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A Study on Design Aspects of two wheeler 4-stroke Engine Connecting Rod of SAE-1020 Steel Material to Improve its Mechanical Efficiency

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Abstract:- *Every vehicle that uses an internal combustion engine requires at least one connecting rod depending upon the number of cylinders in the engine. It undergoes high cyclic loads of the order of 10^8 to 10^9 cycles, which range from high compressive loads due to combustion, to high tensile loads due to inertia. Therefore, durability of the component is of critical importance. Due to these factors the connecting rod has been the topic of research for different aspects such as production, materials, performance simulation, etc.]*

The main objective of the present paper was to explore opportunities to improve mechanical efficiency of engine by inducing structural changes in SAE 1020 steel connecting rods. This has entailed a detailed modified design procedure to obtain higher mechanical efficiency without affecting the factor of safety of the material and also in effect to modified design procedure 0 to 3.45% of increase in mechanical efficiency can be found.

Keywords: *connecting rod; mechanical efficiency;*

1. LITERATURE SURVEY

V.Jose Ananth Vino [1] et al, conducted performance and emission analysis on pulsar 150cc Dtsi engine using petrol and petrol-HHO(Brown's gas) separately. It was found that there was 20% reduction in fuel consumption, increased break power by 5.7%, and increased thermal efficiency by using petrol-HHO mixture. D.Gopinath [2] et al, in his literature conducted finite element analysis on four wheeler forged steel connecting rod and optimized the design using topology optimization technique and found that there was a weight reduction by 10.38% compared to existing connecting rod and reduction in weight contributes to increased engine speed which results in hike in output power, K. Sudershan Kumar [3] et al, described modeling and analysis of Connecting rod. In his project carbon steel connecting rod is replaced by aluminum boron carbide connecting rod. Aluminum boron carbide is found to have working factory of safety is nearer to theoretical factory of safety. In the present paperconstraints such as buckling resistance, static strength had been taken care of, thus paper tries to cover the ideas of above literatures to have improvised engine performance by placing connecting rod as object of interest and also paper tries to discover that without varying fuel consumption rate, just by having a modified design procedure of connecting rod, leads to improvement in mechanical efficiency of the engine.

2. INTRODUCTION

Connecting rod is one of the most critical components internal combustion engines bearing the statically anddynamically fluctuating loads. The optimization of connecting rod had already started as early years. However, everyday consumers are looking for the best from the best. That's why the optimization is really important for automotive industry especially. The main objective of optimization of the component in the present work by employing the modified design procedure is to make the component to be more effective structurally to ensure higher engine performance by improving its mechanical efficiency. The design of the connecting rod influence on vehicle performance. Hence, it effects on the vehicle manufacture credibility. The structural factors considered for design optimization include the buckling load factor, stresses under the loads, fatigue consideration, bending stiffness, and axial stiffness. Thus, the component with efficient design would result in improvised engine performance which would be necessary in automotive and manufacturing industry. The benefits of connecting rod optimization are eventually go back to consumer itself. Among the main objectives are to improve the engine performance by increasing its mechanical efficiency and also to ensure that factor of safety of material is not varied during optimization. As, the safety factor of connecting rod before and after optimization remains unchanged as well as there is no abrupt change in cross section of connecting rod, the life cycle of the connecting rod remains unaffected. Hence, the safety and stability of modified connecting rod is ensured during the practical applications.

Nomenclature

L_{cr} Length of connecting rod
P_{cr} Crippling load
r Crank radius
FOS Factor of safety
D Bore
N Speed of the engine in rpm
IP Indicated power
p_m Mean effective pressure
BP Break power
a Rankine's constant
T_{max} Maximum torque
$(P_p)_{max}$ Maximum force acting on piston due to gas load
P_{max} Maximum gas pressure
η_{mech} Mechanical efficiency in percent
$(P_t)_{max}$ Maximum tangential load acting on connecting rod
S Stroke length
S_v Stroke volume
B width of the section
H Depth of the section
H_1 Depth of the section at big end
H_2 Depth of the section at small end
C Central thickness
t thickness of the web and flange
A Area of I-section
I_{xx} Moment of inertia about X-axis
I_{YY} Moment of inertia about Y-axis
K_{XX} Radius of gyration about X-axis
E Young's modulus
ρ Density
μ Poisson's ratio
σ_u Ultimate tensile strength
$(\sigma_c)_y$ Yield strength in compression
P_{cr}Crippling load
P_p Force acting on piston due to gas load
n Aspect ratio
P_qForce acting on the connecting rod
P_t Tangential component of P_q
P_r Radial component of P_q
k Improvement factor

3. Design of connecting rod

Fig-1. Isometric model of connecting rod

For the optimization or structural modification, connecting rod of pulsar 150cc Dtsi engine is chosen and all the dimensions of connecting rod and engine specifications are mentioned in Table 1. And the isometric model of connecting rod is shown in the Fig1.

Table-1: Configuration of the engine

L_{cr}	103.65mm
r	28.2mm
D	57mm
IP	14HP(10444W) @ 8000rpm
BP	8419W
T_{max}	13.4N-m @ 6000rpm
P_{max}	10.514MPa
η_{mech}	80.6
S	56.4mm
S_v	149cc

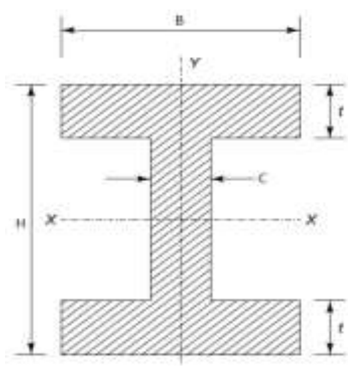

Fig-2. I-section

For the analysis of I.C. Engine connecting rod the most critical area is considered and here the cross-sectional area considered represents I-section as shown in the Fig2., various dimensions of I-section of pulsar engine connecting rod as obtained from the 3-D scanning is listed in the Table 2.

Table-2: Dimensions of the I-section

Description	Units
t	3.951mm
B	4.725mm
H	15.539mm
C	5.728mm
A	104.93mm^2

Table-3: Parametric dimensions of I-section

Description	Units
B	1.96t
H	3.933t
H_1	3.699H
H_2	1.342H
A	6.722t^2
C	1.45t
I_{XX}	9.629t^4
I_{YY}	2.446t^4
I_{xx}/I_{yy}	3.93
K_{XX}	1.196t

It can be observed in Tab2 all the values can be expressed in terms of smallest value 't' and the parametric proportions in terms of paramter 't' is shown in Table 3.

4. DESIGN PROCEDURE

Calculations for P_m, $P_{max}$from the formula of Indicated power(IP):

$\rightarrow$ IP=(P_m*S_v*n)/60W .... (1)

For, 4-stroke engine; n=N/2.

2-stroke engine; n=N.

For, IP=10444W (Tab1)

S_v=149cc (Tab1)

N=8000rpm(Tab1)

$\therefore$n=N/2=4000rpm

$\therefore P_m$=1.05Mpa

As, $P_{max}=10P_m$

$\therefore P_{max}$=10.5Mpa...... (2)

Calculations for Break power(BP):

$\rightarrow$BP=(2π*N*T_{max})/60..... (3)

For,T_{max}=13.4 N-m.

N=6000rpm

$\therefore$BP=8419W

Calculations for mechanical efficiency:

$\therefore \eta_{mech}$=(BP/IP)*100=80.6%.....(4)

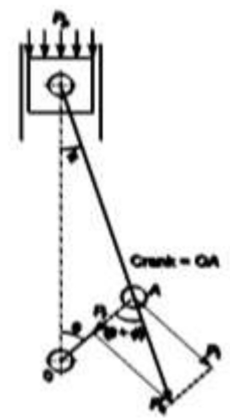

Fig-3: Forces acting on the crank

From Fig 3, θ=Angle made by the crank with TDC.

Φ=Angle made by connecting rod with line of motion of piston.

Set of formulas pertaining to Fig 3. Is given by Eq.5-8.

$\rightarrow(P_p)_{max}$=((π*D^2)/4)*P_{max} (N) .... (5)

$\rightarrow$n=sinθ/sinφ=L_{cr}/r .... (6)

$\rightarrow$ $P_t=P_q\sin(\theta+\varphi)$ (N) .... (7)

$\rightarrow$ $P_r=P_q\cos(\theta+\varphi)$ (N) .... (8)

From, Eq.5. For, D=57mm(Tab1), P_{max}=10.5MPa(Eq.2)

$\rightarrow(P_p)_{max}$=26820N .... (9)

From, Eq.6. For, L_{cr}=103.65mm(Tab1), r=28.2mm(Tab1)

$\rightarrow$n=sinθ/sinφ=L_{cr}/r=3.682 ......(10)

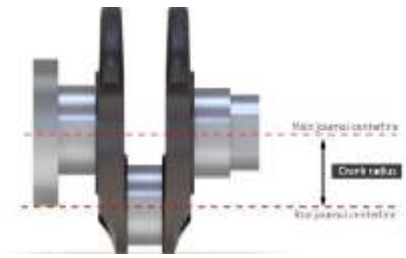

Fig- 4: Crankshaft assembly

It is evident from the Fig 4: crankshaft assembly, that crank radius and crank shaft radius remains the same as a result the maximum torque acting on crankshaft is same as the maximum torque acting on the point A in Fig 3, about the axis passing through O perpendicular to plane of paper. This validates the design procedure followed in the present literature.

From Fig 3, $T_{max}=(P_t)_{max}*r$

For, T_{max}=13.4N-m (Tab1)

r=28.2mm(Tab1)

$\therefore (P_t)_{max}$=475.177N ...... (11)

[4] It is observed that torque is maximum when the tangential force acting on the crank is maximum. For this condition, the crank angle from top dead centre position (θ) is usually 25°-35° for petrol engines and 30°-40° for diesel engines.

∴ For, θ=30°,n=3.682, From Eq.10 we have φ=7.8°

For, $(P_t)_{max}$=475.177N, φ=7.8°, θ=30° we have from Eq.7

$\therefore P_q$=775.283N ...... (12)

Here, $P_q$represents load acting on the connecting rod when maximum torque is acting on the crank.

Corresponding gas load acting on the top of the piston when maximum torque acts on the crank is given by

$\rightarrow P_p=P_q \cos\varphi$

$\therefore P_p$=775.283*Cos(7.8)

$\therefore P_p$=768.1N ..... (13)

Here in Eq.13 P_p is the load provided by fuel combustion when the maximum torque is acting on the crank, for the present design $(P_t)_{max}$ being equal to 475.1N and corresponding P_p=768.1N it has to be noted that even though paper tries to modify the design of connecting rod in further literature P_p will remain the same, as it is the load provided by fuel combustion and there will be no change in fuel consumption rate.

Design calculations for SAE-1020 steel:

Table-4: Material properties

Sl No	Material properties of SAE-1020	Value
1.	E	200GPa
2.	ρ	`7850kg/m³
3.	σ_u	445MPa
4.	$(\sigma_c)_y$	310MPa
5.	μ	0.40
6.	a	0.000157

Table 4, gives data about material properties of SAE-1020 steel which will be used in further calculations.

1.Buckling consideration:

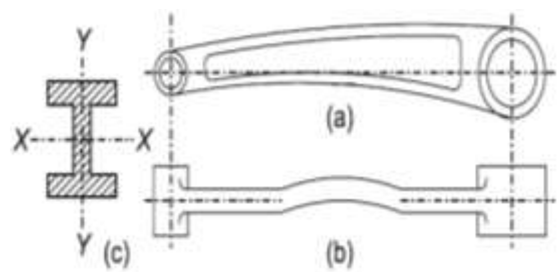

Fig-5: Buckling of connecting rod

(i) The buckling of the connecting rod in theplane of motion is shown in Fig.5(a). In this plane, the ends of connecting rod are hinged in the crank pin and piston pin. Therefore, for buckling about the XX-axis,the end fixity coefficient is one.

(ii) The buckling of the connecting rod in a plane perpendicular to the plane of motion is shown in Fig.5(b). In this plane, the ends of the connecting rod are fixed due to constraining effect of bearings at the crank pin and piston pin. Therefore, for buckling about the YY-axis, the end fixity coefficient is four.

(iii) Therefore, the connecting rod is four times stronger for buckling about the YY axis as compared to buckling about the XX-axis.

(iv) If a connecting rod is designed in such a way that it is equally resistant to buckling in either plane then $4I_{yy}= I_{xx}$…. where, I = moment of inertia of cross-section (mm^4) substituting ($I = Ak^2$), $4k^2_{yy}=k^2_{xx}$ where, k = radius of gyration of cross-section (mm)

(v) The above relationship proves that I-sectionis ideally suitable for the connecting rod. Onthe other hand, a circular cross-section isunnecessarily strong for buckling about theYY-axis.

(vi) But however, practically for efficient design ratio of I_{xx}/I_{yy}maintained in between 3-4.

Calculations for buckling consideration:

For, existing design the ratio of I_{xx}/I_{yy} is 3.93 which is safe under buckling as stated previously, in order to ensure the safety over buckling in $I_{XX}=9.629t^4$,$I_{yy}=2.446t^4$only 't' is varied so that ratio would remain same.

Equation for buckling/crippling load is given by

→ $P_{cr}=((\sigma_c)_y*A)/(1+a(L_{cr}/K_{XX})^2)$ …… (14)

-Rankine's constant, $a=(\sigma_c)_y/(\pi^2*E)$ …… (15)

From eq.(15) it can be observed that 'a' is a material dependent constant.

For, $(\sigma_c)_y$=310MPa, A=104.93mm^2, a=0.000157, L_{cr}=103.65mm, K_{XX}=4.725mm

We have from Eq(14), P_{cr}=30,233N …… (16)

∴ $FOS=P_{cr}/(P_p)_{max}=1.12$ ……. (17)

Iterative procedure adopted to increase mechanical efficiency:

→ If t=3,

Then, for $A=6.722t^2=60.498mm^2$

$(\sigma_c)_y$=310Mpa

a=0.000157

K_{xx}=1.196t=3.588mm

To maintain the same FOS(=1.19286) we have Eq.14

$P_{cr}=(310*6.722t^2)/(1+(0.000157)(L_{cr}/(1.196*t))^2)=30233$ ……. (17.1)

$P_{cr}=(310*60.498)/(1+(0.000157)(L_{cr}/3.588)^2)=30233$ ….. (18)

Eq.18 yield imaginary value of L_{cr} which is not possible as result to have a real L_{cr}

We should have $(310*6.722t^2)/30233>1$,

→ Let $(310*6.722t^2)/30233=k$,…... (19)

where, 1<k<1.5

we can see that for existing design of connecting rod for 't=3.951' we have

→ $(310*6.722*3.951^2)/30233=1.0759=k$

For, this value of 'k', we have η_{mech}=80.6%

Now, let us proceed in the iteration for k=1.06 to understand the behavior of various variables associated with k, here we term constant 'k' as improvement factor.

Then from Eq.19 we have, $t^|$=3.92

From, Eq.17.1, for given '$t^|$' we can find '$L^|_{cr}$' i.e.,

→$(310*6.722*3.92^2)/30233=1+(0.000157)(L^|_{cr}/(1.196*32))^2$

∴$L^|_{cr}$=91.63mm ……. (18)

∴ $n^|=\sin\theta^|/\sin\varphi^|=L_{cr}/r=3.24$

→ for $\theta^|$=30°[4], we have $\varphi^|$=8.85°

From eq.(7) we have

→ $(P_t)^|_{max}$=775.283*sin(30+8.85)=486.32N

→ ∴$T^|_{max}=(P_t)^|_{max}*r$ =486.32*28.2*10^{-3}=13.714N-m…….(20)

∴$T^|_{max} - T_{max}$ =0.977N-m

Hence, we can observe that there is an increase of 0.977N-m of maximum torque acting on crank due to design modification of connecting rod.

As, there is no change in other aspects of the engine we have

For N=6000rpm (rated speed for max. torque),$T^|_{max}$=13.714N-m

We have, $BP=(2\pi*N*T^|_{max})/60$=8612.33W ……. (20)

For IP=10444W we have

∴$\eta_{mech}^{|}$=(BP/IP)*100=82.46% ...... (21)

∴ Increase in mechanical efficiency =$\eta_{mech}^{|}$- η_{mech}= 1.86%

-Hence, it is evident from the above design procedure that decrease in L_{cr} increase mechanical efficiency but however we can't decrease the length of connecting rod below certain threshold due to practical constraints imposed in the engine, but however decrease in L_{cr} accompanies with increase in stroke length, this problem can be overcome by decreasing the engine height which decreases the stroke length hence, same displacement volume can be maintained even though there is decrease in length of connecting rod.

-Same design procedure is employed for values of 'K'(improvement factor) and the results are elucidated with graphs in further discussions.

5. RESULTS AND DISCUSSIONS

Table-5: Chemical composition test of pulsar connecting rod

Elements	Results(%)	Specifications of SAE-1020(%)
Carbon	0.203	0.18-0.23
Manganese	0.354	0.3-0.6
Sulphur	<0.001	0.050 Max
Phosphorous	0.019	0.040 Max

Tab 5 enumerates the result of chemical composition test of existing pulsar 150 connecting rod, test was conducted in Muscat laboratory Bangalore, from results it was observed that material belongs to SAE-1020 grade of steel and the test method used for the same is optical emission spectrometry(OES).

Same design procedure as stated in sec.3 is employed for SAE-1020 steel different values of 'k'and following observations are made.

Fig.6, represents graph between Length of connecting rod vs mechanical efficiency, it can be observed that with increase in length of the connecting rod leads to decrease in mechanical efficiency.

Fig.7, represents plot of improvement factor(k) vs mechanical efficiency(η), here we can observe that with decrease in factor 'k' there is corresponding increase in mechanicalefficiency.

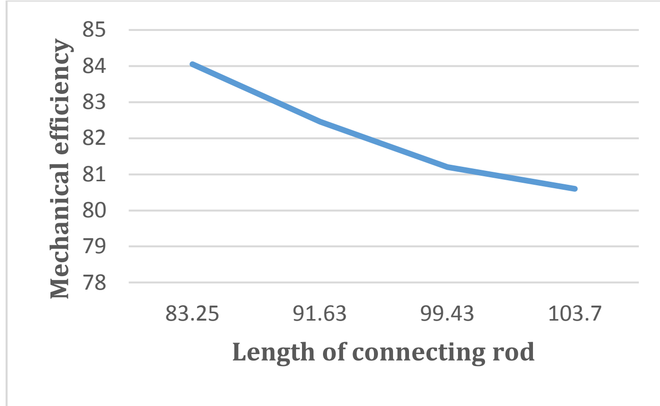

Fig-6: Length of connecting rod(L_{cr}) vs mechanical efficiency(η)

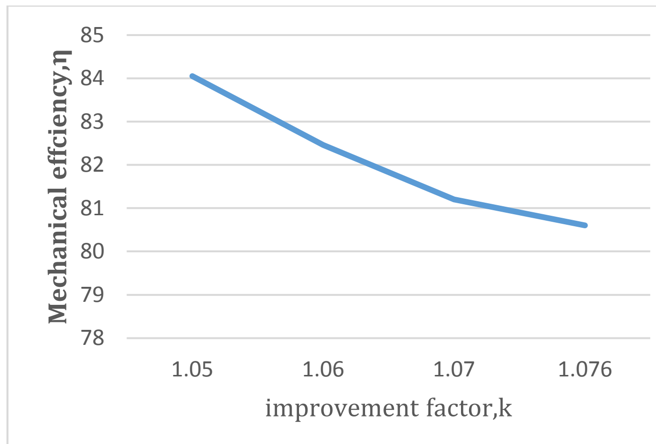

Fig-7 Improvement factor(k) vs Mechanical efficiency(η)

6. CONCLUSION

a. It can be noted that in [1] engine performance is improved by using petrol-HHOmixture, but however further incorporating structurally modified connecting rod as given in the present literature engine performance can be further improved.

b. It can be noted that structurally modified connecting rod has higher resistance against buckling due to reduced column action because of decrease in length of connecting rod.

c. Further, in the point of view of cost factors and manufacturability SAE-1020 steel grade is used in mass production and this is evident from the results of chemical composition test which is described in the Tab 5.

d. Subsequently, manufacturers can have data chart or graphs as illustrated, for various lengths of connecting rods and suitable length and material can be chosen with respect to practical conditions.

e. Hence, we can conclude that change in dimensions of structural member of the mechanism, varies the mechanical output correspondingly, in this literature we tried to induce structural variations in connecting rod of an IC engine and tried to analyze the changes it resulted in the mechanical efficiency of the engine.

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