DESIGN AND ANALYSIS OF CONNECTING ROD USING ALUMINIUM ALLOY 7068 T6, T6511

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ABSTRACT

The connecting rod is the intermediate member between the piston and the 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. This thesis describes designing and Analysis of connecting rod. Currently existing connecting rod is manufactured by using Forged steel. In this drawing is drafted from the calculations. A parametric model of Connecting rod is modeled using SOLID WORK software and to that model, analysis is carried out by using ANSYS 15.0 Software. Finite element analysis of connecting rod is done by considering the materials, viz... Aluminium Alloy. The best combination of parameters like Von misses Stress and strain, Deformation, Factor of safety and weight reduction for two wheeler piston were done in ANSYS software. Aluminium Alloy has more factor of safety, reduce the weight, reduce the stress and stiffer than other material like Forged Steel. With Fatigue analysis we can determine the lifetime of the connecting rod.

Keywords: Connecting Rod, Analysis of Connecting Rod, Four Stroke Engine Connecting Rod, Aluminium Alloy Connecting Rod, Design and Analysis of Connecting Rod.

NOMENCLATURE

A = cross sectional area of the connecting rod. L = length of the connecting rod. C = compressive yield stress. Wcr = crippling or buckling load. \( I_{XX} \) = moment of inertia of the section about x-axis \( I_{yy} \) = moment of inertia of the section about y-axis respectively. \( K_{XX} \) = radius of gyration of the section about x-axis \( K_{yy} \) = radius of gyration of the section about y-axis respectively. D = Diameter of piston r = Radius of crank
1. INTRODUCTION

In a reciprocating piston engine, the connecting rod connects the piston to the crank or crankshaft. In modern automotive internal combustion engines, the connecting rods are most usually made of steel for production engines, but can be made of aluminum (for lightness and the ability to absorb high impact at the expense of durability) or titanium (for a combination of strength and lightness at the expense of affordability) for high performance engines, or of cast iron for applications such as motor scooters. The small end attaches to the piston pin, gudgeon pin (the usual British term) or wrist pin, which is currently most often press fit into the con rod but can swivel in the piston, a "floating wrist pin" design. The connecting rod is under tremendous stress from the reciprocating load represented by the piston, actually stretching and being compressed with every rotation, and the load increases to the third power with increasing engine speed. Failure of a connecting rod, usually called "throwing a rod" is one of the most common causes of catastrophic engine failure in cars, frequently putting the broken rod through the side of the crankcase and thereby rendering the engine irreparable; it can result from fatigue near a physical defect in the rod, lubrication failure in a bearing due to faulty maintenance or from failure of the rod bolts from a defect, improper tightening, or re-use of already used (stressed) bolts where not recommended. Despite their frequent occurrence on televised competitive automobile events, such failures are quite rare on production cars during normal daily driving. This is because production auto parts have a much larger factor of safety, and often more systematic quality control. When building a high performance engine, great attention is paid to the connecting rods, eliminating stress risers by such techniques as grinding the edges of the rod to a smooth radius, shot peening to induce compressive surface stresses (to prevent crack initiation), balancing all connecting rod/piston assemblies to the same weight and Magnafluxings to reveal otherwise invisible small cracks which would cause the rod to fail under stress. In addition, great care is taken to torque the con rod bolts to the exact value specified; often these bolts must be replaced rather than reused. The big end of the rod is fabricated as a unit and cut or cracked in two to establish precision fit around the big end bearing shell. Recent engines such as the Ford 4.6 liter engine and the Chrysler 2.0 liter engine have connecting rods made using powder metallurgy, which allows more precise control of size and weight with less machining and less excess mass to be machined off for balancing. The cap is then separated from the rod by a fracturing process, which results in an uneven mating surface due to the grain of the powdered metal. This ensures that upon reassembly, the cap will be perfectly positioned with respect to the rod, compared to the minor misalignments, which can occur if the mating surfaces are both flat. A major source of engine wear is the sideways force exerted on the piston through the con rod by the crankshaft, which typically wears the cylinder into an oval cross-section rather than circular, making it impossible for piston rings to correctly seal against the cylinder walls. Geometrically, it can be seen that longer connecting rods will reduce the amount of this sideways force, and therefore lead to longer engine life. However, for a given engine block, the sum of the length of the con rod plus the piston stroke is a fixed number, determined by the fixed distance between the crankshaft axis and the top of the cylinder block where the cylinder head fastens; thus, for a given cylinder block longer stroke, giving greater engine displacement and power, requires a shorter connecting rod (or a piston with smaller compression height), resulting in accelerated cylinder wear.

2. SPECIFICATION OF THE PROBLEM

The objective of the present work is to design and analyses of connecting rod made of Aluminium Alloy. Steel materials are used to design the connecting rod. In this project the material (Forged steel) of connecting rod replaced with Aluminium Alloy. Connecting rod was created in SOLID WORK 2014. Model is imported in ANSYS 15.0 for analysis. After analysis a comparison is
made between existing steel connecting rod viz., A Aluminium Alloy in terms of weight, factor of safety, stiffens, deformation and stress.

Fig 2.1: Schematic Diagram of Connecting Rod

3. DESIGN OF CONNECTING ROD

A connecting rod is a machine member which is subjected to alternating direct compressive and tensile forces. Since the compressive forces are much higher than the tensile force, therefore the cross-section of the connecting rod is designed as a strut and the rankine formula is used. A connecting rod subjected to an axial load W may buckle with x-axis as neutral axis in the plane of motion of the connecting rod, y-axis is a neutral axis. The connecting rod is considered like both ends hinged for buckling about x-axis and both ends fixed for buckling about y-axis. A connecting rod should be equally strong in buckling about either axis. According to rankine formulae

\[ W_{cr} \text{ About x-axis} = \frac{\sigma_c \times A}{1 + [L/K_{xx}]} = \frac{\sigma_c \times A}{1 + [l/K_{xx}]} \quad \text{[ :: for both ends hinged L=l]} \]

\[ W_{cr} \text{ About y-axis} = \frac{\sigma_c \times A}{1 + [L/K_{yy}]} = \frac{\sigma_c \times A}{1 + a[l/2K_{yy}]} \quad \text{[ :: for both ends fixed L=l/2]} \]

In order to have a connecting rod equally strong in buckling about both the axis, the buckling loads must be equal. i.e.

\[ \frac{\sigma_c \times A}{1 + [L/K_{xx}]} = \frac{\sigma_c \times A}{1 + a[l/2K_{yy}]} \quad \text{[or]} \quad [l/K_{xx}]^2 = [l/2K_{yy}]^2 \]

\[ K_{xx}^2 = 4K_{yy}^2 \quad \text{[or]} \quad I_{xx} = 4I_{yy} \quad \text{[ :: I=A×K^2]} \]

This shows that the connecting rod is four times strong in buckling about y-axis than about-axis.

If \( I_{xx} > 4I_{yy} \), then buckling will occur about y-axis and if \( I_{xx} < 4I_{yy} \), then buckling will occur about x-axis. In actual practice \( I_{xx} \) is kept slightly less than \( 4I_{yy} \). It is usually taken between 3 and 3.5 and the connecting rod is designed for buckling about x-axis. The design will always be satisfactory for buckling about y-axis. The most suitable section for the connecting rod is I-section with the proportions shown in fig.

Area of the cross section = \( 2[4t \times t] + 3t \times t = 11t^2 \)

Moment of inertia about x-axis = \( 2[4t \times t] + 3t \times t = 11t^2 \)
Moment of inertia about x-axis \( I_{xx} = 1/12 [4t \{ 5t \}^3-3t \{ 3t \}^3] = (419/12)[t^4] \)
And moment of inertia about y-axis \( I_{yy} = (2\times1/12) \times t \times \{ 4t \}^3+(1/12)\{ 3t \}t^3 = 131/12[t^4] \)
\( I_{xx} / I_{yy} = [419/12] \times [12/131] = 3.2 \)
Since the value of \( I_{xx} / I_{yy} \) lies between 3 and 3.5 m therefore I-section chosen is quite satisfactory

3.1 Pressure Calculation for 150 cc Engine Suzuki 150 cc Specifications

Engine type air cooled 4-stroke, Bore x Stroke (mm) = 57x58.6
Displacement = 149.5 CC , Maximum Power = 13.8 bhp @ 8500 rpm
Maximum Torque = 13.4 Nm @ 6000 rpm, Compression Ratio = 9.35/1,
Density of Petrol C8H18 = 737.22 kg/m³ = 737.22E⁻9 kg/mm³, Temperature = 60 °C
F = 288.855 °K, Mass = Density \times Volume
= 737.22E⁻9 \times 149.5E³ = 0.11 kg
Molecular Weight of Petrol 114.228 g/mole From Gas Equation,
\( PV = Mrt \) \( R = (R_x/M_w) = 8.3143/114228 \)
= 72.76 P = \( (0.11\times72.786\times288.85) /149.5E³ \)
P = 15.5 Mpa

4.0 DESIGN CALCULATIONS FOR EXISTING CONNECTING ROD

Thickness of flange & web of the section = t
Width of section B= 4t
The standard dimension of I - SECTION

\[ \text{Fig 4.1: Standard Dimension of I – Section} \]

Height of section H = 5t, Area of section A= 2(4t\times t) + 3t\times t, A = 11t²
M.O.I of section about x axis: \( I_{xx} = 1/12 [4t \{ 5t \}^3-3t \{ 3t \}^3] = 419/12[t^4] \)
MI of section about y axis: \( I_{yy} = 2\times1/12\times t \times \{ 4t \}^3+1/12\{ 3t \}t^3 = 131/12[t^4] \)
\( I_{xx} / I_{yy} = 3.2 \)
Length of connecting rod (L) = 2 times the stroke, ∴ L = 117.2 mm
Buckling load \( w_B = \text{maximum gas force} \times \text{F.O.S} \)
\( w_B = (\sigma_x \times A) / (1+a \left( L/K_{xx} \right)^2) = 37663 \text{N} \)
\(\sigma_c = \) compressive yield stress = 415MPa,
\(K_{xx} = I_{xx}/A, \ K_{xx} = 1.78t, \ a = \sigma_c /\pi^2, \ a = 0.0002\)

By substituting \(\sigma_c, \ A, \ a, \ L, \ K_{xx}\) on \(w_B\) then = 4565t\(^4\) -37663t\(^2\) -81639.46 = 0

\(t^2 = 10.03, \ t = 3.167mm, \ t = 3.2mm\)

Width of section B = 4t = 4\times3.2 = 12.8mm

Height of section H = 5t = 5\times3.2 = 16mm

Area A = 11t\(^2\) =11\times3.2\times3.2 = 112.64mm\(^2\)

Height at the big end (crank end) = \(H_2 = 1.1H \) to 1.25H = 1.1\times16

\(H_2 = 17.6mm\)

Height at the small end (piston end) = 0.9H to 0.75H = 0.9\times16

\(H_1 = 12mm\)

**Fig 4.2:** 2D Drawing for Connecting Rod

Stroke length (l) =117.2mm

Diameter of piston (D) =57mm

P=15.5N/ mm\(^2\)

Radius of crank(r) =stroke length/2

=58.6/2 =29.3

Maximum force on the piston due to pressure

\(F_l = \pi/4\times D^2 \times P = \pi/4 \times (57)^2 \times15.469 = 39473.16N\)

Maximum angular speed \(W_{max} = [2\pi N_{max}] /60 = ([2\pi \times 8500]/60) \ A=\pi r^2 = 768 \text{ rad/sec}\)

Ratio of the length of connecting rod to the radius of crank \(N= l/r =112/ (29.3) = 3.8\)

Maximum Inertia force of reciprocating parts \(F_{im} = Mr (W_{max})^2 \ r (\cos0 + \cos20/n) \ (Or)\)

\(F_{im} = Mr \ (W_{max})^2 \ r (1+1/n) = 0.11 \times (768)^2 \times (0.0293) \times (1+ (1/3.8)), \ F_{im} = 2376.26N\)

Inner diameter of the small end \(d_1 = F_g /Pb_1 \times l_1 = 6277.167/12.5\times1.5d_1 = 17.94mm\)
Design bearing pressure for small end $Pb_1$ = 12.5 to 15.4 N/mm$^2$

Length of the piston pin $l_1$ = (1.5 to 2) $d_1$

Outer diameter of the small end $= d_1 + 2t_b + 2t_m$

$= 17.94 + [2 \times 2] + [2 \times 5] = 31.94$ mm

Where, Thickness of the bush ($t_b$) = 2 to 5 mm

Marginal thickness ($t_m$) = 5 to 15 mm, Inner diameter of the big end $d_2 = \frac{F_g}{Pb_2 \times l_2}$

$= \frac{6277.167}{10.8 \times 1.0 d_1} = 23.88$ mm

Where, Design bearing pressure for big end $Pb_2$ = 10.8 to 12.6 N/mm$^2$

Length of the crank pin $l_2$ = (1.0 to 1.25) $d_2$. Root diameter of the bolt $= \frac{2 d_2}{\pi (St)}$

$= \frac{2 \times 6277.167 \times 56.667}{1/2} = 4$ mm

Outer diameter of the big end $= d_2 + 2t_b + 2d_b + 2t_m$

$= 23.88 + 2 \times 2 + 2 \times 4 + 2 \times 5 = 47.72$ mm

Where, Thickness of the bush ($t_b$) = 2 to 5 mm

Marginal thickness ($t_m$) = 5 to 15 mm

Nominal diameter of bolt $[d_b] = 1.2 \times \text{root diameter of the bolt} = 1.2 \times 4 = 4.8$ mm

<table>
<thead>
<tr>
<th>Sno</th>
<th>Parameters (mm)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Thickness of the connecting rod (t) = 3.2</td>
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<tr>
<td>2</td>
<td>Width of the section (B = 4t) = 12.8</td>
</tr>
<tr>
<td>3</td>
<td>Height of the section (H = 5t) = 16</td>
</tr>
<tr>
<td>4</td>
<td>Height at the big end = (1.1 to 1.125)H = 17.6</td>
</tr>
<tr>
<td>5</td>
<td>Height at the small end = 0.9H to 0.75H = 14.4</td>
</tr>
<tr>
<td>6</td>
<td>Inner diameter of the small end = 17.94</td>
</tr>
<tr>
<td>7</td>
<td>Outer diameter of the small end = 31.94</td>
</tr>
<tr>
<td>8</td>
<td>Inner diameter of the big end = 23.88</td>
</tr>
<tr>
<td>9</td>
<td>Outer diameter of the big end = 47.72</td>
</tr>
</tbody>
</table>
5. ANALYSIS OF THE CONNECTING ROD

Modified Connecting Rod (Aluminium Alloy 7068 T6, T6511)

![Meshing of Connecting Rod](image1)

![Total Deformation](image2)

![Directional Deformation X-axis](image3)

![Directional Deformation Y-axis](image4)

![Directional Deformation Z-axis](image5)

![Equivalent Stress](image6)
Fig 5.6: Normal Stress-X-axis

Fig 5.7: Normal Stress-Y-axis

Fig 5.8: Normal Stress-Zaxis

Fig 5.9: Shear Stress XY plane

Fig 5.9: Shear Stress XZ

Fig 5.10: Shear Stress YZ
### Stresses and Deformation of Aluminium Alloy 7068 T6,T6511

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<thead>
<tr>
<th>SN</th>
<th>Types</th>
<th>Max (Mpa)</th>
<th>Min (Mpa)</th>
<th>Max (Mpa)</th>
<th>Min (Mpa)</th>
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<tbody>
<tr>
<td>1</td>
<td>Equivalent stress</td>
<td>25.142</td>
<td>0.093156</td>
<td>38.298</td>
<td>4.0317e-9</td>
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<tr>
<td>2</td>
<td>Normal stress (x-axis)</td>
<td>35.934</td>
<td>-34.953</td>
<td>25.283</td>
<td>-15.692</td>
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<tr>
<td>4</td>
<td>Normal stress (z-axis)</td>
<td>9.9224</td>
<td>-9.4259</td>
<td>1.1978</td>
<td>-0.85736</td>
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<td>5</td>
<td>Shear stress(xy plane)</td>
<td>14.152</td>
<td>-14.914</td>
<td>20.166</td>
<td>-20.183</td>
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<tr>
<td>6</td>
<td>Shear stress(yz plane)</td>
<td>6.4729</td>
<td>-7.2802</td>
<td>0.91522</td>
<td>-0.96534</td>
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<tr>
<td>7</td>
<td>Shear stress(zx plane)</td>
<td>6.2828</td>
<td>-6.2138</td>
<td>0.7183</td>
<td>-0.72013</td>
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<td>8</td>
<td>Total deformation(mm)</td>
<td>0.0044016</td>
<td>0</td>
<td>0.0025932</td>
<td>0</td>
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<tr>
<td>9</td>
<td>Directional deformation (x-axis)</td>
<td>0.00082689</td>
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<td>0.0005354</td>
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<td>10</td>
<td>Directional deformation (y-axis)</td>
<td>0.0044014</td>
<td>-1.9783e-7</td>
<td>0.0016764</td>
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<td>11</td>
<td>Directional deformation (z-axis)</td>
<td>0.0001689</td>
<td>-0.00017897</td>
<td>0.00013292</td>
<td>-0.0001347</td>
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### Mechanical properties for Aluminium Alloy 7068 T6,T6511

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<th>Sno</th>
<th>Mechanical Properties</th>
<th>Aluminium Alloy 7068 T6,T6511</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Density( g/cc)</td>
<td>2.85</td>
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<tr>
<td>2</td>
<td>Average hardness(HRB)</td>
<td>174</td>
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<tr>
<td>3</td>
<td>Modulus of elasticity,(Gpa)</td>
<td>73.1</td>
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<tr>
<td>4</td>
<td>Yield strength, YS,(Mpa)</td>
<td>683</td>
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<tr>
<td>5</td>
<td>Ultimate strength ,Su,(Mpa)</td>
<td>710</td>
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<tr>
<td>6</td>
<td>Fatigue Strength,(Mpa)</td>
<td>159</td>
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<tr>
<td>7</td>
<td>Poison ratio</td>
<td>0.33</td>
</tr>
</tbody>
</table>

### CHEMICAL COMPOSITION OF Aluminium Alloy 7068 T6,T6511

Si 0.12;Fe 0.15,Cu 1.6-2.4,Mn 0.10,mg 2.2-3.0, Cr 0.05 ,Zn 7.3-8.3, Ti 0.10, Zr 0.05-0.15, Other, each 0.05, Other, total 0.15

### 7. CALCULATION

#### 7.1 Calculation for factor of safety of connecting rod

\[
\text{f.s} = \text{factor of safety}, \quad \sigma_m = \text{Mean stress}, \quad \sigma_y = \text{Yield stress}, \quad \sigma_v = \text{Variable stress}, \quad \sigma_e = \text{Endurance stress} \\
1/ \text{f.s} = \sigma_m / \sigma_y + \sigma_v / \sigma_e
\]
For Aluminium Alloy 7068 T6, T6511

\[
\sigma_{\text{max}} = 45.142 \quad \sigma_{\text{min}} = 0.093156
\]

\[
\sigma_m = (\sigma_{\text{max}} + \sigma_{\text{min}})/2 = 22.617578
\]

\[
\sigma_y = 683 \text{MPa}
\]

\[
\sigma_v = (\sigma_{\text{max}} - \sigma_{\text{min}})/2 = 22.617578
\]

\[
1/f .s = \sigma_m / \sigma_y - \sigma_v / \sigma_e = \sigma_e = 0.3 \times 683 = 204.9
\]

\[
1/f .s = 22.617578/683 + 22.617578/204.9 = 0.033115 + 0.11038349 = 0.143498494
\]

\[
f .s = 6.9687142
\]

Calculation for Weight and Stiffness for Aluminium Alloy 7068 T6, T6511

Density of Aluminium Alloy 7068 T6, T6511 = 2.85*10^{-6} kg/mm^3

Volume = 60477 mm^3

Deformation = 0.0044061 mm,

Weight of Aluminum = volume × Density = 60477 × 2.85 × 10^{-6} = 0.17235 kg

Mass = 0.17235 × 9.81 = 1.69084 N

Stiffness = weight / deformation = 1.6908 / 0.0044061 = 383.73 N/mm

Fatigue calculation

Result for fatigue of connecting rod:

\[
N = 1000 \left( \frac{3}{0.9} \right)^{1.05} \left( \frac{\sigma_e}{\sigma_u} \right)^{1.07/13}
\]

Where,

\[
N = \text{No. of cycles}
\]

\[
\sigma_e = \text{Endurance Limit}, \sigma_u = \text{Ultimate Tensile Stress}, \sigma_v = \text{Endurance limit for variable axial stress}
\]

\[
k_\alpha = \text{Load correction factor for reversed axial load} = 1.5, k_{\text{sr}} = \text{Surface finish factor} = 0.78
\]

\[
k_\text{sz} = \text{Size factor} = 1
\]

\[
\sigma_v = \sigma_e \times k_\alpha \times k_{\text{sr}} \times k_\text{sz}
\]

\[
S_f = \frac{f .s \sigma_v}{1 - f .s \sigma_m / \sigma_u}
\]

For Aluminium Alloy 7068 T6, T6511

\[
\sigma_u = 710 \text{MPa}
\]

\[
\sigma_e = 0.4 \times 710 = 284 \text{MPa}
\]
\[ \sigma_e = 284 \times 0.8 \times 1.2 \times 1 = 272.64 \text{MPa} \]

\[ S_f = \frac{6.9687142 \times 22.617578}{1 - 6.9687142 \times 22.617578} = \frac{157.615}{0.778} = 202.58997 \text{MPa} \]

\[ N = 1000 \left( \frac{202.58997}{0.9 \times 710} \right)^{\frac{3}{2}} \left( \frac{272.64}{0.9 \times 710} \right) = 11.116 \times 10^3 \text{cycles} \]

**CONCLUSION**

Conclusion and future scope Solid modeling of connecting rod were made according to production drawing specification and analysis under the effect of tensile and compressive loads in terms of pressure is done in ANSYS Workbench. In the present design and analysis of connecting rod using aluminum alloy 7068 T6, T6511 have been done with the help of SOLID WORK and ANSYS 15.0. Here Analysis is done for the Normal stress as well as Shear stress in x-y plane. From modeling and simulation, Solid work is good but for the Analysis, it is observed that Ansys is better than other software. Here we can find minimum stresses among all loading conditions, were at crank end cap as well as at piston end. So the material can be reduced from those portions, thereby reducing material cost.

For further optimization of material dynamic analysis of connecting rod is required. After considering dynamic load condition, once again finite element analysis will have to be perform. It will give more accurate results than existing results.

**REFERENCES**


AUTHOR’S DETAILS

MOHAMED ABDUSALAM HUSSIN, I am working as an Engineer at Morzk Umm-Alaraneb Governorate, I have completed my Bachelor at College of Engineering, The University of Hoon, Republic of Libya and I am going to complete M. Tech. in Mechanical Engineering (CAD/CAM) in SSET, Faculty of Engineering, Sam Higginbottom Institute of Agriculture, Technology & Sciences, Allahabad, India.

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