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DESIGN AND OPTIMIZATION OF CONNECTING ROD FOR 4 – STROKE PETROL ENGINE BY USING FINITE ELEMENT ANALYSIS

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ABSTRACT

The connecting rod is the mediating member between the piston and the Crankshaft. Its main function is to convert the reciprocating motion of the piston into rotary motion of the crank. This paper describes about a real time problem of using Cast Iron connecting rod in Hero Honda Splendor + motorbike it's modelling and analysis and optimization of connecting rod. Here, the connecting rod is replaced by various materials like stainless steel, aluminium, C70 steel and also a design change by inducing truss member is suggested. The connecting rod is modelled using CATIA software for both existing solid and modified truss designs. Boundary conditions are applied to the models after finishing the pre – processing work in ANSYS 14.0 software. The best combination of parameters like Von misses stress and strain, Deformation, Factor of safety, fatigue and life cycle calculation, bi-axiality indication for two wheeler piston were done in ANSYS 14.0 software. This project also tends to optimize the design by calculating weight and stiffness for various materialistic designs by using the output values of mass and volume of the connecting rod which will also be obtained from the software. This paper will conclude whether the modified design is safe along above selected materials. And will be presenting the best design for future reference.

Keywords: connecting rod, design-change, truss design, optimization, von misses stress.

1. INTRODUCTION

Connecting rod is an integral component of an engine and it is classified under functional component based on its application. It acts as a linking member between piston and crank shaft. The function of the connecting rod also involves transmitting the thrust of the piston [1]. Connecting rod has three main zones. The piston pin end, the center shank and the big end. The piston pin end is the small end, the crank end is the big end and the center shank is of I cross section. Connecting rod is a pin jointed strut in which more weight is concentrated towards the big end [2]. In this paper a design change is suggested in which truss is induced in the connecting rod design. But, before inducing the truss member, basic design calculation will be used to derive the constant and varying design parameters [3].

2. DESIGN OF CONNECTING ROD

a) Engine specifications

- Engine type air cooled 4-stroke
- Bore × Stroke (mm) = 50×49.5
- Displacement = 97.2CC
- Maximum Power = 5.5KW@8000rpm
- Maximum Torque =7.95Nm @ 5000rpm
- Compression Ratio = 9.0:1

The connecting rod is used to convert the reciprocating motion of the piston to oscillatory motion of itself which is finally converts to rotary motion of the crank shaft [4]. The main parts of connecting rod are:

i. The small end which connect the connecting rod to the piston through the piston pin.

ii. The shank, usually of I-section and

iii. The big end which is usually split to surround crank pin.

The length of connecting rod is usually kept 3 to 4.5 times the crank radius [5]. The shorter length of connecting rod increases obliquity and there by the side thrust on the cylinder whereas the longer length increases the height of the engine. Maximum gas force

$$Fgas = \frac{\pi}{4} \times (D)^2 \times P_{MAX}$$

Where,
D = Diameter of piston head
P_{max} = Maximum combustion pressure

$$\text{Diameter of piston head} = \sqrt{\frac{\text{engine displacement}}{stroke \times 0.7854 \times no.\,of\ cycles}}$$

$$\text{Diameter of piston head} = \sqrt{\frac{5.93153}{1.9488 \times 0.7854 \times 1}}$$

Diameter = 1.9685 inches = 5cm.
Therefore,
F_{gas} = 3013 Kgf
F_{gas} = 29527.4 N

Since a connecting rod is subjected to severe load conditions including fatigue load, a high factor of safety (5-6) is used while treating it as static strut. Thus according to Rankine formula,

$$P_{cr} = \frac{\sigma_{cr} \times A}{1 + a\left[\frac{L}{K_{xx}}\right]^2}$$

Where,
P_{cr} = Crippling load

σ_{cr} = compressive stress
A = Area of section

$$a = \frac{\sigma_c}{\pi^2 \times E}$$

l = length of connecting rod
K_{xx} and K_{yy} = radius of gyration of the section about x-axis and y- axis respectively. For crippling load P_{cr}:
$P_{cr} = F_{gas} \times$ factor of safety
$P_{cr} = 3013.96 \times 5$
$P_{cr} = 15069.82$ Kgf
Dimension of small end considering bearing failure of the pin:
$P_{br} = F_{gas} / (l_s \times d_{ps})$
Assuming allowable bearing pressure, $P_{br} = 15\ N/mm^2$,
l_s = length of small end
d_{ps} = diameter of piston pin
$l_s / d_{ps} = 2$

$$d_{ps} = \sqrt{\frac{F_{gas}}{2 \times P_{br}}}$$

$d_{ps} = 10.02$mm
Inner diameter of the small end,
$d_{si} = (1.1\text{-}1.25)\ d_{ps}$
$d_{si} = 1.25 \times d_{ps} = 1.25 \times 10.02$
Inner diameter of small end $d_{si} = 12.52$mm
Outer diameter of the small end,
$d_{so} = (1.25\text{-}1.65)\ d_{ps} = 1.65 \times d_{ps} = 1.65 \times 10.02$
Outer diameter of small end $d_{so} = 16.53$ mm
Length of small end,
$l_s = (0.3\text{-}0.45)$ D
Length of small end, $l_s = 0.380 \times 50 = 19$ mm
Dimension for Big end,
Considering bearing failure of crank and assuming empirical relations:
Diameter of crank pin,
$d_{pc} = (0.55\text{-}0.75)$ D
$d_{pc} = 0.55$ D $= 0.55 \times 50 = 27.5$ mm
Diameter of crank pin, $d_{pc} = 27.5$mm.
Inner diameter of the big end,
$d_{bi} = (1.1\text{-}1.25)\ d_{pc}$
$d_{bi} = 1.18 d_{pc} = 1.18 \times 27.5$
Inner diameter of bigger end, $d_{bi} = 30.25$mm
Outer diameter of the big end,
$d_{bo} = (1.25\text{-}1.65) d_{pc} = 1.42$
$d_{bo} = 1.42 \times 27.5 = 39.05$mm
Outer diameter of the big end, $d_{bo} = 39.05$mm
Length of the big end:-
$l_c = (0.45\text{-}1.0)\ d_{pc}$
$l_c = 0.73 d_{pc} = 0.73 \times 27.5 = 20.075$mm
Length of the big end, $l_c = 20.075$mm
Bearing pressure (P_{br}),
$P_{br} = F_{gas} / l_c\ d_{pc}$
$P_{br} = 3013.96/20.075 \times 27.5 = 5.45\ Kgf/mm^2$
Based on the Rankine formula dimensions are obtained and then compared with actual dimensions of the connecting rod.

Table-1. Comparison of dimensions of connecting rod shank.

Sr. no.	Parameters	Actual values	Theoretical values
1	Length of connecting rod	122.66mm	117mm
2	Outer diameter of Big end	39.02mm	39.05mm
3	Inner diameter of big end	30.19mm	30.25mm
4	Outer diameter of small end	17.75mm	16.53mm
5	Inner diameter of small end	13.02mm	12.52mm

b) For modified truss design

- Creating the 2D cross section on XY plane using two circle, line and fillets with the help of sketcher option.
- Fill material in sketch with the help of pad command.
- Creation of hole on piston end and crank end with the help of pocket command.
- Creation of second sketch in shank portion of the connecting rod.
- Pocket the second sketch on both sides of the shank up to desired depth to make the I-section.
- Sketching the necessary truss arrangement to show up static stability.

c) Reasons for selecting truss design

- A truss is a structure composed of slender members joined together at their end points.
- Each member only takes axial forces
- The trusses are statically determinate
- If a truss is in equilibrium, then each of its joints must also be in equilibrium.
- In this proposed design truss consideration is taken as an equally angled truss member, which is aligned with equal spacing from both the end of the connecting rod.
- The truss design also has good manufacturing feasibility in terms of the process of manufacturing. Such kind of design can be forged easily, through which it obviously reduces some grams of weight in the connecting rod.
- By this feasibility the ultimate aim of our project can be achieved.
- Considering the reaction forces acting on the truss design, the outcome i.e., the stress distribution along the connecting rod will be even, by which the defect of location of extreme stress point in the connecting rod will also get modified.
- We can conclude that, this type of truss design may act as a valid reason for the improvement of the engine performance in future.

Since the length of I – section varies along with the length of the connecting rod, and also the thickness varies depending on the material used in the connecting rod, it is necessary to do separate model for separate materials. So, we get a total of eight models for two different design and four different materials [6].

3. FINITE ELEMENT MODELLING

A three dimensional connecting rod model has been developed to simulate for steel using the ANSYS 14.0 Software [7]. The rod is modeled as an isotropic material. SOLID45 element type is use for connecting rod material. The mesh of the rod consists of 85167 elements. 17535 nodes are included in the finite element model [8].

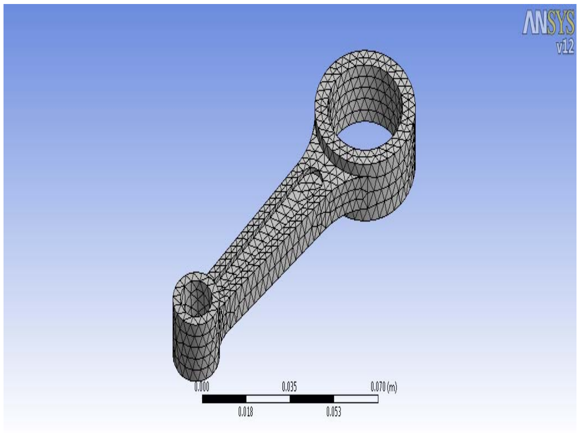

Figure-1. Mesh generation for existing design.

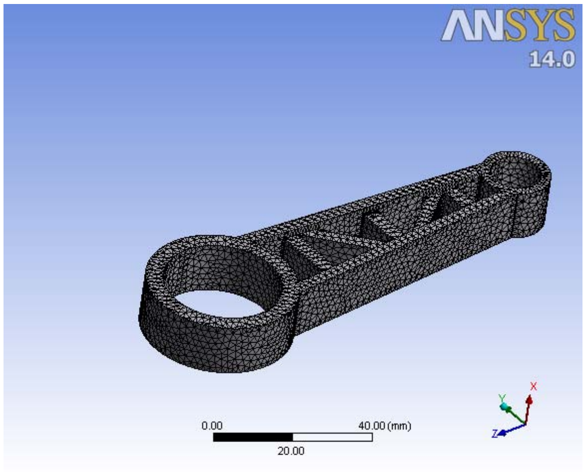

Figure-2. Mesh generation for modified design.

a) Material specifications

Table-2. Material specification for analysis of connecting rod.

Sr. no.	Material	Youngs modulus (gpa)	Poissons ratio	Density (kg/m^3)
1	Cast iron astm grade 20 (iso grade 150, en-jl 1020 grey cast iron)	97	0.3	$7.197x10^{-6}$
2	Alumnum 360	210	0.3	$2.700x10^{-6}$
3	Stainless steel grade 304 (uns s30400)	203	0.3	$7.850x10^{-6}$
4	c70 steel	211.5	0.3	$7.695x10^{-6}$

b) Loading conditions and constrains

The loading conditions are assumed to be static [9]. The applied load distributions were based on research by Webster et al [10]. Two cases were analyzed for each case, one with load applied at the crank end and restrained at the piston pin end, and the other with load applied at the piston pin end and restrained at the crank end. The tensile load was applied over 180^o of crank contact surface with cosine distribution,

whereas compressive load was applied as a uniformly distributed load over 120^0 of crank contact surface.

For all practical purposes, the force in the connecting rod is taken equal to the maximum force on the piston due to pressure of gas (P_g), neglecting piston inertia effects.

The pressure is acting on the contact surface area of the connecting rod. The normal pressure (p_o) was calculated from the following equations:

$P = P_o \cos\theta$

$p_o = P_t / (r\, t\, \pi / 2)$

$p_o = P_c / (r\, t\, \sqrt{3})$

Where, θ = Crank angle, 0 degree for top dead center
r = Radius of crank or pin end
t = Thickness of the connecting rod at the loading surface
P_t = Force magnitude in tension
P_c = Force magnitude in compression

Axial load for both tension and compression is F_{max}

Compressive loading: Crank End: $p_o = 6.340$ MPa
Piston pin End: $p_o = 14.65$MPa

Tensile loading: Crank End: $p_o = 6.95$MPa
Piston pin End: $p_o = 16.15$ MPa

4. RESULTS AND DISCUSSIONS

The Finite Element Analysis of both the connecting rod is done in ANSYS Workbench 14.0 considering all the loading conditions. Stress analysis has been done to calculate factor of safety.

a) Stress results

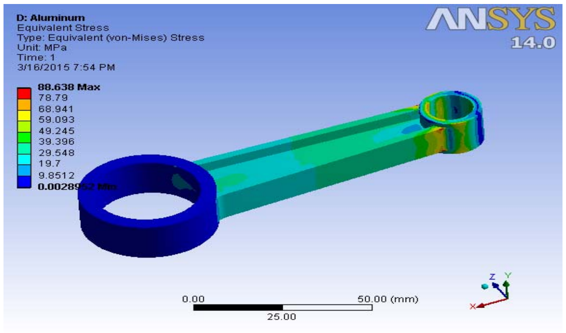

Figure-3. Equivalent stress for Al 360 alloy (Existing design).

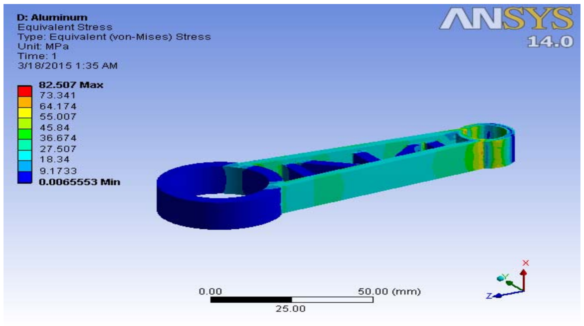

Figure-4. Equivalent stress for Al 360 alloy (Modified design).

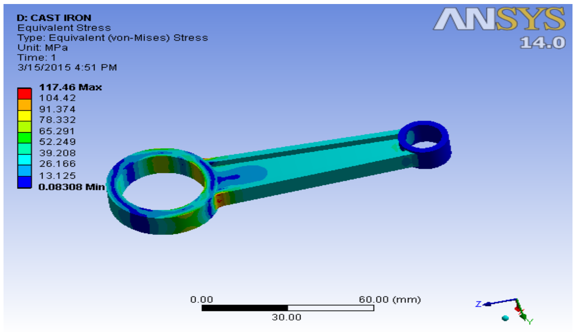

Figure-5. Equivalent stress for cast iron (Existing design).

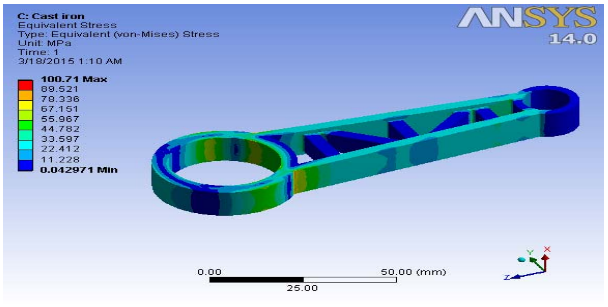

Figure-6. Equivalent stress for cast iron (Modified design).

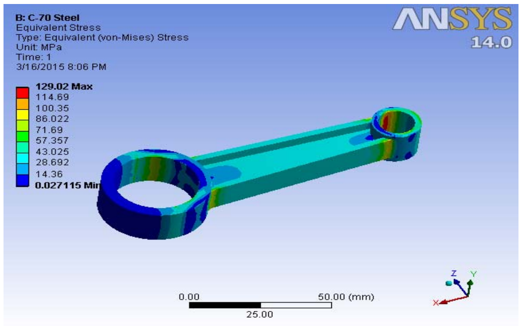

Figure-7. Equivalent stress for C- 70 steel (Existing design).

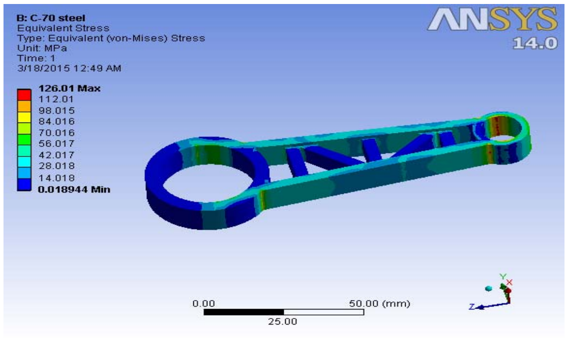

Figure-8. Equivalent stress for C- 70 steel (Modified design).

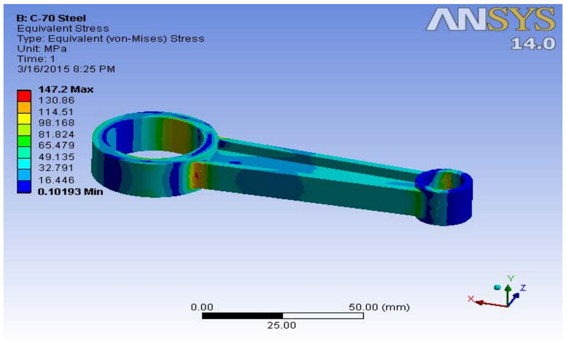

Figure-9. Equivalent stress for stainless steel (Existing design.

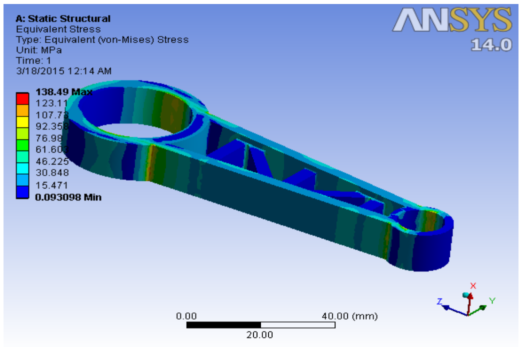

Figure-10. Equivalent stress for stainless steel (Modified design).

b) Comparison of weight

Result for stiffness of existing connecting rod

Cast Iron:
Weight of connecting rod =0.122Kg
Deformation =0.069057mm
Stiffness =Weight/Deformation =1.7666 kg/mm

Aluminum360
Weight of connecting rod = 0.045Kg
Deformation =0.031898mm
Stiffness =Weight/Deformation =1.410 kg/mm

C70 Steel
Weight of connecting rod =0.130Kg
Deformation =0.032998mm
Stiffness =Weight/Deformation =3.939 kg/mm

Stainless steel
Weight of connecting rod =0.133Kg
Deformation =0.032998mm
Stiffness =Weight/Deformation =4.033 kg/mm

Result for stiffness of connecting rod

Cast iron
Weight of connecting rod =0.112Kg
Deformation =0.04673mm
Stiffness =Weight/Deformation =2.398 kg/mm

Aluminum 360
Weight of connecting rod = 0.041Kg
Deformation =0.01432mm
Stiffness =Weight/Deformation =2.863 kg/mm

C70 Steel
Weight of connecting rod =0.120Kg
Deformation =0.03024mm
Stiffness =Weight/Deformation =3.968 kg/mm

Stainless steel
Weight of connecting rod =0.122Kg
Deformation =0.03214mm Stiffness =3.812 kg/mm

Table-3. Material specification for analysis of connecting rod.

S#	Material	Weight(Kg)		Diff %	Stiffness (Kg/mm)		Diff %
		Existing	Modified		Existing	Modified	
1	Aluminium 360	0.045	0.041	8.88	1.41	2.863	50.75
2	Cast Iron	0.122	0.112	8.19	1.7666	2.398	26.33
3	C-70 Steel	0.13	0.12	7.69	3.939	3.968	0.73
4	Stainless Steel	0.134	0.122	8.95	4.033	3.812	-5.79

From the below mentioned comparison graph, it can be noted that the modified truss design are comparatively less in weight.

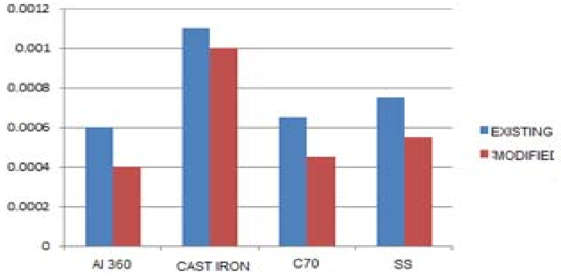

Figure-11. Equivalent strain.

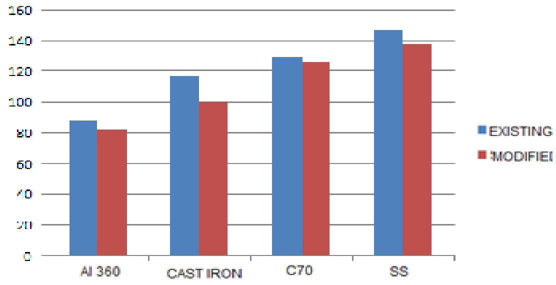

Figure-12. Equivalent stress.

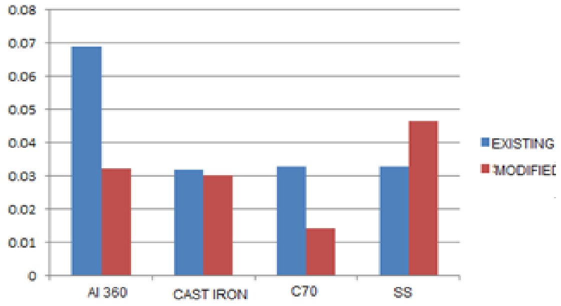

Figure-13. Deformation.

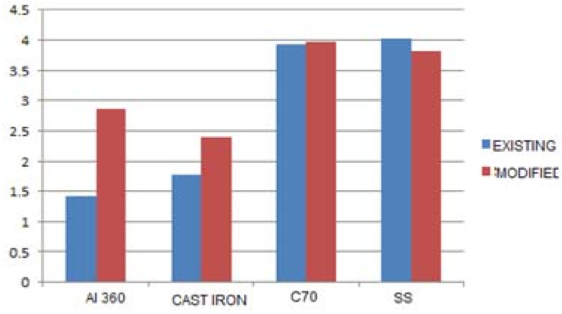

Figure-14. Stiffness.

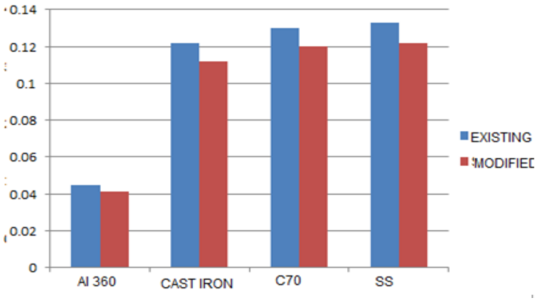

Figure-15. Weight.

5. CONCLUSIONS

- The existing and modified design is modeled using modeling software and various parameters are obtained and the results are taken and compared.
- A truss type connecting rod modeling is done using CATIA software and the feasible parameters are been obtained.
- From the above analysis it is clear that the stress and strain obtained by the modified design is less when compared to the existing design.
- Weight reduction can be clearly viewed in the comparison graph between the solid and truss design.
- The obtained design life cycle for modified design is 10^8 cycles, which is same as that of the existing design.
- Thus, we can conclude that in all the materials, modified design is much better than the existing solid type of design.

Further development can be made by manufacturing the modified design using the method of forging and also by inducing composite materials. Select various grades of material, take its chemical composition and mechanical properties as input details for obtain the stress, strain, displacement and volumetric efficiency of the machined connecting rod.

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