Connecting Rod Optimization for Weight and Cost Reduction

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Abstract - *The main objective of this study analysis of single cylinder diesel engine connecting rod. Therefore, this study has dealt with two subjects, first, static load and second dynamic load analysis of connecting rod. In the first part of the study, the loads acting on the connecting rod as a function of time are obtained. The relations for obtaining the loads and accelerations for the Connecting rod at a given constant speed of the crankshaft are also determined. Dynamic finite element analysis is performed at several crank angles. The stress-time history for a few locations is obtained. The difference between the static FEA, dynamic FEA is study. It is the conclusion of this study that the connecting rod can be design and analyses under different crank angle at the maximum engine speed. The material use for connecting rod is carbon steel subcategory EN9.*

Key Words: Connecting Rod, FEM, cost reduction, meshing, weight optimization.

1. INTRODUCTION

The automobile engine connecting rod is a high volume production, critical component. It connects reciprocating piston to rotating crankshaft, transmitting the thrust of the piston to the crankshaft. Every vehicle that uses an internal combustion engine requires at least one connecting rod depending upon the number of cylinders in the engine. Connecting rods for automotive applications are typically manufactured by forging from either wrought steel or powdered metal. They could also be cast. However, castings could have blow-holes which are detrimental from durability and fatigue points of view. The fact that forgings produce blow-hole-free and better rods gives them an advantage over cast rods. Due to its large volume production, the analysis of connecting rod is very important for check it is safe for all condition.

1.1 Need

Connecting rod is most important engine component subjected to number of forces. These forces are introduced because of motion of connecting rod and gas force acing on piston. So when any vehicle traveling then different combination of these forces acting on the connecting rod at different crank angle. So it is necessarily study the connecting rod under static and dynamic conditions. This total static analysis is carried out at high pressure and torque values. This is useful for determination of high stress area and then by making changes in the parameters required results are easy to obtain. Here connecting rod is analyze for static condition at very fast in this project because o to study the where maximum stress occurred. This total static analysis is carried out at maximum peak pressure condition. This is helpful in dynamic analysis for concentrating on particular area. From this we decide density and element size of meshing of that particular crank angle.

1.2 Objective

Connecting rod subjected to various intermittent loads due to gas force and inertia of masses. The nature of these loads can be easily found with various torque and inertia measurement technique. The effect of all these forces is very difficult to find out with various experimental techniques. To find out the stresses by using analysis software is easy. Connecting rod failure occurs due to bending, various combinations of the forces etc. So, connecting rod must be analyzed for the maximum load conditions to find out the critical zones. So here static analysis is suitable for this kind of stresses. Then equate these stresses to the yield stress.

1.3 Connecting rod details

Every engineering component is specified by certain properties of that component. Every connecting rod has specified properties that are utilize in every analysis. By using this property we can make conclusion. The material use for this connecting rod is EN9. The specification, composition and material properties are given table I, II and III. Specification: C55Mn75

Table -1: Chemical composition

Elements	Weight%	Elements	Weight%
C	0.5 – 0.6	S	0.03 (max)
Fe	98.41 – 98.9	P	0.0 (3max)
Mn	0.6-0.9	Al	0.015 - 0.025
Si	0.15 – 0.3		

Table -2: Material properties

Material Properties	**Value**
Hardness	Hardness
Modulus of Elasticity	Modulus of Elasticity
Poisson's Ratio	Poisson's Ratio
Tensile Strength, Yield	Tensile Strength, Yield
Density	Density

Table -3: Technical Data for HP @ 1500 rpm W/C Diesel Engine

Model	VRC- 14
Type of engine	Single cylinder, vertical, compression ignition, 4 stroke cycle, water cooled cold starting diesel engine
No. of Cylinders	one
Rated Power B.H.P. KW	14 10.3
Bore (mm)	114.3
Stroke (mm)	116
Rated RPM	1500
Swept Volume (CC)	1230
Compression Ratio	18.0:1
Overload capacity	1120% of rated load
Max. gas pressure	80 Kg. / cm^2

2. STATIC ANALYSIS

A static analysis calculate the effects of steady loading condition on a structure, while ignoring inertia and damping effects, such as those caused by time varying loads. A static analysis can, however, include inertia loads and time varying loads that can be approximated as static equivalent loads.

In our analysis tensile and compressive load are calculated. Some boundary conditions are applied on connecting rod. These loads are calculated at maximum peak pressure condition of connecting rod. By using this analysis we can determine the displacement, stresses and strains. [1]

2.1 Element type

Here our outline objective in building a solid model is to mesh that model with nodes and elements. Once you create solid model, set element attributes, and established meshing controls, you can that turn the ANSYS program loose to generate the finite element mesh. For defining the elements attributes, we have to select the correct element type. This is most important task in finite element analysis because it decides the accuracy and computational time of your analysis, here in this solid 92 elements is used as element type. This element is most suitable for more curved profile. For this basic reason I have used this element for this analysis.

2.2 Mesh generation

In this analysis mesh generation is auto mesh generation with element lengths edge is 5 mm.

The meshed model is shown in Fig. 1.

Numbers of elements generated are;

No. of nodes = 40080

No. of element = 21990

Element type = solid 92 (10 noded).

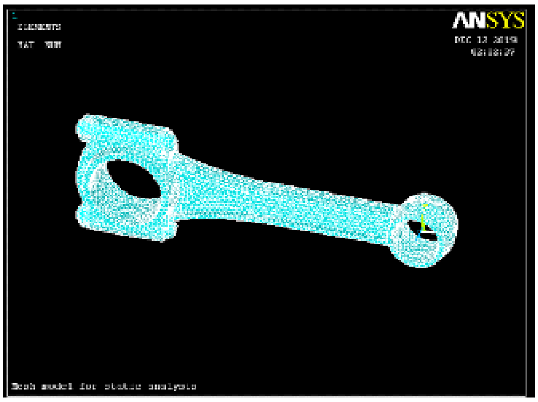

Fig -1: Mesh generation

2.3 Loading & boundary condition

Loads are calculated for given gas pressure. First calculated force on the piston due to gas pressure then again calculated separate pressure affected by area. Analysis for both tensile and compressive loads are calculated. Two cases are analyses 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. For tensile loading of the connecting rod, the crank and the piston pin ends are assumed to have a cosine distribution loading through 180 degree contact surface [1]. For compressive loading of the connecting rod, the crank and the piston pin ends are assumed to have a uniformly distributed loading through 120 degree contact surface. Therefore for static analysis four cases are required.

1) Tensile force at big end.
2) Tensile force at small end.
3) Compressive force at big end.
4) Compressive force at small end.

2.4 Restraints

As already mention above, four models are solved. Fig. 2 shows a model in which tensile load is applied at the crank end and the piston pin end is restrains. Note that half of the piston pin inner surface (180°) is completely restrain (180° of contact surface area is totally restrained, on this surface are set to zero if the connecting rod is in tension). Similarly, when the connecting rod is under axial compressive load, 120° of contact surface area is totally restrained. [1].

2.5 Solution

After running the solution of above model, we get the deformed shape and stress plot for applied loading and boundary condition as shown below. We have taken von mises stress plot. From Figure deformed plot we absorbed that the deformation.

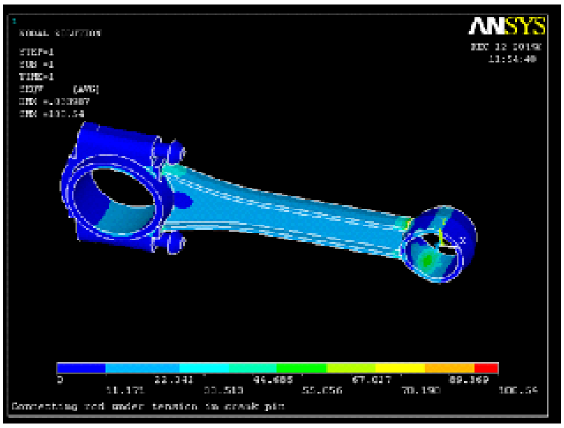

Fig -2: Connecting rod under tension in crank pin

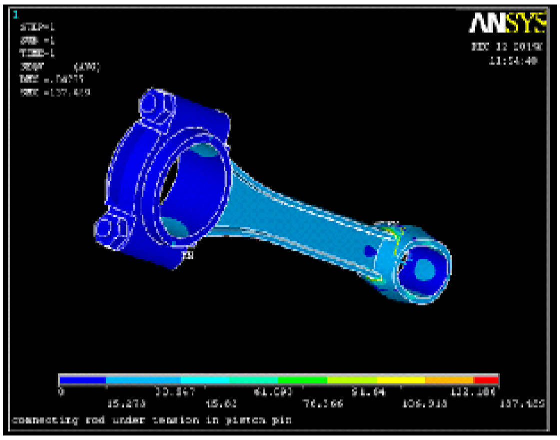

Fig -3: Connecting rod under tension in piston pin

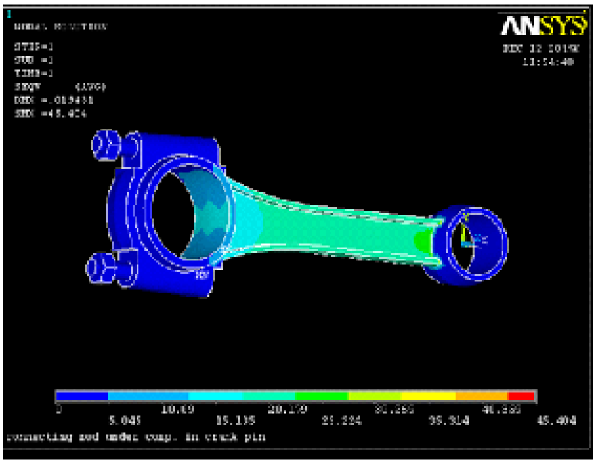

Fig -4: Connecting rod under compression in crank pin

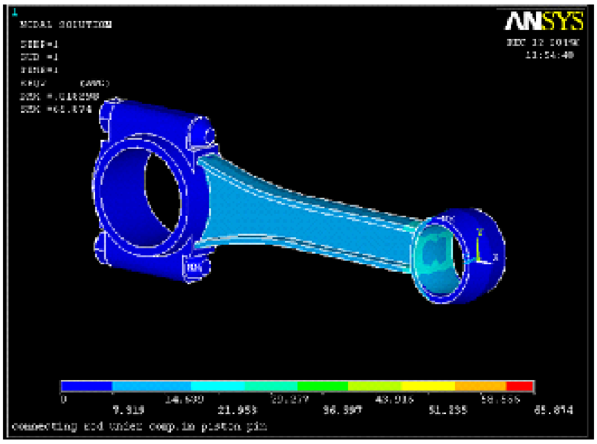

Fig -5: Connecting rod under compression in piston pin

2.6 Validation

The properties of the material used for linear elastic finite element analysis are listed in Table 4. In order to validate the FEA model, the stresses in the shank region half way along the length of the connecting rod are compared under two conditions of compressive load application. First, a 5.99 MPa uniformly distributed load is applied at the piston pin end, while the crank end is restrained. Second, 2.33MPa uniformly distributed load is applied at the crank end, while the piston pin end is restrained. Since the magnitude of the loads is identical under the two conditions, we can expect the stresses to be same at a location away from the loading and restraints (i.e mid-span) under the two conditions. A similar comparison is also made for tensile load application. Strain gage measurements are also made on a connecting rod under tensile as well as compressive loads. A comparison of the FEA predictions with the strain gage measurements is in order. The location of the strain gages, the average strain gage reading from four strain gages is 217 micro strain under a compressive load of 8208.2N, and 502 micro strain under a tensile load 8208.2N. The results are tabulated in Table V

From Table 5, it is clear that the differences are small and there is very good agreement between the experimental results and FEA results. This verifies the accuracy of the modeled geometry, as well as the convergence of the FE mesh. In addition, it indicates that in the shank region the structural behavior of the connecting rod is independent of the way the load is applied at the ends. The two FE models differed in the way the load is applied. FEA load is applied through the crank pins.

Table -4: Properties of connecting rod material

Material Property	Scalar Value
Modulus of Elasticity (GPa)	205
Poisson's Ratio	0.29
Mass Density (Kg/m3)	7850

Table -5: Measured and predicted strain

Load	Measured Strain (μ strain)	FEA prediction test Assembly (μ strain)	Different measured (%)
8208.2 Tensile	502	490	-2.39
8208.2 compressive	207	221	6.74

3. DYANAMIC LOAD ANALYSIS

The connecting rod undergoes a complex motion, which is characterized by inertia loads that induce bending stresses. This work serves two purposes. It can used be for determining the inertia loads and reactions for any combination of engine speed, crank radius, pressure-crank angle diagram, piston diameter, piston assembly mass, connecting rod length, connecting rod mass, connecting rod moment of inertia, and direction of engine rotation. Secondly, it serves as a means of verifying that the results from ANSYS-12 are interpreted in the right manner. However, for reasons of convenience of reading and transferring data the analytical work is use as the basis and the commercial software is used as a verification tool.

3.1 Analytical Vector Approach

The analytical vector approach is used, for the case of zero offset (e = 0), for any given crank angle θ, the orientation of the connecting rod is given by [3]

$\beta = \sin-1\{-r1 \sin\theta / r2\}$. (1)

Angular velocity of the connecting rod is given by the expression:

$\omega 2 = - \omega 1 \cos\theta / [(r2/r1)2 - \sin 2\theta]\ 0.5$ (2)

Note that bold letters represent vector quantities. The angular acceleration of the connecting rod is given by:

$\alpha 2 = (1/ \cos\beta) [\omega 12 (r1/r2) \sin\theta - \omega 22 \sin\beta]$ (3)

Absolute acceleration of any point on the connecting rod is given by the following equation:

$a = (-r1\ \omega 12 \cos\theta - \omega 22\ u \cos\beta - \alpha 2\ u \sin\beta) + (-r1\ \omega 12 \sin\theta - \omega 22\ u \sin\beta + \alpha 2\ u \cos\beta)$ (4)

Acceleration of the piston is given by:

$ap = (-\omega 12\ r1 \cos\theta - \omega 22\ r2 \cos\beta - \alpha 2\ r2 \sin\beta) + (-\omega 12 r1 \sin\theta - \omega 22\ r2 \sin\beta + \alpha 2\ r2 \cos\beta)$ (5)

Forces acting on the connecting rod and the piston are shown in Fig. 6. Neglecting the effect of friction and of gravity, equations to obtain these forces are listed below. Note that mp is the mass of the piston assembly and mc is the mass of the connecting rod. Forces at the piston pin and crank ends in X and Y directions are given by:

$FBX = -(mp\ aP + \text{Gas Load})$ (6)

$FAX = mc\ ac.gX - FBX$ (7)

$FBY = [mc\ ac.gY\ u \cos\beta - mc\ ac.gX\ u \sin\beta + Izz\ \alpha 2 + FBX\ r2 \sin\beta] / (r2 \cos\beta)$ (8)

$FAY = mc\ ac.gY - FBY$ (9)

This provides values of angular velocity and angular acceleration of the connecting rod, linear acceleration of the crank end center, and forces at the crank and piston pin ends. These results are used in the FE model while performing dynamic FEA. An advantage of this program is that with the availability of the input. The output could be generated in a matter of minutes. This is a small fraction of the time required when using commercial soft wares.

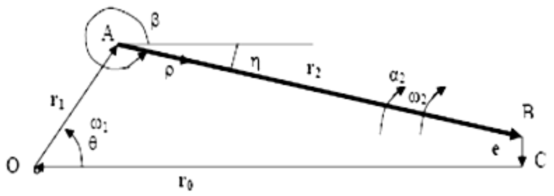

Fig -6: Vector representation of slider crank mechanism

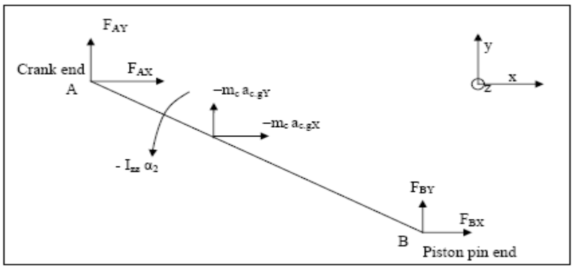

Fig -7: FBD and vector representation of connecting rod

3.2 FEA with dynamic load

Once the components of forces at the connecting rod ends in the X and Y directions are obtained, they can be resolved into components along the connecting rod length and normal to it. The components of the inertia load acting at the center of gravity can also be resolved into similar components. It is neither efficient nor necessary to perform FEA of the connecting rod over the entire cycle and for each and every crank angle. Therefore, a few positions of the crank are selected depending upon the magnitudes of the forces acting on the connecting rod, at which FEA is performed. [4]

The justification used in selecting these crank positions is as follows:

The stress at a point on the connecting rod as it undergoes a cycle consists of two components, the bending stress component and the axial stress component. The bending stress depends on the bending moment, which is a function of the load at the C.G. normal to the connecting rod axis, as well as angular acceleration and linear acceleration component normal to the connecting rod axis. The variation of each of these three quantities over 0°–360° is identical to the variation over 360°-720°. Therefore, for any given point on the connecting rod the bending moment varies in an identical fashion from 0°–360° crank angle as it varies from 360°–720° crank angle. The axial load variation, however, does not follow this repetitive pattern. (i.e. one cycle of axial load variation consists of the entire 720°). This is due to the variation in the gas load, one cycle of which consists of 720°. However, the variation over 0°–360° can be superimposed with the variation over 360°–720° and this plot can be used to determine the worst of the two cycles of 0°–360° and 360°–720° to perform FEA, The axial load at the crank end and at the piston pin end are not generally identical at any point in time. They differ due to the inertia load acting on the connecting rod. The load at either end could be used as a basis for deciding points at which to perform FEA. The load at the crank end is used in this work. [2]

3.3 Loading boundary condition

While performing dynamic FEA of the connecting rod, load applied to both crank end and the piston pin end of the connecting rod. The angular velocity, angular acceleration, and linear acceleration are specified in both magnitude and direction for the connecting rod. All the above-mentioned quantities are for the crank angle of interest. While applying the loads, the manner in which loads are applied for axial static is extended to the case of dynamic. If the component of the resultant force along the connecting rod length suggested a tensile load to act on the connecting rod, the resultant load is applied with cosine distribution. The cosine distribution is applied 90° on either side of the direction of the resultant load, totally 180°. But if the component of the resultant force along the connecting rod length suggested a compressive load to act on the connecting rod, the resultant load is applied with uniform distribution. The uniformly distributed load is applied 60° on either side of the direction of the resultant load, totally 120°. The results at the regions near the ends of the connecting rod are sensitive to the type of load distribution used (uniformly distributed or cosine distribution). [2]

3.4 Restraints

If restraints and forces are both applied to a surface, force will not be transmitted in the direction in which the restraints are applied. This presents a problem in simulating a pin joint. A way to simulate the pin joint is to apply all the loads acting on the connecting rod that keep the connecting rod in dynamic equilibrium at the instant under consideration (i.e. at a specific crank angle) and then solve the model. Therefore, no restraints are applied to the model while solving for the case of dynamic analysis. Not applying restraints and using loads at both ends of the connecting rod permits better representation of the loads transferred through the pin joints. [2]

4. CONCLUSION

The failure in the connecting rod has been initiated mostly from the small end fillet region. From this analysis, we conclude that to avoid failure from small end fillet region inducing fillet to this end and structure is desirable. In short we can conclude the following point; the maximum stress found from the static analysis is near the small end. From static analysis the maximum stress is 138MPA. It is safe value as compared to the tensile yield strength is 560MPA.

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