Vibrational Analysis and Optimization of Connecting Rod

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Abstract— *The aim of this study is to explore weight and cost reduction opportunities for a manufacture of forged steel connecting rod. In the first part of the study, the loads acting on the connecting rod were found. Further vibrational behavior of existing connecting rod has been studied for real time boundary conditions. Based on the observations of the static FEA, modal FEA and the load analysis results, the desired optimization technique will be study and selected. In the conclusion of this study connecting rod can be designed and optimized. Under a load range which includes tensile load and maximum engine speed as one extreme load, and compressive load corresponding to the peak gas pressure as the other extreme load. The existing connecting rod can be substituted with a new connecting rod. New connecting rod is better that is lighter and less expensive due to the steel's fracture crack ability.*

***Keywords*—Connecting Rod, Optimization Technique, Static FEA, Modal FEA**

INTRODUCTION

The connecting rod is a major association inside a combustion engine. It connects the piston to the crankshaft and is responsible for transferring power from the piston to the crankshaft and sending it to the transmission. The objective of connecting rod is to transmit push & pull from the piston pin to the crank pin. This transmits converts reciprocating motion of the piston into the rotary motion of crank. The components are big shank, a small end and a big end. The cross section of shank may be rectangular, circular, tubular, I- Section, + -section or ellipsoidal-Section. It sustains force generated by mass & fuel combustion. The resulting bending stresses appear due to eccentricities, crank shaft, case wall deformation & rotational mass. There are different types of materials and production methods used in the construction of connecting rods. The most common types of Connecting rods are steel and aluminium. Connecting rods are highly dynamically loaded components used for power transmission in combustion engines.

Fig 1: connecting rod

The optimization of connecting rod had already started in 1983 by Webster and his team. However, each day consumers are looking for the best from the best. That's why the optimization is really important especially in automotive industry. Optimization of the component is to make the less time to produce the product that is stronger, lighter and less cost. The design and weight of the connecting rod impact on car performance. Hence, it is effect on the car manufacture credibility. Change in the structural design and also material will be significant increments in weight and performance of the engine.

II PROBLEM STATEMENT

Connecting rod is the critical component of the engine. A lot of research has been done to improve the connecting rod. Still there is a lot of scope for its optimization. Topology optimization can be carried out to increase its strength and weight reduction. Also vibrational analysis of the connecting rod to find its natural frequency at different mode shapes.

The connecting rod can be designed and optimized under a load range comprising tensile load, maximum engine speed as one extreme load, and compressive load corresponding to the peak gas pressure as the other extreme load. Furthermore, the existing connecting rod can be substituted with a new connecting rod. New connecting rod is better that is lighter and less expensive due to the steel's fracture crack ability. However, the same performance can be expected in terms of component durability.

III. METHODOLOGY

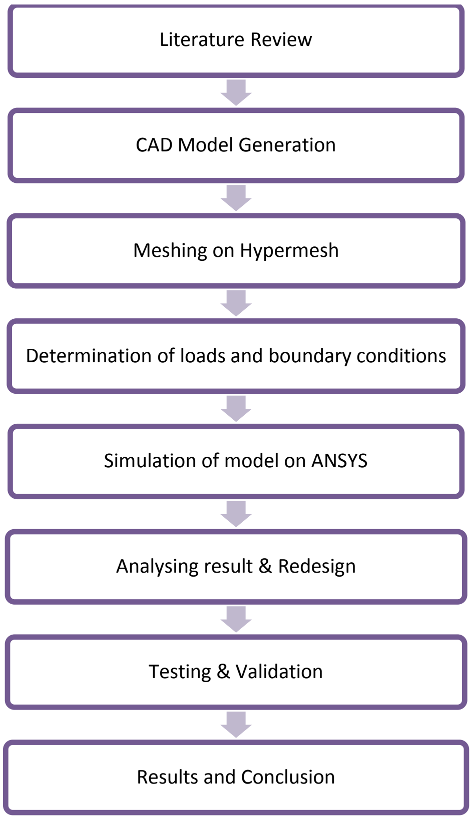


Fig 2: Methodology flowchart

IV. CAD MODEL OF CONNECTING ROD

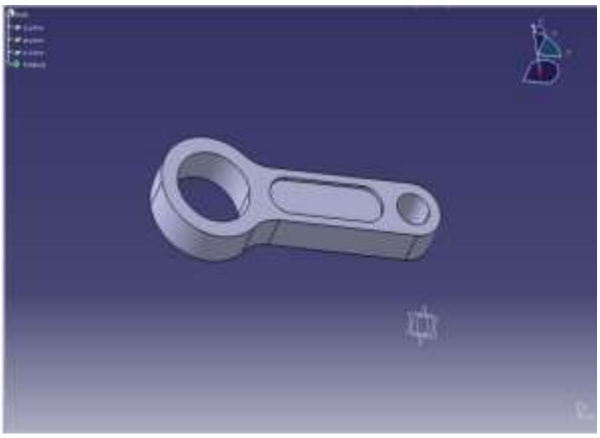


Fig 3: Reversed cad developed design of connecting rod

V. ANALYTICAL FORCE CALCULATIONS

Force calculations

Specifications of Bike Pulsar 180:

a. Specifications of Engine**:** Fuel tank capacity (litter): 15
b. Engine type: 4-stroke, DTS-i, air cooled, single cylinder
c. Kerb weight (kg): 145
d. Dimensions (mm): 2035 x 765 x 1115

Specifications of Engine:

a. Engine Type : 4-stroke, DTS-i, air cooled
b. No of cylinders : One
c. Displacement : 178.6 cc
d. Max. Power : 17.02 @ 8500 (Ps @ RPM)
e. Max. Torque : 14.22 @ 6500 (Nm @ RPM)
f. Bore x Stroke : 63.0 mm x 52.0 mm
g. Ignition : Digital Twin Spark Ignition (DTS-i)
h. Fuelling : Carbureted
i. Transmission Type : Manual
j. Gears : 5

Specifications which are assumed while design of the connecting rod:

1. Connecting rod length = 104.5mm,
2. Speed of the engine = 1400r.p.m.
3. Maximum gas pressure = 3.7MPa,
4. Bearing pressure at big end = 8.5MPa
5. Bearing pressure at small end = 15MPa
6. Allowable stresses in the bolts = 60MPa
7. Allowable stresses in the cap = 80MPa

The dimensions of the connecting rod are as follow-

1. Length of Connecting Rod = 104.5 mm
2. Outer diameter at big end = 55 mm
3. Inner diameter at big end = 38 mm
4. Inner diameter at small end = 17 mm
5. Outer diameter at small end = 29 mm
6. Thickness =18

The maximum force acting on the piston due to gas pressure,

$$F = \frac{\pi * D^2 * p}{4}$$

= 3404.7 N

Where D =Inner diameter at small end=17 mm

p=Bearing pressure at small end.

Material properties of steel (20CrMo)

Table 1: Material properties of steel

Sr No.	Mechanical Properties	Symbol	Unit	Value
1	Young's Modulus	E	Gpa	207
2	Shear Modulus	G	Gpa	80
3	Poisson's Ratio	v		0.3
4	Density	ρ	Kg/m^3	7600
5	Yield Strength	Sy	Mpa	370
6	Shear Strength	S_X	Mpa	275

Finite Element Analysis of Existing connecting rod

Force has applied from one side of the connecting rod the other side has been fixed.

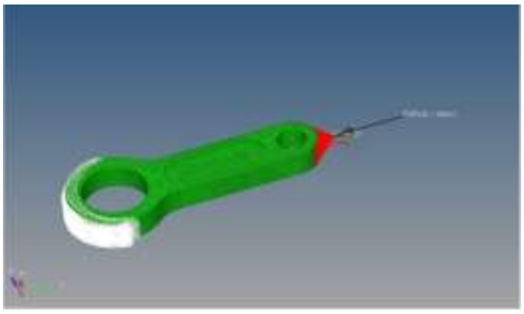


Fig4: Meshed model with applied boundary condition

Deformation Plot:

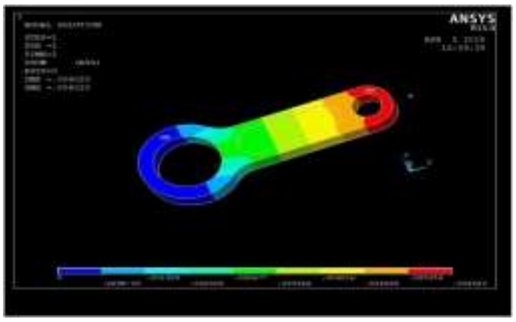


Fig.5: deformation of 0.006023 mm

Von-mises stresses

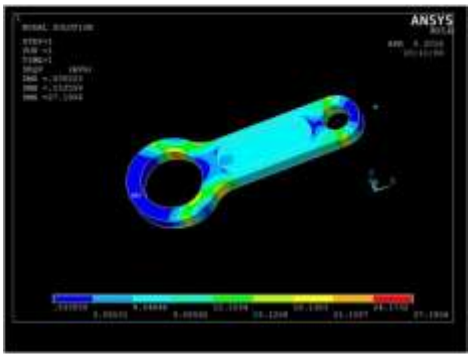


Fig.6: von Mises stress of 27.19 Mpa

VI. OPTIMIZATION OF CONNECTING ROD

Optimization methods were developed to have lighter, less cost and may have better strength too. Many optimization types, methods, software technique, and tools are available due to the revolution of the high-speed computing and software development. There are four disciplines for the optimization process.

a. Topology optimization: it is an optimization process which gives the optimum material layout according to the design space and loading case.

b. Shape optimization: These optimizations give the optimum fillets and the optimum outer dimensions.

c. Size optimization: the aim of apply this optimization process is to obtain the optimum thickness of the component.

d. Topography: it is a superior form of shape optimization, in which a design region is defined and a pattern of shape changeable will generate the reinforcement.

Weight reduction is done using optimization software OPTISTRUCT. The weight reduction is done using Topology optimization by the strength, safety factor targets. And the associated weight reduction is analyzed.

Topology Optimization Methodology:

Advanced optimization engine allow users to combine topology, topography, size and shape optimization methods to create better and more unusual design proposals leading to structurally sound and light-weight design. Manufacturing requirements can also be defined as an input to the replication to create design proposals that are easier to understand and to manufacture.

Topology optimization of connecting rod:

After observing FEA results of connecting rod and above discussed optimization techniques we can go for topology optimization to reduce weight, material, and cost.

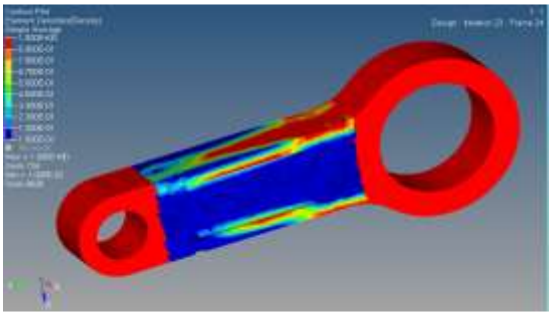


Fig.7: plotting of optimization

As per above discussion topology optimization is done by removing material from the stress free

It uses highly advanced optimization algorithms; OptiStruct can solve the most complex optimization problems with thousands of design variables in a short period of time. OptiStruct. Regions indicated by dark blue regions to reduce weight aiming to get optimal design by using minimum material. Red colored regions indicates non design space which has to retain without disturbing to safe the design.

IT-3 Deformation plot

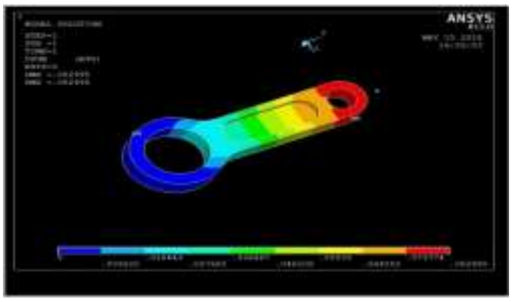


Fig.8: Deformation produced in connecting rod

Stress plot

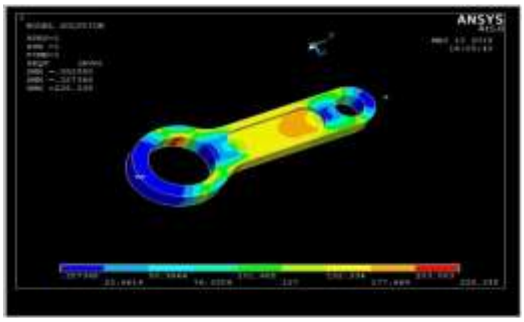


Fig.9: Von mises stress produced in connecting rod

Weight reduction table

Table 2: Weight reduction table

Cases	Stress	Deformation	Weight
Existing connection rod	27.19	0.006023	0.489 Kg
Iteration 1	30.03	0.0065	0.454 Kg
Iteration 2	129.33	0.0406	0.419 Kg
Iteration 3	228.338	0.082	0.383 Kg
Iteration 4	245.064	0.093	0.366 Kg

From table it's clear that iteration 3 has safe design, hence we select this design for manufacturing.

% weight reduction obtain in iteration 3

= (weight of existing connecting rod-weight of iteration 3 connecting rod)/weight of existing connecting rod.

= (0.489-0.383)/0.489

= 0.2167

= 21 %

So there is 21 % weight reduction from iteration.

Model analysis of iteration 3 connecting rod

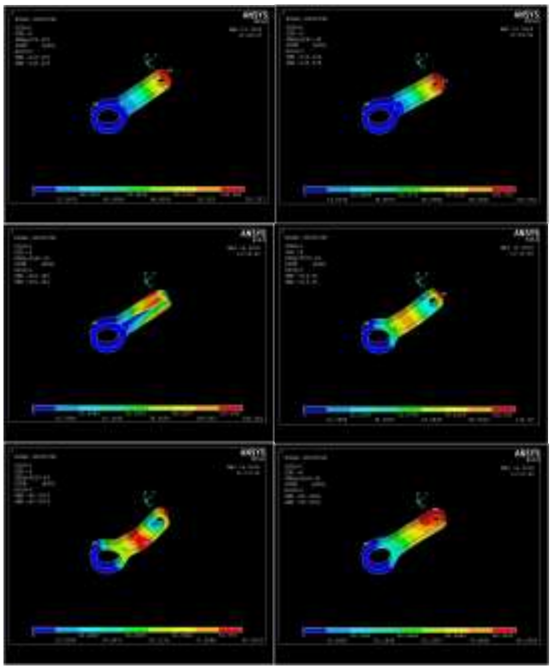


Fig10: Model analysis of iteration 3 connecting rod

Comparison of Modal Analysis Results:

Table 4.3 Comparison of model analysis results

Sr. No.	Mode	Frequency (Hz)	
		Existing	**Iteration 3**
1	1	829.146	875.007
2	2	2137.66	2041.48
3	3	4915.73	3562.02
4	4	5452.6	5079.63
5	5	7702.74	9020.44
6	6	8500.39	9034.93

Fabrication of optimized connecting rod

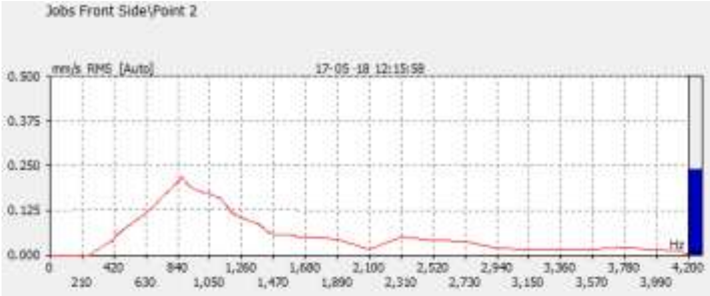
Fabrication of optimized connecting rod is done by considering thick steel plate of 18 mm thickness, later the plate is cut into required shape of connecting rod according to design drawing with the help of water jet cutting machine.

Fig11: Fabricated connecting rod according to optimized dimensions

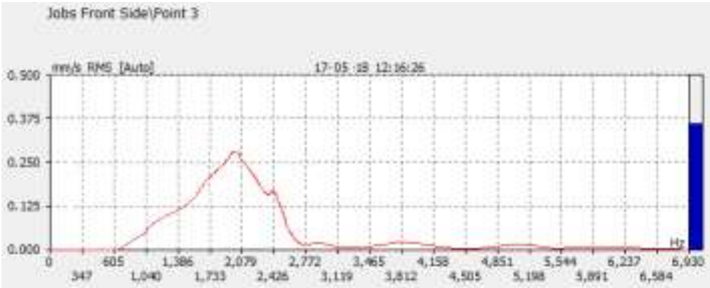
Experimental Testing Of Connecting Rod

To validate the above modal analysis results, experimental testing has been done with the help of portable FFT analyzer to find out the frequencies for respective modes of vibration. Since the specification of the portable FFT analyzer is restricted. That is the accerlometer of FFT analyzer is capable of sensing only translation in any one of the direction. we can carry the test for only x y z translations and get the respective frequencies and amplitude once results for three translations gets matched with FEA results. It has been considered that the reaming three rotations will be in good arrangement with FEA results.

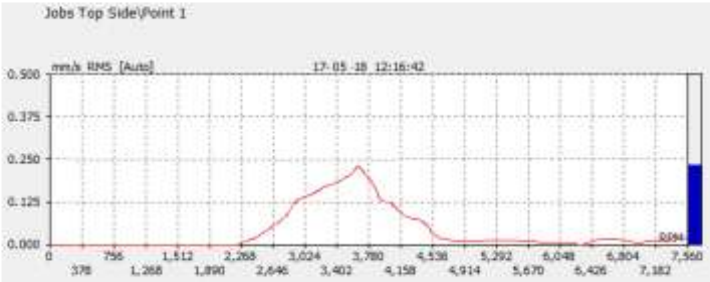
Test Plots



Frequency recorded at peak: 870 Hz



Frequency recorded at peak: 2050 Hz



Frequency recorded at peak: 3550 Hz

RESULT AND DISCUSSION

Compression of FEA and Experimental results

Modes	FEA Frequency (Hz)	FFT Experimental Frequency (Hz)	% Error
Mode 1	875.00	870	1.3
Mode 2	2041.48	2050	2.8
Mode 3	3562.02	3550	3.0

From the above compression table we can observe that experimental results obtained by FFT analyzer for first three mode shapes are in good arrangement with respective FEA results.

As we observed here, the magnitude of frequencies are very high because the optimized connecting rod is completely fixed at the bottom so there are very less chances to vibrate during normal operating conditions to make it vibrate or the resonance to occur with the operating frequency of the vehicle.

CONCLUSION

- Static and modal analysis results of existing connecting rod proved that the model is more stable and there is scope for optimization.
- The comparison, between modal analysis results of existing and optimized has been performed and it is summarized in table shown above.
- The comparison shows that the frequencies of vibration of the optimized connecting rod in six different modes are almost equal that of existing connecting rod
- This is due to the implementation of topology optimization. .
- Hence the comparison shows that the main objective of this project work has been satisfied.
- This modal result is validated experimentally by performing vibration testing of the optimized connecting rod on the FFT Analyzer.
- The above steady confirmed the optimized connecting rod is vibrational, structurally stable then existing.

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