Optimizing the Design of Connecting Rod under Static and Fatigue Loading

Om Parkash¹, Vikas Gupta², Vinod Mittal³

¹Department of Mechanical and Automation Engineering
Amity University, Haryana, India
om.mech8@gmail.com

²Mechanical Engineering Department, CDLMGEC
Panniwala Mota, Sirsa, Haryana, India
vikasbrcm@rediffmail.com

³Mechanical Engineering Department
NIT, Kurukshetra, Haryana, India
mit_vkum@hotmail.com

Abstract—The main objective of this work is to re-optimize the existing design of connecting rod of universal tractor (U650) by changing some of the design variables. The existing design performs modelling and evaluates critical regions in the connecting rod under fatigue loading. In the present work, the model is developed, analyzed and designed using CATIA 19, PRO-E and ANSYS workbench v12. Optimization of connecting rod is done under same boundary and loading conditions for variation in the few stress and fatigue parameters i.e. stresses, weight, life, damage, bi-axiality indication and safety factor. The allowable numbers of cycles under fully reversed fatigue loading are increased and assumed up to a maximum limit of 10⁸ cycles. Stress concentration coefficient is varied to obtain the maximum cycles condition. The critical regions under both static and fatigue analysis are identified and improved. The connecting rod is modelled and optimized for the reduced weight, improved life and manufacturability. The results obtained from performed analysis can be used to modify the design of existing connecting rod, so that better performance i.e. reduced inertia, fatigue life and manufacturability can be obtained under varying static and fatigue conditions.

Key Words - Connecting rod, finite element analysis, optimization.

I. INTRODUCTION

The function of the connecting rod is to transfer the reciprocating motion of the piston into rotary motion of the crankshaft. The maximum stress occurs in the connecting rod near the piston and at the end of the shank e.g. [1]. The tensile and compressive stresses are produced due to the gas pressure and bending stresses are produced due to centrifugal effects. So the connecting rods are designed generally for I-section to provide maximum rigidity with minimum weight. A. Mirehei et al. [1] carried out the fatigue analysis of connecting rod of universal tractor (U650). The objective of the research was to determine the life span of connecting rod due to cyclic loading. The results were carried out under fully reversed loading. The numbers of critical points were located from where the crack propagation initiates. Allowable number of load cycles using fully reverse loading was gained up to 10⁸. Pravardhan et. al. [5] presented the Finite Element Analysis (FEA) procedure for optimization for connecting rod cost reduction. A study was performed on a forged steel connecting rod with a consideration for improvement in production cost. Vasele et. al. [6] presented a method used to verify the stress and deformation in the connecting rod using the finite element method with Ansys v.11. The study only analyses the connecting rod foot. The obtained results provided by this method were compared to the results obtained by classic calculation, in similar conditions of application, and after wards conclusions were drawn. Pranav et. al. [3] carried out the finite element analysis and optimization of connecting rod using ANSYS work bench 9. Few researchers carried out the modal analysis of connecting rod of a reciprocating mud pump [5]-[6]. Modal analysis is an effective method to determine vibration mode shapes and weak parts of the complex mechanical system, its main purpose is to use optimal dynamics design method of mechanical structure system instead of the experience analogue method [2], [4].

In this paper, mathematical model of connecting rod describing normal pressure is developed in Section II. Three-dimensional finite-element model of connecting rod is modelled in Section III which provides analytical frequencies and mode shapes. The modal distribution and vibration mode shapes for connecting rod are obtained analytically. Loading and boundary condition for finite element analysis is defined in Section IV. This work combines the results of two analysis i.e. static and fatigue failure analysis. Section V illustrates and compares the results with existing design i.e. [1]. The proposed design explores weight reduction opportunities for a production forged steel connecting rod. Finally the paper is concluded and recommendations are proposed in Section VI.

II. MATHEMATICAL MODEL OF CONNECTING ROD

The normal pressure (P) on the contact surface is given as in Eqn. 1.

\[ P = P_0 \cos \theta \]

where, P is Normal pressure. \( P_0 \) is Normal pressure constant.
The load is distributed over an angle of $180^\circ$. The total resultant load ($P_t$) is illustrated in Eqn. 2.

$$P_t = \int_0^\pi P_0 \cos \theta \, d\theta = P_0 \, r \, t \left( \frac{\pi}{2} \right)$$

(2)

where, $P_t$ is Total resultant load (Tensile), $r$ is small end radius, $R$ is big end radius, $t$ is thickness of connecting rod at loading surface.

The normal pressure constant ($P_0$) is calculated via Eqn. 3.

$$P_0 = \frac{P_t}{\pi^2}$$

(3)

For compressive loading of the connecting rod, the crank and the piston pin ends are assumed to have a uniformly distributed loading through $180^\circ$ contact surface. The normal pressure is given by Eqn. 4.

$$P = P_0$$

(4)

The total resultant load ($P_c$) is expressed in Eqn. 5.

$$P_c = \int_0^\pi P_0 \cos \theta \, d\theta = P_0 \, r \, t \sqrt{3}$$

(5)

where $P_c$ is total resultant load (compression)

The normal pressure constant ($P_{oc}$) is then given by Eqn. 6.

$$P_{oc} = \frac{P_c}{\pi^2}$$

(6)

III. MODELING OF CONNECTING ROD

The model of connecting rod was generated in CATIA V5 R19. The model of connecting rod is shown in Fig.1.

![Fig.1 Model of connecting rod](image)

The steps in modelling are described as below:

- 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 in shank portion of the connecting rod.
- Select an arbitrary rectangle in XY plane at the centre of the crank end in order to make the crank end open.
- Cut half of the crank end with the help of pocket command.

The connecting rod is modelled for reduced weight.

IV. FINITE ELEMENT ANALYSIS OF CONNECTING ROD

The meshed model of connecting rod is shown in Fig. 2. The model of connecting rod contains 29512 nodes and 17817 elements (tetrahedral shape).

![Fig.2 Mesh generation](image)

Material of connecting rod and respective properties are assumed same as in [1] and are shown in Table I.

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>MATERIAL AND PROPERTIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material selected</td>
<td>C-70 Alloy Steel</td>
</tr>
<tr>
<td>Young's Modulus (E)</td>
<td>207 MPa</td>
</tr>
<tr>
<td>Poisson's Ratio</td>
<td>0.30</td>
</tr>
<tr>
<td>Tensile Ultimate strength</td>
<td>621 MPa</td>
</tr>
<tr>
<td>Tensile Yield strength</td>
<td>483 MPa</td>
</tr>
<tr>
<td>Density</td>
<td>7700 kg/m3</td>
</tr>
<tr>
<td>Shear modulus</td>
<td>79 GPa</td>
</tr>
<tr>
<td>Behavior</td>
<td>Isotropic</td>
</tr>
</tbody>
</table>

In this analysis, four finite element models are analysed. FEA for both tensile and compressive loads are conducted. Two cases are analysed for each model, 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. In the analysis carried out, the axial load was 9500 N (Gas Force) in both tension and compression finally the comparisons are done for static and fatigue loading under same boundary condition.

V. RESULTS, DISCUSSION AND COMPRISON

A. Results and Comparison for Static Analysis

The term static means that the forces do not vary with time. The equation can be written neglecting the inertia forces, damping forces and nonlinearity. Outputs or results of the linear static analysis are demonstrated via stresses, strain and deformation under the effects of applied load.

The FEA results for static analysis i.e. Von-Misses stress, Elastic Strain, and Total Deformation are shown in Fig. 3, 4 and 5 respectively.

![Fig. 3 Equivalent Von-Mises stress](image)

![Fig. 4 Equivalent elastic strain](image)

![Fig. 5 Total deformation](image)

Results are compared for static analysis. The comparison illustrates and ensures the better design than the existing design, as shown in Table II.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Result Parameter</th>
<th>Optimized Result</th>
<th>Existing Result</th>
<th>% Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Equivalent Von-Misses Stress</td>
<td>26.636 MPa</td>
<td>29.4 MPa</td>
<td>9.4 %</td>
</tr>
<tr>
<td>2.</td>
<td>Elastic Strain</td>
<td>0.00013318 mm/mm</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3.</td>
<td>Total Deformation</td>
<td>0.018395 mm</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

B. Results and Comparison for Fatigue Analysis

The fatigue analysis carried out under Goodman theory for a life cycle of $10^9$. Here the tensile or compressive loads are assumed equal to 9500N [1]. The FEA results for connecting rod life, bi-axiality indication and safety factor are shown in Fig. 6, 7 and 8.

![Fig. 6 Life in cycles](image)
From the above results, it is found that the maximum stress of magnitude 26 MPa is concentrated at the end of the shank of connecting rod. Fatigue damage is defined as the designed life divided by the available life. The result of stress biaxiality contour plot over the model gives a qualitative measure of the stress state throughout the body. A biaxiality of value ‘0’ is identified as uni-axial stress, ‘-1’ as pure shear and ‘1’ equivalent to pure biaxial state. A damage of greater than value ‘1’ indicates the part will fail from fatigue before the design life is reached. This result for safety factor (FS) is a contour plot with respect to fatigue failure at a given design life. The maximum FS reported is 15.

The maximum and minimum values of the resulting parameters are shown in Table III. As discussed in previous section, the results for stress are improved in the proposed connecting rod for the same life. The results for parameters i.e. life, damage, bi-axiality indication, safety factor are also appreciable and acceptable as compared to existing design.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Fatigue Parameters</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Life (cycle)</td>
<td>1e6</td>
<td>1e6</td>
</tr>
<tr>
<td>2.</td>
<td>Biaxiality indication</td>
<td>0.947</td>
<td>-0.9969</td>
</tr>
<tr>
<td>3.</td>
<td>Damage</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>4.</td>
<td>Safety factor</td>
<td>15</td>
<td>3.2362</td>
</tr>
</tbody>
</table>

C. Model Comparison for Weight Reduction

Models of existing and new designed connecting rod are compared as shown in Fig. 10. The new design clearly indicates a better design.

The weight of existing and new connecting rod is compared as given in Table IV.

<table>
<thead>
<tr>
<th>Weight Reduction Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing weight(kg)</td>
</tr>
<tr>
<td>2.131</td>
</tr>
</tbody>
</table>

The weight of connecting rod might not be reduced by much margin i.e. only 5gm, but it reduce the resulting inertial and centrifugal force which definitely improves static and fatigue results.
VI. CONCLUSIONS

Existing design of connecting rod is re-optimized by considering same boundary and loading conditions under static and fatigue loading. In this work, the weight of connecting rod is reduced and four models of connecting rod are modelled in CATIA. The results are compared with existing design for static and fatigue analysis. The stress is found maximum near the end of the shank or piston pin end. The weight of the connecting rod is also reduced by 0.005 kg which might not be significant but reduces the inertia forces and cost of material. Fatigue strength, which is the most important driving factor in the optimization of connecting rod, is improved significantly. Thus, the modified design assures weight reduction and improved life and manufacturability for the U650 connecting rod.

REFERENCES