Optimum Analysis of I.C. Engine Connecting Rod

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Abstract:- The connecting rod is intermediate member between the piston and crankshaft. Its primary function is to transmit the push and pull from the piston pin to the crank pin, thus converting the reciprocating motion of the piston into rotary motion of the crank. The study incorporates Structural analysis, Buckling analysis and Modal analysis of Pulsar 220cc connecting rod. In dynamic condition the connecting rod subjected to several forces like tensile force, compressive force and inertia force. It leads to damage of connecting rod so FEA analysis is done to prevent the connecting rod from damage and improve the performance.

***Keywords**:- Connecting rod, Structural analysis, Buckling analysis, Modal analysis, FEA.*

I. INTRODUCTION

A connecting rod is a member which connects a piston to a crank or crankshaft in a reciprocating engine. Together with the crank, it forms a simple mechanism that converts reciprocating motion into rotating motion.

A connecting rod may also convert rotating motion into reciprocating motion, its original use. Earlier mechanisms, such as the chain, could only impart pulling motion. Being rigid, a connecting rod may transmit either push or pull, allowing the rod to rotate the crank through both halves of a revolution. In a few two-stroke engines the connecting rod is only required to push.

The connecting rod is best known through its use in internal combustion piston engines, such as automobile engines. These are of a distinctly different design from earlier forms of connecting rod used in steam engines and steam locomotives.

II. PROBLEM STATEMENT

The proposed topic related with the automobile sector. As automobile is very large sector with advancement in the technology it is required to study the components of the vehicle. The connecting rod is the very important link in the I.C. engine.

The analysis of connecting rod is carried out to find out the stresses induced in structural analysis, to find out load multiplier or factor of safety in buckling analysis and to obtain natural frequency of connecting rod.

The design of connecting rod of pulsar 220 is shown below:

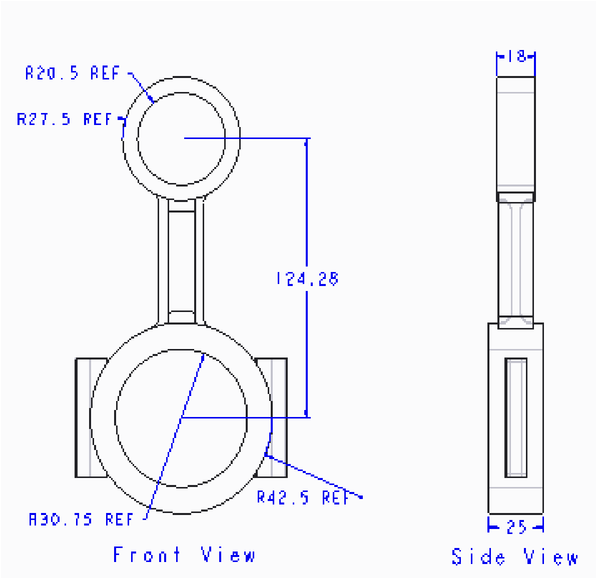

Fig 1:- Orthographic view of connecting rod

III. OBJECTIVE

The objectives of the study are

- To develop a geometrical model for connecting rod using CAD software.
- To analyze the connecting by using Static Structural analysis.
- To analyze the connecting rod for buckling analysis.
- To obtain natural frequency of connecting rod using Modal analysis

IV. MATERIAL SPECIFICATION

The material selected for the analysis of connecting rod is aluminum alloy as it has high strength to weight ratio. The properties of aluminum alloy are listed below:

- Density = 2770 kg/mm^3
- Modulus of Elasticity = 7.1E+10 Pa
- Bulk Modulus = 6.9608E+10 Pa
- Modulus of Rigidity = 2.66E+10 Pa
- Poisson's Ratio = 0.33
- Yield Tensile Strength = 2.8E+08 Pa
- Yield Compressive Strength = 2.8E+08 Pa
- Ultimate Tensile Strength = 3.1E+08 Pa

V. SPECIFICATION OF ENGINE

- Bore × stroke = 67 mm × 62.4mm
- Displacement = 220 cc
- Compression Ratio = 9:5+0.5:1
- Idling Speed = 1400 ± 100
- Maximum net power = 21PS at 8500 rpm
- Maximum net torque = 19.12 Nm at 7000 rpm

VI. PRESSURE CALCULATION

Density of Petrol at 288.85K $=737.22 \times 10^{-9}$ kg/mm^3

Molecular Weight, M =114.228 g/mole

Ideal Gas Constant, R =8.3143 J/mol-K

Mass, m = density × volume

= 737. $737.22 \times 10^{-9} \times 220 \times 10^3$

= 0.1622 kg

$R_{specific} = \frac{R}{m}$

$= \frac{8.3143}{0.1622}$

= 51.250

From gas equation,

$p \times V = m \times R_{specific} \times T$

$p = \frac{m \times R_{specific} \times T}{V}$

$= \frac{0.1622 \times 51.260 \times 288.855}{220 \times 10^3}$

Pressure, p = 10.91 MPa ≅ 11 MPa

Pressure Force, Fp $= \frac{\pi}{4} d^2 \times$ gas pressure

$= \frac{\pi}{4} \times 67^2 \times 11$

= 38782.1759 N

= 38.78 KN

The Inertia force of on connecting rod depends upon the angular position of the crank. As the angle of crank changes the force acting on the rod changes. It is observed that, as the angle increases, inertia force increases to a certain limit after that it decreases.

Inertia Force, Fi = m × f

$= m \times r \times \omega^2 (\cos\theta + \frac{\cos 2\theta}{n})$

Where,

m = mass of reciprocating part = 0.5 kg
r = radius of crank = 31.2mm
ω = Angular velocity = 890.11 rad/sec
$n = \frac{\text{Length of connecting rod}}{\text{radius of crank}} = 4$

Sample Calculation of forces at 0˚

Inertia Force, Fi = 15450 N
Total Force, F = Pressure Force – Inertia Force
= 38782.17 - 15450
= 23332 N
Safe Load, Fs = F × Factor of Safety
= 23332 × 1.5
= 34998 N

Pressure at small end, $P = \frac{Fs}{\sqrt{3} \times r \times l}$

$= \frac{34998}{\sqrt{3} \times 20.5 \times 124.8}$

= 7.25 MPa

The following table shows the pressure and forces acting on connecting rod at various angles:

Sr. No.	Angle (˚)	Pressure Force Fp (N)	Inertia Force Fi (N)	Total Force F (N)	Pressure at Small end P (MPa)
1	0	38782.17	17357.14	32137.55	7.25
2	60	38782.17	5207.14	50362.55	11.36
3	90	38782.17	-3471.42	63380.39	14.30
4	180	38782.17	-10414.3	73794.68	16.65
5	270	38782.17	-3471.42	32137.55	14.30

Table 1. Applied pressure at different angles

VII. STRUCTURAL ANALYSIS OF CONNECTING ROD

The structural analysis of connecting rod is carried out as the connecting rod subjected to high gas pressure. Therefore there may be chances of failure of connecting rod due to the tensile or compressive load. So it is important to analyze the con rod structurally. The structural analysis of the connecting rod is done by using a software ANSYS 14.0. The modelling of the connecting rod is done in CREO Parametric 2.0.

The steps involved in the structural analysis are given below:

A. *Importing Geometry to workbench*

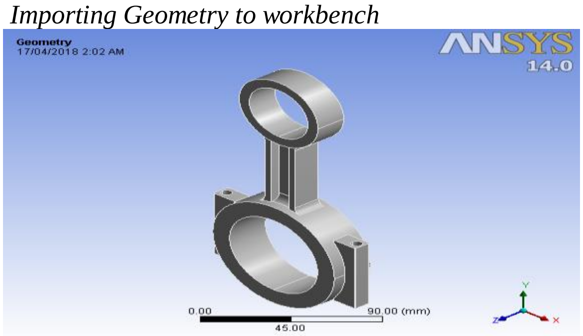

Fig 2:- Geometry of connecting rod

B. Meshing of con rod

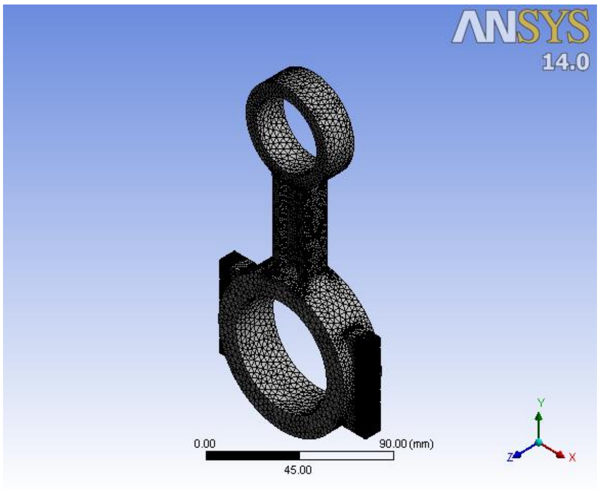

Fig 3:- Meshing of connecting rod

C. Applying Constrain to con rod

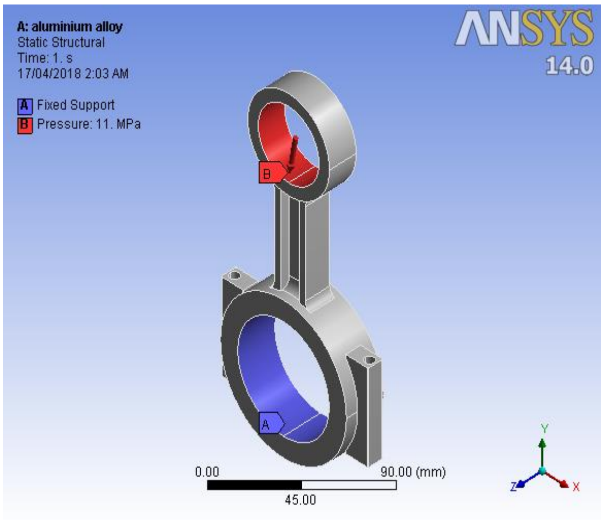

Fig 4:- Constrain applied to connecting rod

D. Results

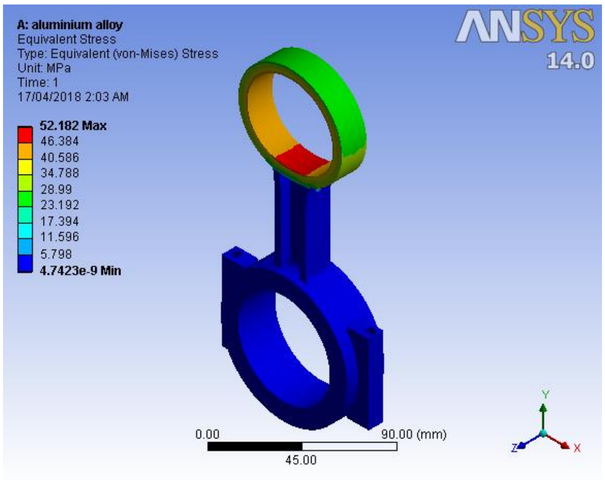

Fig 5:- Stress contour of connecting rod

The analysis is carried out considering only gas pressure. So, the further analysis is carried out considering the inertia force. For the inertia force mass is taken into account. But as the connecting rod rotates, the mass changes at different angles. Therefore analysis is carried out at various angles i.e. 0˚, 60 ˚, 90 ˚, 180 ˚ and 270 ˚.

The pressure applied at the small end is tabulated in the table 1. The calculation of inertia force is discussed above. The results of the analysis are shown below:

- *Structural Analysis Of Connecting Rod At 0˚*

The fig. 6. and fig.7. shows the stress and deformation contour of connecting rod. The pressure of 7.25 MPa is applied at the small end and big end is constrained. The stress induced is 32.43 MPa and deformation is 0.012 mm.

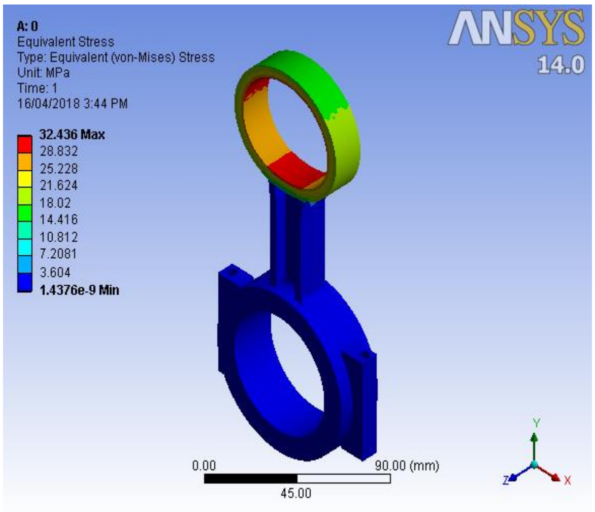

Fig 6:- Stress contour of connecting rod at 0˚

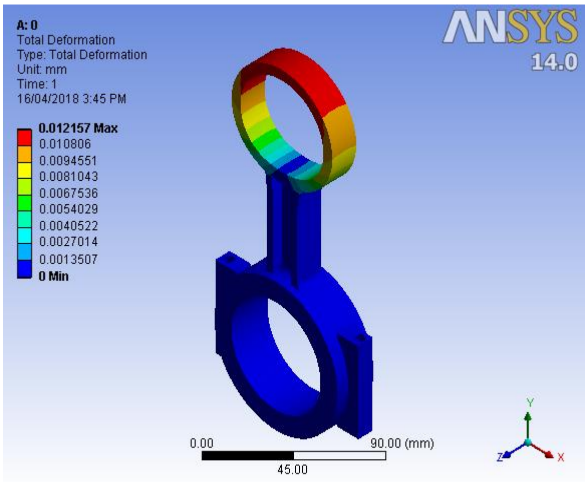

Fig 7:- Total deformation contour of connecting rod at 0˚

- *Structural Analysis Of Connecting Rod At 60˚*

The fig. 8. and fig. 9. shows the stress and deformation contour of connecting rod. The pressure of 11.36 MPa is applied at the small end and big end is constrained. The stress induced is 50.87 MPa and deformation is 0.019 mm.

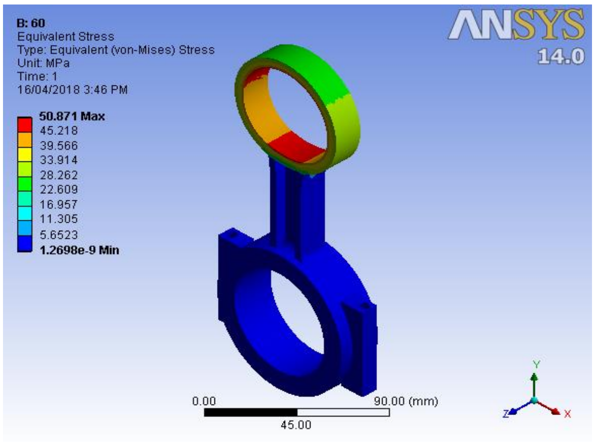

Fig 8:- Stress contour of connecting rod at 60˚

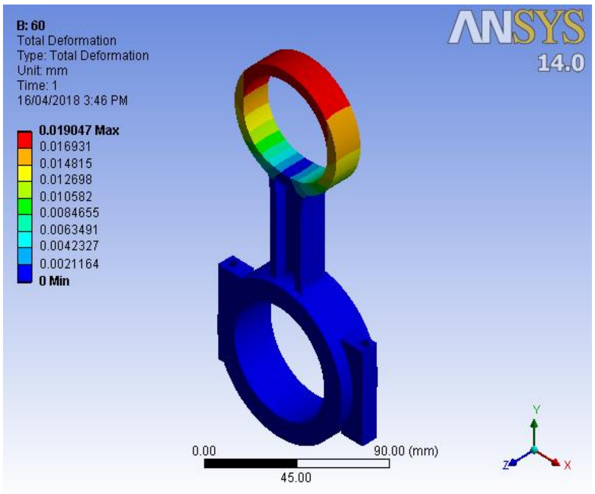

Fig 9:- Total deformation contour of connecting rod at 60˚

* *Structural Analysis of Connecting Rod At 90 ˚*

The fig. 10. and fig. 11. shows the stress and deformation contour of connecting rod. The pressure of 14.30 MPa is applied at the small end and big end is constrained. The stress induced is 64.11 MPa and deformation is 0.023 mm.

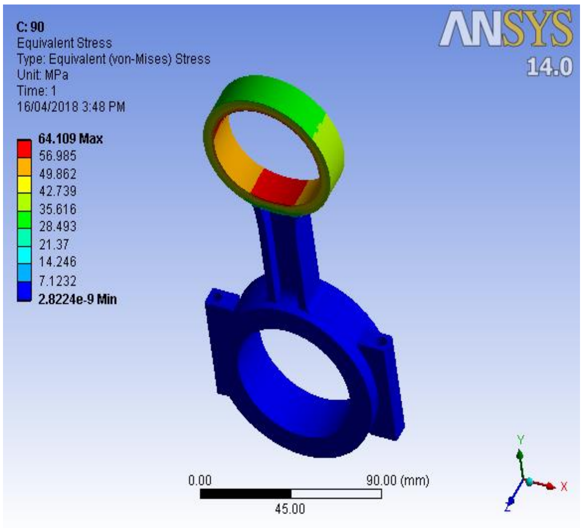

Fig 10:- Stress contour of connecting rod at 90˚

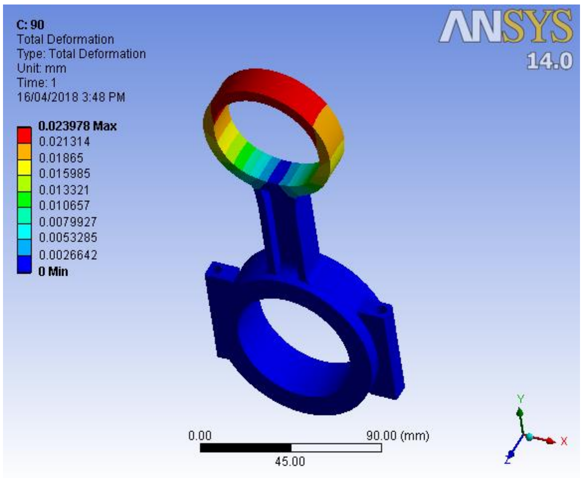

Fig 11:- Total deformation contour of connecting rod at 90˚

* *Structural Analysis of Connecting Rod At 180 ˚*

The fig. 12. and fig. 13. shows the stress and deformation contour of connecting rod. The pressure of 16.65 MPa is applied at the small end and big end is constrained. The stress induced is 74.47 MPa and deformation is 0.027 mm.

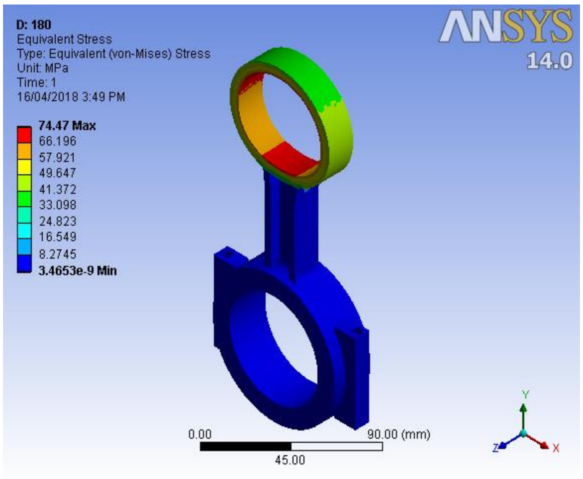

Fig 12:- Stress contour of connecting rod at 180˚

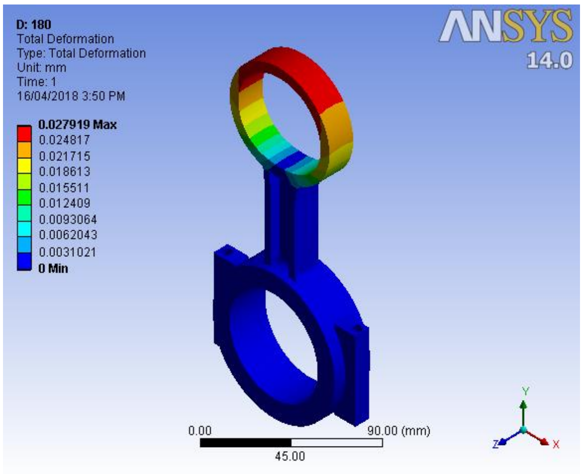

Fig 13:- Total deformation contour of connecting rod at 180˚

* *Structural Analysis of Connecting Rod At 270 ˚*

The fig. 14. and fig. 15. shows the stress and deformation contour of connecting rod. The pressure of 14.30 MPa is applied at the small end and big end is constrained. The stress induced is 63.96MPa and deformation is 0.023 mm.

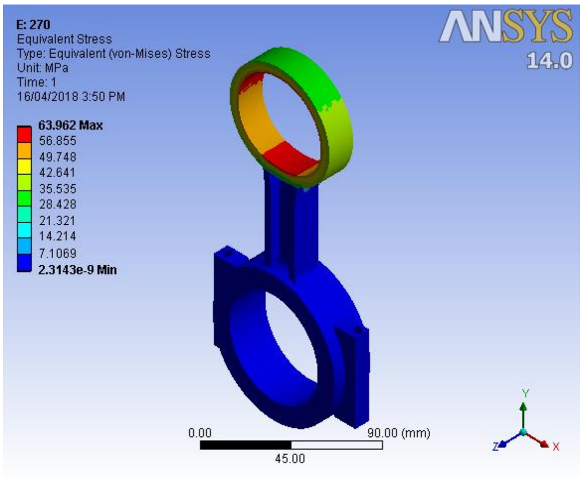

Fig 14:- Stress contour of connecting rod at 270˚

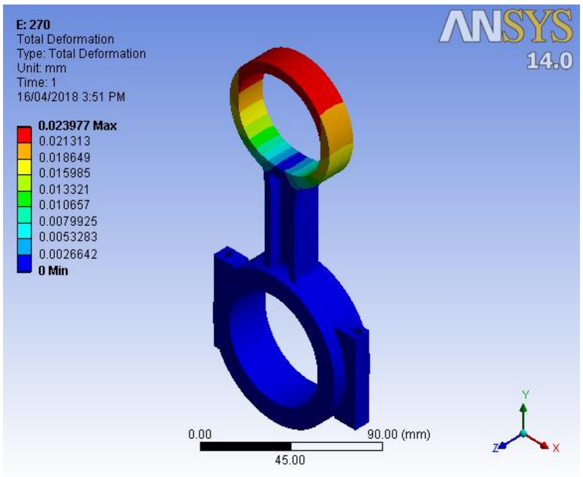

Fig 15:- Total deformation contour of connecting rod at 270˚

VIII. BUCKLING ANALYSIS OF CONNECTING ROD

Buckling analysis is a technique used to determine buckling loads-critical loads at which a structure becomes unstable-and buckled mode shapes-the characteristic shape associated with a structure's buckled response.

A. Calculation of Buckling Force

The Buckling force on the connecting rod given by:

Buckling load = $\frac{f_c \times A}{1+a(\frac{L}{k})}$

Where,

f_c = Critical stress
A = Area of I-section
a = Rankine constant according to material

$= \frac{S_u}{\pi^2 E} = \frac{310}{\pi^2 \times 71000}$

$= 4.42 \times 10^{-4}$

L = Length of connecting rod
K = Radius of gyration

Buckling load $= \frac{310\times194.04}{1+4.42\times10^{-4}(\frac{124.8}{7.476})}$

= 59711.81 N

Load Multiplier $= \frac{Buckling\ load}{Pressure\ Force}$

$= \frac{59711}{38782}$

= 1.54

8.2 FEA Analysis Result

The linear Buckling analysis is carried out by constraining the big end and buckling load is applied at the small end.

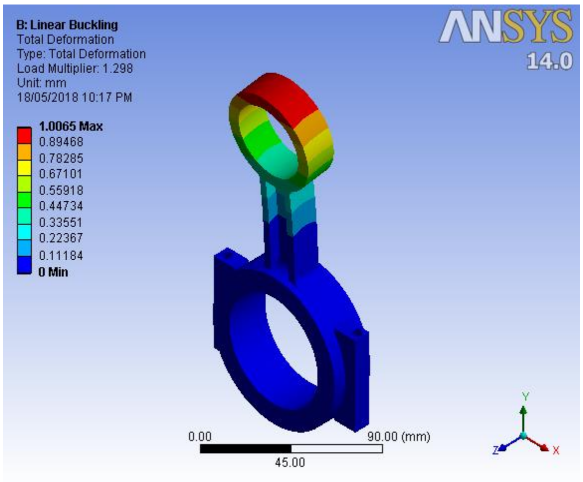

Fig 16:- Deformation contour of mode 1

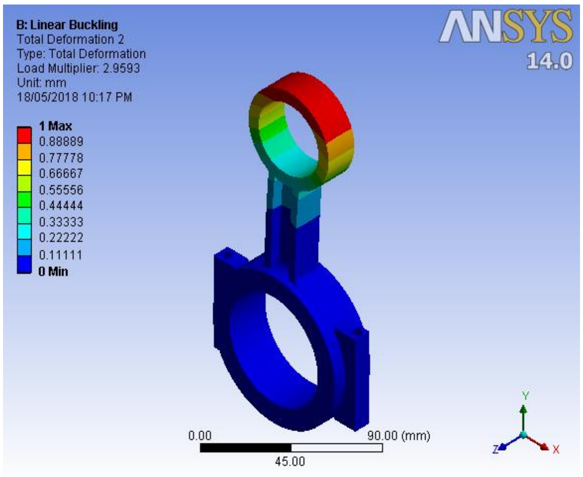

Fig 17:- Deformation contour of mode 2

The fig. 16. and fig. 17. shows the contour of total deformation of mode shape obtained in the solution. The mode are defined according to the effective mass participation factor in the respective axes. The load multiplier obtained in the first and second mode are 1.2 and 2.9. The maximum deformation obtained in both the modes is 1mm.

IX. MODAL ANALYSIS OF CONNECTING ROD

Modal analysis is use to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. It also can be a starting point for another, more detailed, dynamic analysis, such as a transient dynamic analysis, a harmonic response analysis, or a spectrum analysis.

A. Calculation

- *Natural Frequency by Bi-Filer Method*

Frequency = $\frac{1}{2\pi k} \times \left(\sqrt{\frac{g \times x \times y}{l}}\right)$

Where,

Radius of gyration, k = $\sqrt{\frac{I}{M}} = \sqrt{\frac{1.0865\times10^{-8}}{0.291}} = 1.93\times10^{-4}$

Length of string, l = 0.06 m

The bi-filer suspension is usually used for finding the moment of connecting rod of an engine. In these the wire are attached at equal distance from the center of gravity of connecting rod i.e. x = y.

So that tension induced in the wire are same.

Frequency = $\frac{1}{2\pi k} \times \left(\sqrt{\frac{g \times x \times y}{l}}\right)$

$$= \frac{1}{2\times\pi\times1.93\times10^{-4}} \times \sqrt{\frac{9.81\times0.0625\times0.0625}{0.06}}$$

f = 659.02 Hz.

- *Actual Natural Frequency*

It is given that the maximum speed of engine is 8500 rpm that means crank rotates 8500 in a single minute. The crank is connected to the big end of connecting rod and rotation of the cranks transferred to connecting rod which is in four link mechanism. Due to this later on rotational displacement is converted into linear displacement. As the crank rotates, the connecting rod oscillates so the actual frequency given by:

Frequency, f = $\frac{2\pi N}{60}$

= $\frac{2\times\pi\times8500}{60}$

f = 890.12 Hz.

B. FEA Result

The Modal analysis is carried out by constraining the big end. The range is specified in the analysis is 0 to 2000 Hz and two mode shape are taken for the result.

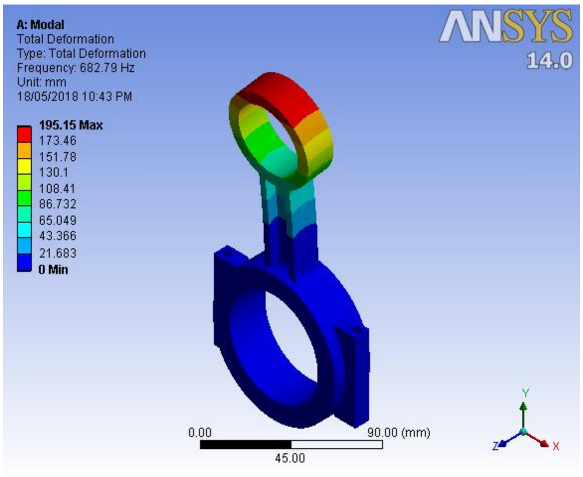

Fig 18:- Deformation contour of mode 1

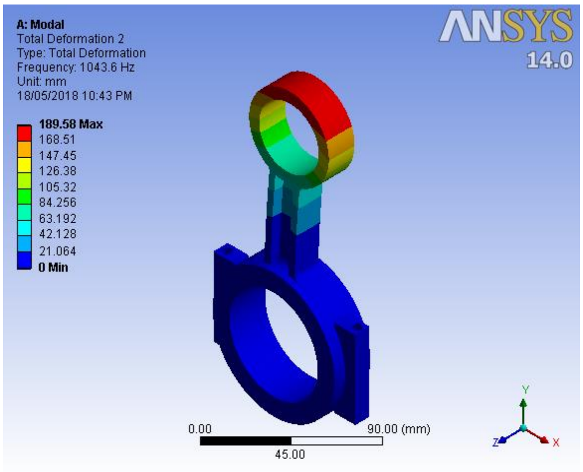

Fig 19:- Deformation contour of mode 2

The fig. 18. and fig. 19. shows the contour of total deformation of mode shape obtained in the solution. The mode are defined according to the effective mass participation factor in the respective axes. The frequency obtained in the first and second mode are 682.79 Hz and 1043.6 Hz.

X. RESULT

The connecting rod of Pulsar 220cc is tested for the Static structural analysis, Buckling analysis and Modal analysis.

- *Structural Analysis*

The stress and deformation obtained at angles are tabulated in table 2.

Angle	Von mises stress	Theoretical Stresses
0	32.43	42.56
60	50.87	66.61
90	64.11	70.06
180	74.47	97.6
270	63.96	70.06

Table 2. Stress and deformation at various angles

The fig. 20. shows the comparison between stresses induced at different crank angle. The crank angle is shown on the abscissa and stresses shown on the ordinate.

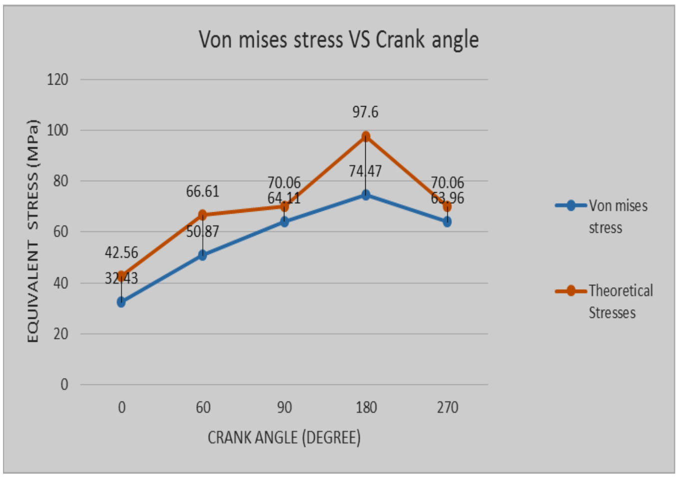

Fig 20:- Von mises stress vs. crank angle

From Table 2. and fig. 20., it is observed that as the angle increases stresses induced increases up to 180˚ and after that stresses induced are decreases. Also the maximum stress obtained is 74.47 MPa at 180 ˚.

- *Buckling Analysis*

In Bucking analysis of connecting rod, the load multiplier obtained through the FEM is 1.2 in the first shape mode and 2.95 in the second mode shape. Theoretically, the value of load multiplier is obtained as 2.95.

- *Modal Analysis*

The natural frequency of connecting rod is obtained through the FEM is 682.79 Hz for first mode shape and 1043.6 Hz for second mode shape. The actual frequency of connecting rod is 890.11 Hz.

XI. COCNLUSION

- The analysis has been carried out for the pulsar 220cc connecting rod. It is observed that the stresses induced are increases as the crank angle increases to a certain limit i.e. up to 180˚. After that the stresses induced are decreased. The stresses induced are lesser than the yield tensile strength of material. So the connecting rod is safe in the structural analysis.
- In Buckling analysis, it is observed that the load multiplier obtained is 1.2, it means that connecting rod sustain 1.2 times larger than the existing force. Also the theoretical and FE load multiplier is very much equal which shows the connecting rod is safe in buckling analysis.
- The modal analysis is done to check whether the connecting rod is safe in vibration. The natural frequency of connecting rod obtained through FE is 682.70 Hz and the actual frequency is 890.11 Hz. There actual frequency is 23% more than the natural frequency. So there is no chance of occurring resonance and therefore the connecting rod is safe.

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