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ANALYSIS AND OPTIMIZING CONNECTING ROD FOR WEIGHT AND COST REDUCTION

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Abstract

The objective of this work is to explore weight and cost reduction opportunities, in the design and production of connecting rod. The study has been dealt with two steps. First part of the study analysis includes the determination of loads acting on connecting rod as a function of time. This is done in order to find out the minimum stress area and to remove the material in those areas. The relationship between the load and acceleration of connecting rod for a given constant speed of the crankshaft are also determined. Finite element analysis was performed at several crank angles. The connecting rod can be designed and optimized under the loads ranging from tensile load, corresponding with 360º crank angle at the maximum engine speed as one extreme load and compressive load corresponding with the peak gas pressure as the other extreme load. Modal analysis is performed to find out the natural frequencies.

***Keywords**:* Connecting rod, Optimization, Stress, Tensile load, Compressive load, Natural frequencies.

1. INTRODUCTION

The necessary of an automobile vehicle is very important in our day to day life. The human comfort is the main criteria in any automobile vehicle. To increase the human comfort, we need to reduce the vibration and noise in the vehicle which is mainly generated by force transmitting parts like piston, connecting rod, crankshaft, camshaft, and valves. In automobile vehicles the connecting rod is the main part which transmits rotary motion into reciprocating motion. This force transmitting part involves in greater stress when load is applied. It connects the piston and crankshaft by its small end and big end. The number of connecting rods in an IC engine depends upon the number of cylinders used in the engine.

1.1 Steps Involved in Design Methodology

Step 1: Modeling of connecting rod using 3D modeling software.
Step 2: Finite element modeling of the connecting rod.
Step 3: Analysis of connecting rod using Ansys software.
- Element selection.
- Discretization.
- Mesh generation.

Step 4: Finite element stress analysis.
Step 5: Modal analysis.
Step 6: Optimization.

1.2 Analytical Evaluations

- Digitizing Connecting Rod Geometry
- Stress (FEA) Analysis
- Modal Analysis and Life Predictions Optimization Analysis

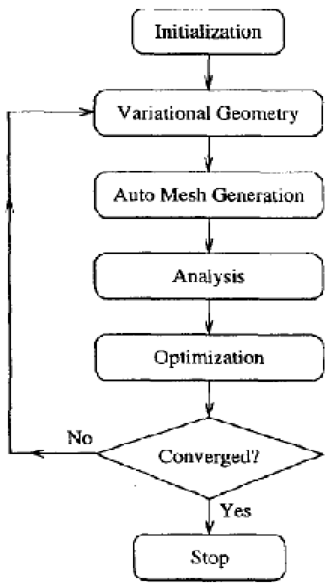

Figure: 1 Optimization Flow Chart

1.3 Optimization Procedure

The main objective of optimization is to minimize the mass of the connecting rod such that the maximum, minimum and the equivalent stress amplitude are within the limits of allowable stress. The production cost also had to be minimized by reducing the machining costs respectively.

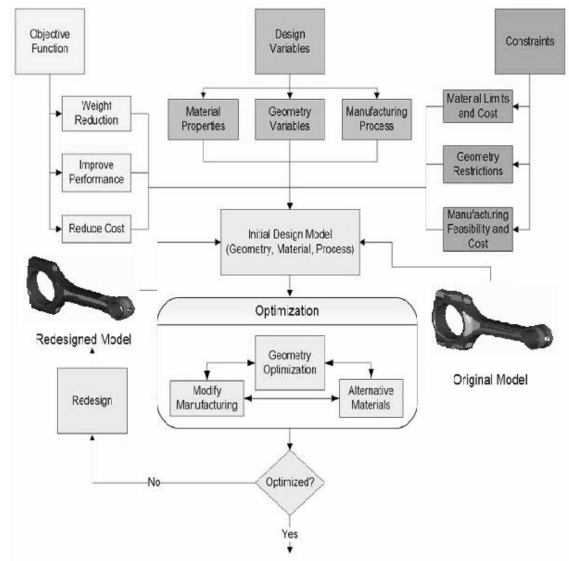

Figure: 2 Optimization Procedure

2. DESIGN OF CONNECTING ROD

For the initial design of the connecting rod, it is assumed that the peak cylinder pressure occurs at top dead centre position and the design is based on the axial loads. As there is no angularity of the connecting rod and the acceleration of the parts at this position is zero, the axial load is approximately equal to the gas load.

2.1 Design of the Shank Portion

The I-Section of the connecting rod is shown in Figure: 3. The safe load is given by Euler's formula,

$$\text{Axial load } Q = [\sigma_c]\, A_i / [1 = c(L/k)^2]$$

$$(Q) = \pi D^2 P_{max} / 4$$

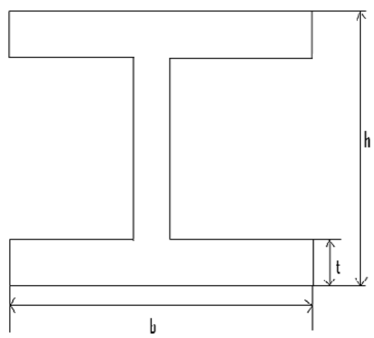

Figure: 3 Section of The Connecting Rod

The calculated value of the I-section thickness at the mid-section of the connecting rod is used to model the shank portion of the connecting rod. The height of the connecting rod I-section is modified depend up on the value obtained.

2.2 Design of the Eye End and Big End Bore

The big and small ends of the connecting rod serve as bearings for the crank pin and the gudgeon pin respectively. Since the dimensions of these parts are limited, the high bearing pressures are likely to be encountered at these bearings. The crank pin bearing is more severely loaded due to the larger relative rubbing speed in comparison to the small end bearing, which is subjected to oscillatory motion only. This requires a lower value of the recommended bearing pressure for the big end bearing. The length of the small and big ends are assumed to be equal to the breadth of the I-section and the diameter is equal to the diameter of the gudgeon pin and crank pin respectively. The thickness of the eye end is calculated by considering the failure due to shear stress. The shear failure occurs due to tensile load caused by the inertia of the reciprocating parts of the engine. The mass of the reciprocating parts is assumed to be equal to the sum of the mass of the piston assembly and one third of the mass of the connecting rod. The maximum value of this force is occurring at inner dead center and is given by,

$$F_i = m_r^2 R (\cos\theta = \cos(2\theta / n))$$

$$m_r = m_c + m_p$$

$$n = L/R$$

Considering the Shear Failure,

$$F_i = (d_o - d_p) \times b \times \tau$$

Considering The Tensile Stress For The Initial Design Of The Connecting Rod**,**

$$F_i = \sigma_t \times b \times t_c$$

As the big end cap of the connecting rod is inclined, it is subjected to tensile stress and bending stress.

3. RESULTS AND DISCUSSION

The connecting rod of a high speed automotive compression ignition engine is modeled using Modeling Technique and is analyzed using Finite Element Technique. Various alternatives are discussed for the assumed conditions in the above modeling and analysis of the connecting rod and the final dimensions obtained after finite element analysis, satisfies, the requirements.

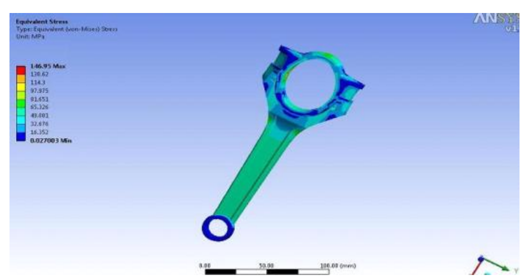

Figure: 4 Structural Analysis on Existing Connecting Rod

The static analysis of the connecting rod has been taken into consideration for the axial and bending loads. The axial loads and the bending loads are calculated analytically at different crank-angles and it is subjected to finite element technique for analysis purpose. The result of the finite element analysis is compared with analytical stress values. From the analysis it is found that the stress values are well below the yield strength of the connecting rod material. Comparison of results shows that the shank region of the connecting rod offers the highest potential for weight reduction. In the shank region, the rib and the web thickness were reduced only up to certain limits.

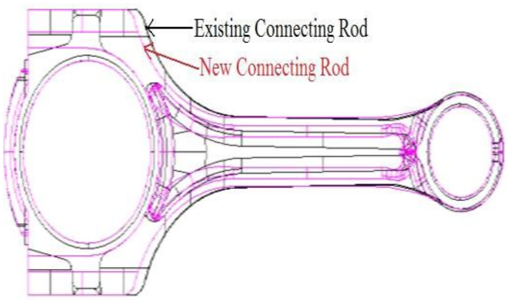

Figure: 5 Shape optimization

After several iterations of calculating loads for different speeds, and performing analysis, a constrained model is obtained.

Object Name	Shape Finder
State	Solved
Scope	
Geometry	All Bodies
Definition	
Target Reduction	10. %
Results	
Original Mass	4.6kg
Optimized Mass	4.14kg

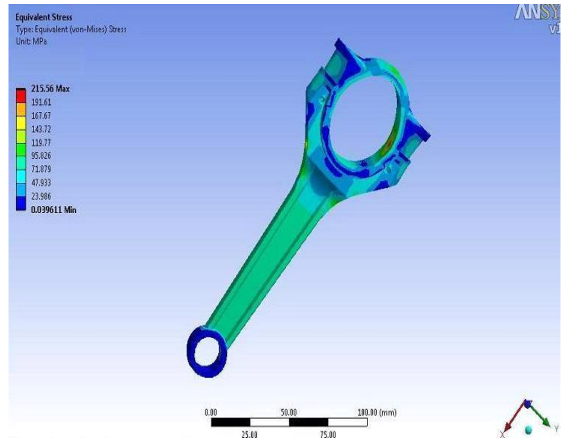

Figure: 6 Structural analysis on new connecting rod

The study of weight optimization is performed under two cyclic loads composing of dynamic tensile and static compressive as the two extreme loads and also the cyclic loading conditions for life predictions analysis is also considered. In the optimization process, fatigue strength is very significant factor. The study results in an optimized connecting rod that is about 10% lighter and 25% less expensive, as compared to the existing connecting rod.

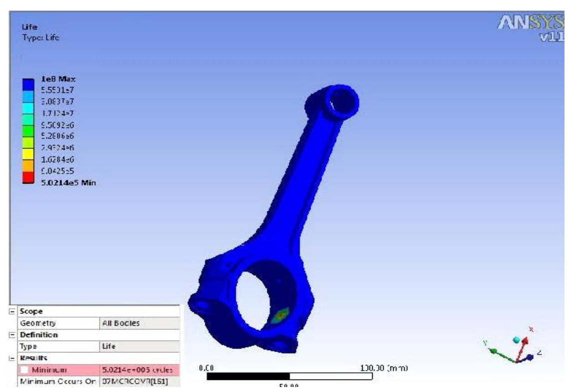

Figure: 7 Life predictions analysis on connecting rod

Generally we use C45 steel for connecting rod manufacturing diesel engines. In this study we have proposed an alternative material C70 steel for manufacturing connecting rod with a purpose to reduce the weight of connecting rod. When we compared among C45 steel and C70 steel

ISSN: 2394 – 4854
Pages 1 – 7

surprisingly we noted that around 10% of weight reduction occurs. The change of material does not influence the performance of the engine in any way because material properties such as Tensile strength and Endurance limits are almost the same.

S.No	Material Properties	Values for C45 steel CR	Values for C70 steel CR
1.	E (GPa)	207	212
2.	Yield strength(MPa)	700	574
3.	% Elongation	24	27
4.	% Reduction in area	42	25
5.	Tensile strength(MPa)	938	966
6.	Endurance limit(MPa)	415	399
7.	Density (kg/m^2)	0.000782	0.000796
8.	Axial Displacement(mm)	0.206	0.208
9.	Weight(gms)	440	396
10.	Izz (kg-m^2)	0.00144	0.00139
11.	Buckling load factor	7.8	9.6

Table: 1 Material properties of C45 and C70 steel

The study of vibration shall be part and parcel with a mechanical engineer to minimize the vibrational effects over mechanical components by designing suitably. To avoid excessive and unpleasant stress in the rotating system, we have searched for the natural frequency of the system.

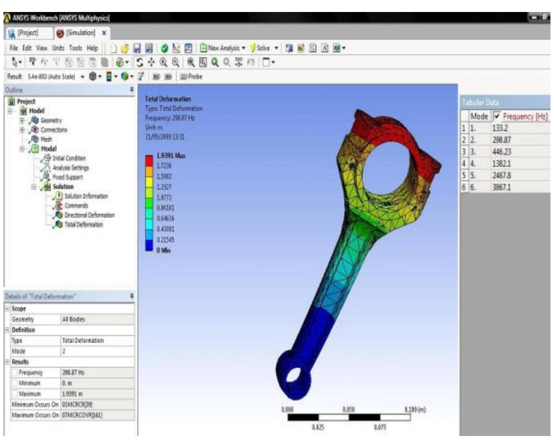

Figure: 8 First 6 natural frequencies

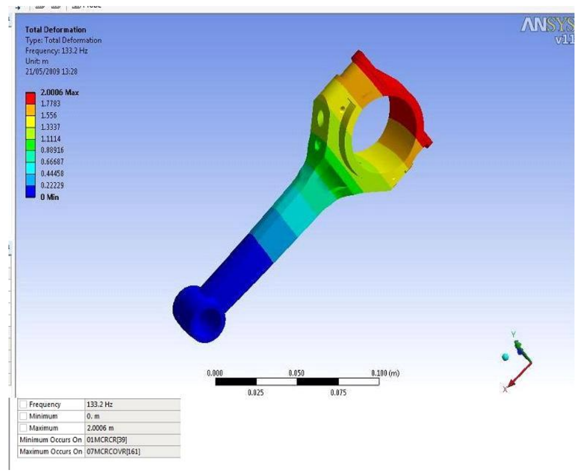

Figure: 9 Natural frequency -axial mode

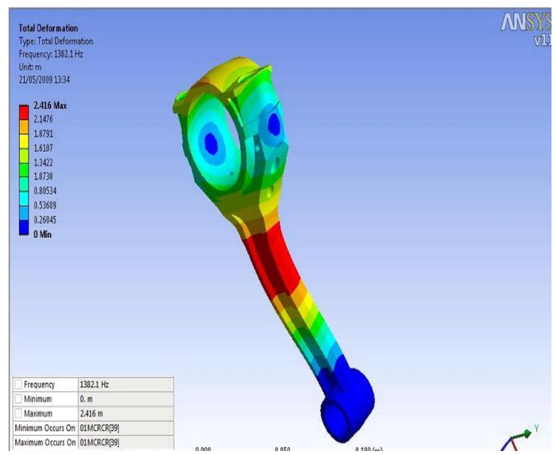

Figure: 10 Natural frequency -bending mode

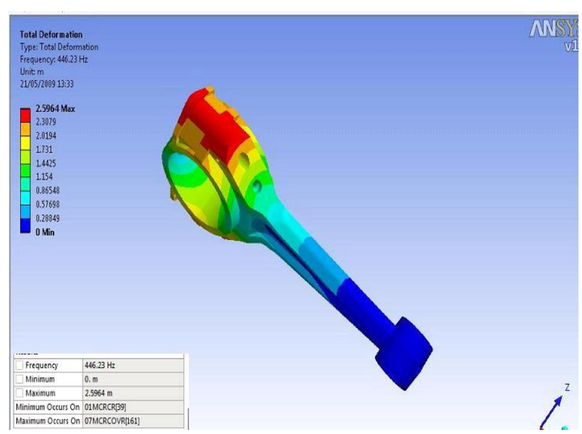

Figure: 11 Natural frequency -twisting mode

When we analyzed the natural frequency using modal analysis, we noticed that there is no chance of resonance. If the frequency of excitation coincides with any of the natural frequencies, resonance occurs and that may result in the mechanical failure of the system.

4. CONCLUSION

Connecting rod is optimized to reduce weight and manufacturing cost of steel when it is subjected to cyclic load composing of compressive gas load and the dynamic tensile load at different speed, corresponding with various crank angles. The cost is reduced by changing the material of the existing C45 steel connecting rod to C70 steel. With more informative data, we will be able generate very good designs relatively in a short period of time and there we may use best designs. We believe that the techniques employed in this study will be of great use to the designer. Similar studies may be taken up for the effective design of the other internal combustion engine components.

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