Modal Analysis and Optimization of I.C. Engine Connecting Rod

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Abstract— In the presented work an I.C. Engine Connecting Rod is undertaken to analyse and design the dynamic changes of boundary condition in running engine are investigated using modal analysis performed using ANSYS to determine the required boundary conditions. Using the same boundary conditions and by analytically designing the connecting rod according to specific engine specifications of TVS Apache 150 model. On the model, parametric study is carried out to know the effect of input parameter such as shank fillet radius and shank thickness both near the big end as well as the small end side off the connecting rod. Based on the parametric study, an optimized value for shank fillet radius is obtained which is found that there is considerable reduction of maximum value of Von Misses stress as well as deformations obtained for the modal analysis performed on the modified model of the connecting rod.

Key words: ANSYS, WORKBENCH, Parametric Study, Optimization

I. Introduction

The connecting rod is the intermediate member between the piston and crankshaft. Its primary function is to transmit the push and pull from the piston pin to crankpin and thus convert the reciprocating motion of the piston into the rotary motion of the crank. The connecting rod is therefore considered as a key component in terms of the structural durability and efficiency of an engine. A connecting rod consists of a long shank, a small end and big end. The cross-sectional area of shank may be rectangular, circular, and tubular, I section or h-section, according to the application and requirement cross-section of a connecting rod is taken. In this study I-section has been taken because of its greater ability to resist bending moment.

Smaller end of connecting rod is made in the form of eye and is provided with the bush with some suitable material like phosphors bronze and connected to piston by means of piston pin. The big end of connecting rod is usually made split so that it can be mounted easily on the crankpin bearing shells. The split cap is fastened to the big end with two cap bolts. The big end of bearing shell generally made of steel, brass or bronze with thin lining of white metal. The wear of the big end bearing is allowed for by inserting thin metallic strips known as shims which are about 0.04-0.05 mm thick between the cap and the fixed half of the connecting rod. As the wear takes place, strips are removed and trued up.

A. Stress Generation and Failure of Connecting Rod

The connecting rod is under enormous stress from the reciprocating load represented by the piston , actually elongates and being compressed with each rotation, and the pressure increases as the square of the engine rpm increase. Failure of a connecting rod, usually called throwing a rod, is one of the mostly used causes of catastrophic engine failure in cars, frequently puts the broken rod through the side of the crankcase and thereby contibuting the engine irreparable, it can result from cyclic loading near a physical defect in the rod, lubrication damage in a bearing due to uneven maintenance, or from failure of the rod bolts from a defect, improper gripping or over-revving of the engine.

B. Modal Analysis of Connecting Rod

As the structure of a connecting rod is complex, generally made with different number of parts. Because of the separate of the connecting rod cap, connecting rod shaft, connecting rod bushes, connecting rod bearing shells, and connecting rod bolt are assemble and analyse. Analysis of this much number of parts is difficult, so some parts of the connecting rod like connecting rod and connecting rod shaft were integrated to simplify the link mechanism to convenient analysed the connecting rod, without affecting accuracy that much. Meshing has been done using ANSYS software.

C. Parameterization

Parameterization is the process of deciding and defining the parameters necessary for a complete or relevant specification of a model or geometric object. Parameterization studies calculate the effect of the each parameter on the response by changing the parameters one by one.

Parameterization is a mathematical process involving the identification of a complete set of effective coordinates or degrees of freedom of the system, process or model, without taking to their utility in some design. Example implies identification of a set of coordinates that allows one to uniquely identify any point (on the line, surface & volume) within ordered list of numbers. Each coordinates can be defined parametrically in the form of a parametric curve (one-dimensional) or a parametric equation.

Generally, the no. of minimum number of parameters required to describing a model or geometric object is equal to its dimensions, and the scope of the parameters within their allowed range is called parameters space. Though a good set of parameters permits identification of every point in the parameter space, it may be that, for a given parameterization, different parameter value can refer to the same 'physical' point. Such assumptions are subjective but not injective. An example is the pair of the cylindrical polar coordinates (ρ,φ,z) and $(\rho,\varphi + 2\pi,z)$.

D. Connecting Rod Design Parameters

Here, considering frontal profile diameter of small bore is D1,diameter of big bore is D2, effective length is L, shank length is Ls. Considering shank section fillet radius 1 is R1, fillet radius 2 is R2 ,total width is L1, side width is L2, total thickness is T1, middle thickness is T2.

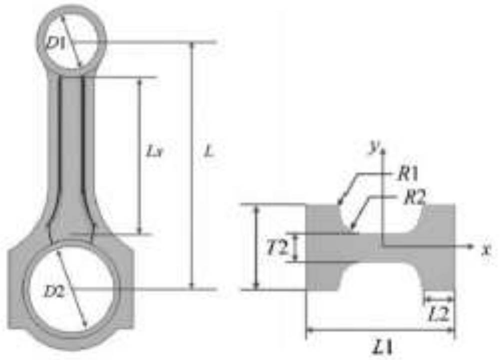

Fig. 1: Connecting Rod Design

II. METHODOLOGY

A. Design of Connecting Rod

The methodology involves design calculations for the connecting rod considered. The design calculations are done by assuming the connecting rod to be equivalent to a standard ‘I’ section whose thickness is assumed to be ‘t’, width ‘4t’ and height ‘5t’. The design calculations for any specific connecting rod is done on the basis of the engine under consideration as the connecting rod length depends on the crank radius for the crank mechanism and is equal to almost twice that of the crank radius. The connecting rod model is then prepared in CREO using the respective geometrical dimensions that are calculated.

The connecting rod that is considered in this project work is based on standard engine specifications of TVS Motor – Apache 150.

The specifications for the engine are mentioned below:

- 4 stroke, air cooled engine
- Displacement volume = 147.5 cc
- Maximum Power = 9.95 kW @ 8500 rpm
- Maximum Torque = 12.3 kW @ 6000 rpm
- Bore and Stroke = 57 × 57.8 mm
- Compression Ratio = 9.5:1
- Power to Weight Ratio = 101.6 bhp / ton.

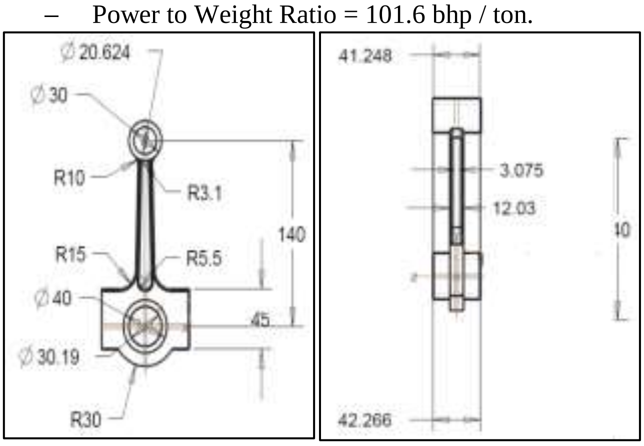

Fig. 2: Design

B. Meshing of Connecting Rod :

The mesh in initial and proposed model is generated with same element size because they have comparable geometry. The shank portion was given element size of 1 mm and rest of the model was given element size of 2 mm. So, total of 0.24 million elements are generated in the mesh of initial model while 0.26 million elements were generated in proposed model.

Frequency (Hz)	502.99	510.84	520.23	2822.7	3446	5259.6
Max deformation (mm)	76.427	109.67	73.524	97.253	82.675	68.778

Table 1: Results

The relevance centre was given to be medium in order to have fine mesh at small element size sections and coarse mesh at large element size sections. The mesh is refined again and again using refinement option in ANSYS meshing in order to match the result nearer to experimental results as was mentioned in literature. The mesh generated was tetrahedron in order to match connectivity between elements.

Since the elements were used as tetrahedron so number of nodes per element is 4 while for 0.26 million elements the number of nodes were found to be 1 million approximately. Using tetrahedron mesh maximum aspect ratio of elements was found to be 12:1 which is considered to be good for a mesh with 0.26 million elements. The mesh was also checked for independency. Moreover the average orthogonally of element was found to be 0.8 this shows that mesh generated is up to the standard and there is no need to refine the mesh further.

Fig. 3: Design

C. Boundary Conditions

Boundary conditions for the connecting rod are decided based on the analytical calculations performed. Following are the boundary conditions for the connecting rod model:

- Big end Bearing: Fixed Support condition is applied to the inner surface of the big end bearing.
- Small end bearing: Bearing force of 63.8 kN(Based on the Analytical calculation) is applied to the inner surface of the small end bearing.
- Further, the parameterization is based on geometrical dimensions keeping the entire boundary conditions intake and at last finalizing the results for the optimized setup.

III. RESULTS AND DISCUSSIONS

A. Modal Analysis of Connecting Rod

Modal analysis is the study of the natural characteristics of structures. Both the natural frequency (which depends on the mass and stiffness distributions in structure) and mode shape are used to design the structure for noise and vibration applications.

In present study initially 6 mode shapes were found for design parameters considering TVS apache 150 model: shank fillet of small end (Fse)-10 mm, shank fillet of big end (Fbe)- 15 mm, Shank upper end width(Wup)- 12.684 mm and shank thickness(t)- 1.5 mm on designed connecting rod.

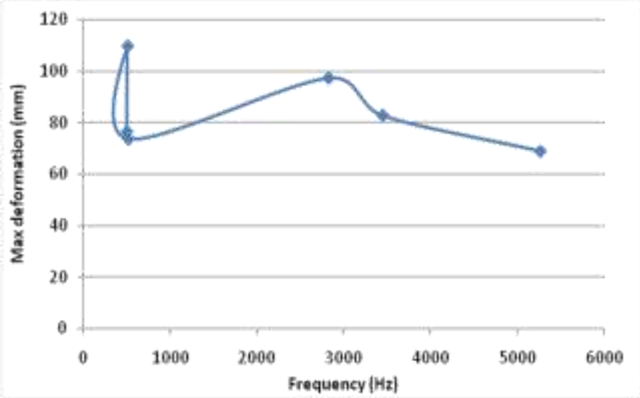

Fig. 4: Frequency versus maximum deformation of initial model

IV. PARAMETRIC STUDY

The input parameters (F_{se}, F_{be}, W_{up} and t) are varied with output parameter in order to predict orthogonal effect of one parameter with respect to output parameter i.e. Max von misses stress. The main geometrical dimension in this project which is focused is Shank fillet small end radius since the maximum stress is acting near small end fillet only. We can see from parametric study behaviour of every parameter with respect to maximum Von Misses stress. The optimized value will be set based on parametric study.

Shank fillet Small end	Shank fillet big end	Shank upper end width	Shank thickness	Eq stress Max
10	15	12.684	1.5	902.3511638
10	15	12.684	2	981.9434276
10	15	12.684	2.5	995.2860172
10	15	12.684	3.075	886.0417665
10	15	12.684	4	894.3488493
10	15	12.684	6	876.3275594
10	15	12.683	8	1127.493842
10	15	12.684	10	954.9079626
10	15	13	3.075	975.7192813
10	15	14	3.075	981.2372148
10	15	15	3.075	907.6245345
10	15	16	3.075	930.6003886
12	15	12.684	3.075	997.7358057
14	15	12.684	3.075	935.3524809
16	15	12.684	3.075	934.0425663
18	15	12.684	3.075	795.3237873
20	15	12.684	3.075	769.4085486
22	15	12.684	3.075	801.4338006
10	17	12.684	3.075	884.3468798
10	19	12.684	3.075	939.4256638
10	21	12.684	3.075	961.4470619

The highlighted parameters are kept constant in parametric study of parameters in order to predict orthogonal behaviour with respect to Maximum Von Misses stress.

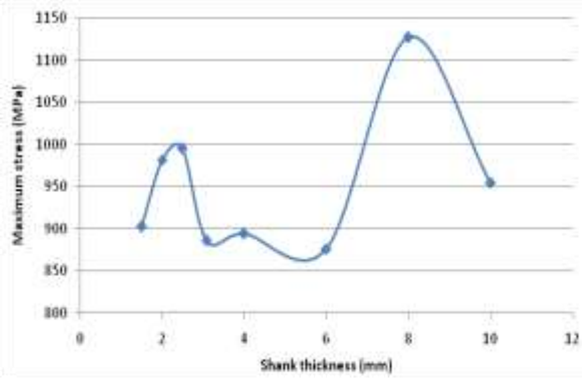

Fig. 5: Variation in Max.stress with change in shank thickness

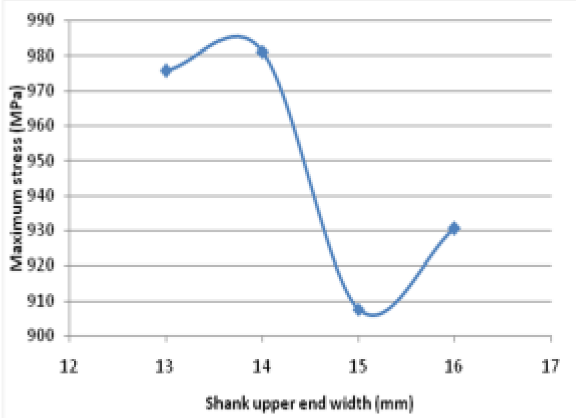

Fig. 6: Variation in Max.stress with change in Shank upper end Width

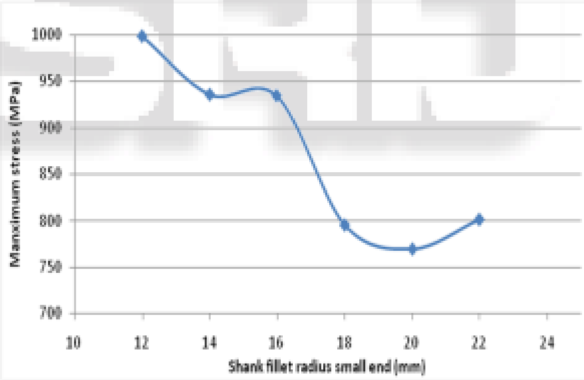

Fig. 7: Variation in Max.stress with change in Shank fillet radius small end Width

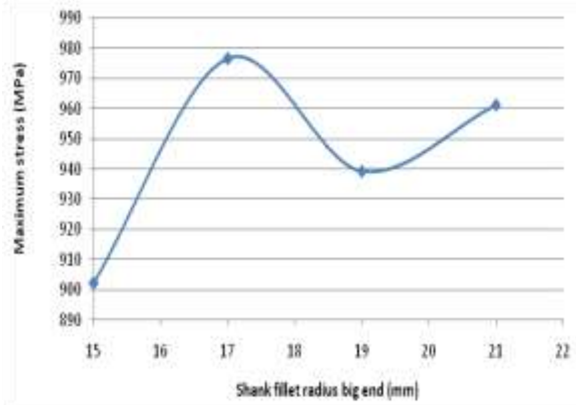

Fig. 8: Variation in Max.stress with change in Shank fillet radius big end Width

In simulation study it was found that maximum Von Misses stress was found to be acting on shank fillet at the small (upper) end of connecting rod. Thus in order to reduce the maximum stress the geometric parameters are varied in parametric study. From Fig.4.7 it was found that there is quite large reduction in maximum stress acting on connecting rod 747 MPa around which is much less than 883 MPa as was measured initially on designed connecting rod. The value of maximum stress as can be seen in highlighted yellow colour when shank fillet radius at small end is 20 mm was found to be minimum as compared to other results in which max stress is varying with the parameters.

A. Maximum Stress Comparison for New Parameter Based On Parametric Study

Frequency (Hz)	501.98	511.22	519.41	2860.5	3524.8	5307.6
Max deformation (mm)	76.133	109.57	73.127	96.658	84.939	68.485

Table 2: Results

Since it was observed from parametric study that shank fillet radius of 20 mm max stress reduces from 883 MPa to 747 MPa so the models are compared to check overall stress reduction in model.

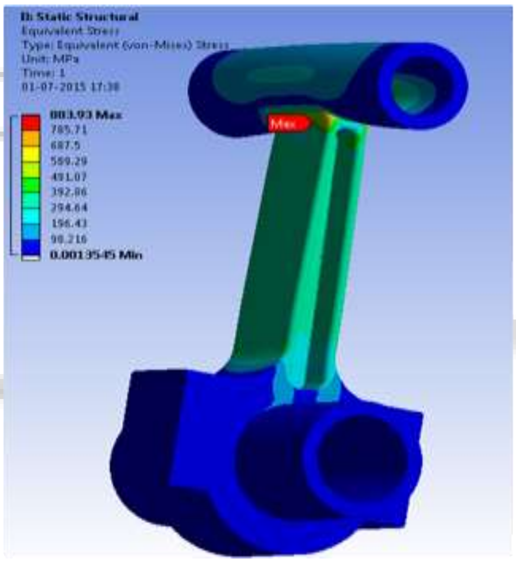

Fig. 9: Max. Stress before optimization

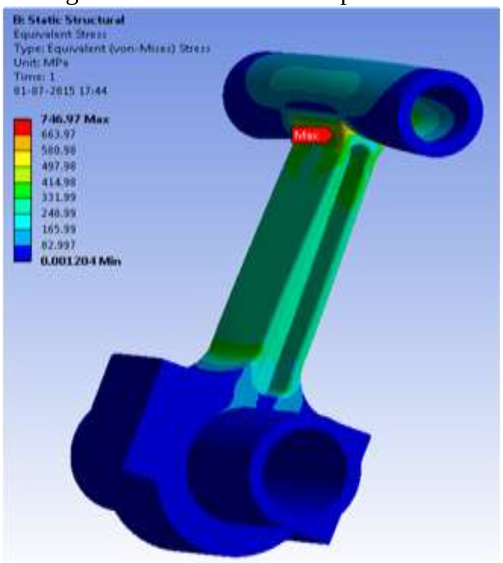

Fig. 10: Max. Stress after optimization

B. Modal Analysis for New Parameter Based On Parametric Study

Since max Von misses stress was found to decrease to a minimum value of 747 MPa when shank fillet radius is increased to 20 mm. Therefore Modal analysis is performed in new optimized model in order to check the new mode shapes and deformations at different natural frequencies.

Since mode shapes 5 and 6 are for lower end in which no design improvement is done so they are not considered for comparison of initial modal analysis and present modal analysis. Figure shown below shows mode 1-4 of optimized model compared with initial model.

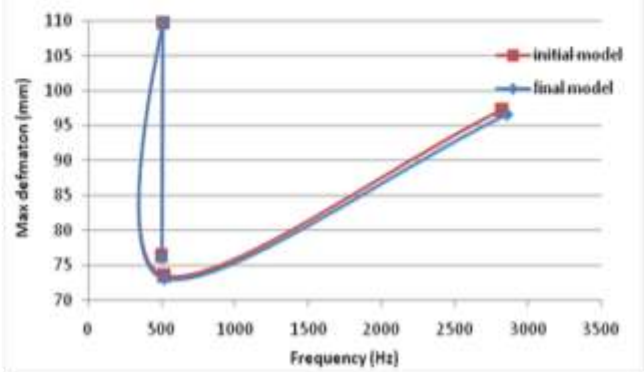

Fig. 11: Graphs

Thus it can be observed from the model that deformation in optimized model is less then initial model. Hence the present optimized model is more effective then initial mode it not only reduces the maximum von misses stress but also reduces the deformations related to particular natural frequencies.

V. CONCLUSION

Based on the study following conclusion can be obtained which are as follows:

1) By Parametric optimization it is found that shank fillet radius has big influence on the stress distribution on the shank portion of the connecting rod.
2) It was found that at shank fillet radius of 20mm we get the minimum von misses stress(747 MPa) compared to other parametric studies.
3) Modal analysis is performed with changed shank fillet radius and reduced deformation was observed in the model and compared with the initial model. Thus our proposed optimized value for shank fillet radius to reduce maximum equivalent von misses stress is observed to be precise for the desired application of connecting rod.

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