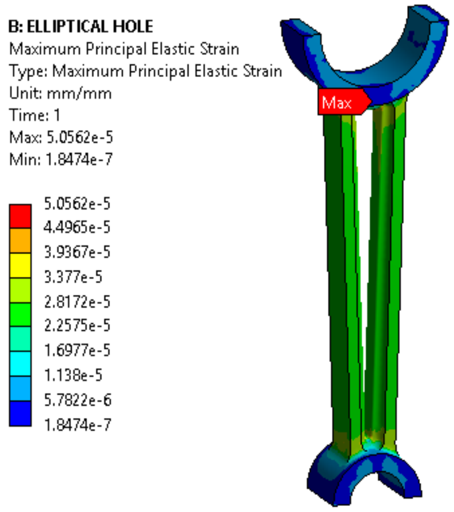

Fig. 17 Maximum Principle Strain of Connecting rod having Elliptical Hole

Above fig. shows Maximum Principle Strain of elliptical hole connecting rod. Maximum Principle Strain is 5.0562x10-5 at bigger end & Min 4.4965x10-7.

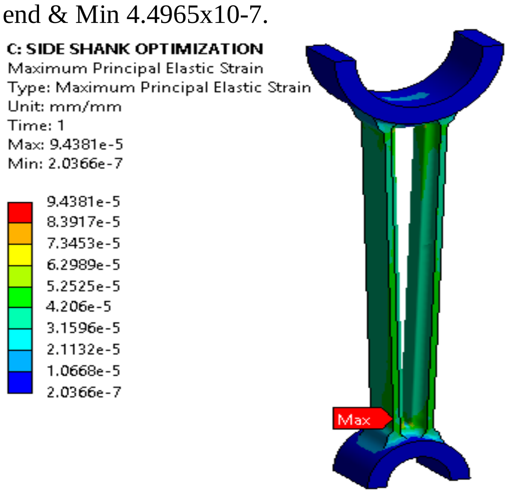

Fig. 18 Maximum Principle Strain of Connecting rod having Elliptical hole & side shank optimization

Above fig. shows Maximum Principle Strain of elliptical hole & side shank optimization connecting rod. Maximum Principle Strain is 9.4381x10^{-5} at smaller end & Min 2.0366x10^{-7}.

III. EXPERIMENTAL VALIDATION

A universal testing machine (UTM), also known as a universal tester, materials testing machine. UTM is used to test the tensile strength and compressive strength of materials. An alternate name for a tensile testing machine is a tensometer.

The specimen is placed between the grips and an extensometer in the machine during the test, the change in gage length recorded automatically. This method, however, not only records the change in the length of the specimen, but all other extending/elastic components of the testing machine and its drive systems, including any slipping of the specimen in the grips. Once the machine is started it begins to apply an increasing load on specimen. Throughout the tests the control system and its associated software record the load and extension or compression of the specimen.

Mass of component is measured using digital weighing machine. Apply strain gauge at high strain location shown by FEA. Paste linear strain gauge at same location using adhesive. Connect DB9 connector to data acquisition system via strain gauge and wires. Then mount specimen on UTM and apply compressive load. Check strains and validate it with FEA results.

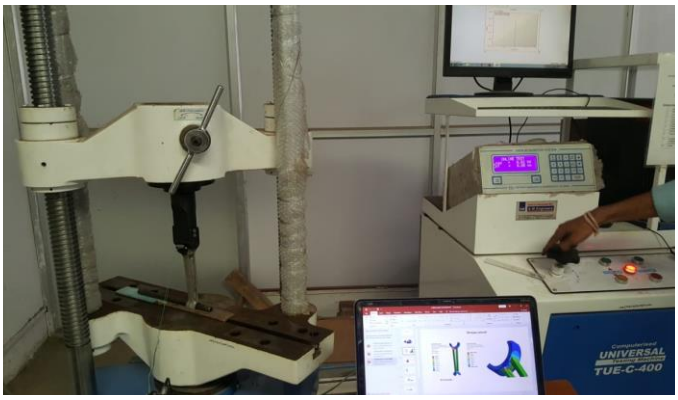

Fig. 16 Connecting rod testing on UTM

From this experimentation on topology optimized connecting rod i.e. elliptical hole and side shank optimization connecting rod maximum principle strain is obtained 102 microstrain.

IV. RESULTS

Table II-Result obtain for all three modifications

Design	Deformation (mm)	Equivalent Stress (MPa)	Maximum Principle Strain x10^{-5}	Mass (g)
Existing connecting rod(CR)	0.011	8.13	4.25	234.6
Elliptical hole CR	0.014	9.33	5.05	207
Elliptical hole & Side shank optimization CR	0.022	16.96	9.43	167

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V. CONCLUSION

From the above table Elliptical Hole and Side Shank optimization design is optimized design with reduction in mass of 29% and stress values are within yield limit of material (i.e 280 MPa) Hence design with Elliptical Hole and Side Shank optimization is finalized and tested using strain gaging for experimental validation. The maximum principle strain obtained after the analysis is 94.3microstrain and that of the maximum principle strain value obtained from the testing is 102microstrain. The results from analysis & testing are nearly equal. So, the result is validated. Similarly, different materials can be also used for the designing of the air compressor connecting rod.

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