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Design and Shape Optimization of Connecting Rod End Bearing through ANSYS

Anurag Vijayvergiya[1], *Emarti Kumari* [1], *Shiv Lal*[2]

[1] *Department of Mechanical Engineering, M.B.M. Engineering College, Jai Narain Vyas University, Jodhpur, 342001, Rajasthan, India*

[2] *Department of Mechanical Engineering, Rajasthan Technical University, Rawatbhata Road, Kota, 324010, Rajasthan, India*

Email: embhaskar.mech@jnvu.edu.in

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Abstract

Connecting rod is a part of internal combustion engine that performs very important task by converting the translator or reciprocating motion of piston to rotary motion of crankshaft. It is consisting of big end and small end; small end has attached to the piston pin and big end with the crankpin. Our main focus of study was to explore force on different type of shapes of connection rod. In this we perform detailed load analysis on various shape of connecting rod ends. In this research first generating proper models of connecting rod with different type of cross- section. we create I section connecting rod, H section connecting rod, rectangular section connecting rod. Then we analysis different loads of static structural and also analysis of buckling load of all types of connecting rods using finite element method and FE analysis is carried out using ANSYS software

1. Introduction

The connecting rod is a part of internal combustion engine that transmits motion and forces amongst piston and crankshaft. In engine all moving part are subjected to variable load and change in the direction of motion. Cross-section (I-section, H-section, C-section, square or rectangular hollow section) and material (Mild steel, forged steel, functionally graded material, hybrid material) of connecting rod will play vital role to design a safe and reliable connecting rod. Automobile, defence, aircraft and spacecraft industry largely depends on alternative materials or manmade materials such as laminated composite materials, functionally graded material, viscoelastic materials and hybrid materials. These alternative materials have high strength to weight ratio, stiffness and corrosion resistance.

The various parts of connecting rod have shown in Figure.1 as presented by (Godara et al.) where big end has been connected to the journal bearing mounted on crank shaft and small end with piston pin.

Topology optimization of connecting rod has been performed using finite element based MSC/NASTRAN software, the flow chart of design variables for connecting is presented in Figure. 2. The material and geometric properties of connecting rod is very important to design a durable connecting rod.

Here, author has modelled the connecting rod in three-dimensional AUTO CAD and imported it to ANSYS APDL / WORKBENCH, thereafter carried out the linear static analysis to obtain stress / strain state analysis by considering four different cross-sections (I-section, H-section, C-section, square or rectangular hollow section) and four different material properties.

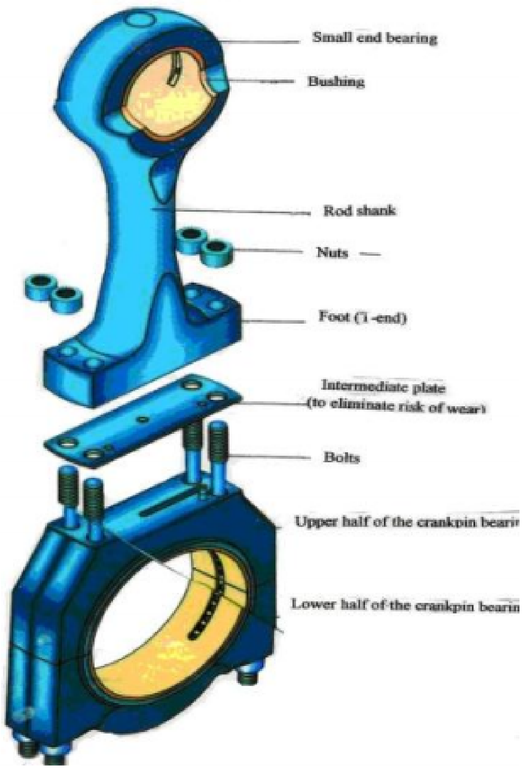

FIGURE 1. **Parts of the connecting rod**

Several researchers have been attempted the linear static analysis of connecting rod through commercial software ANSYS, MSC/NASTRAN and in-house developed FORTRAN/MATLAB. Seralathan et al. (Seralathan et al.) carried out the stress analysis of connecting rod considering four types of materials through finite element based commercial software ANSYS. They calculated the deformation, elastic strains and von-misses stresses of connecting rod. It was found that total deformation of alloy aluminum Al356-5%SiC-10% Flyash stir cum squeeze casting material might be minimum compare base material Al356, whereas distribution of elastic strains and von-misses stresses will be similar is base material Al356 and hybrid material Al356-5%SiC-10% Flyash stir cum squeeze casting material. The stress analysis of connecting rod carried out (Witek et al.) for turbocharged diesel engine using finite element method software ANSYS. Ali *et al. (Ali et al.)* was analyzed the connecting rod materials such as steel, aluminum alloy, cast iron to optimize it. Authors noticed that weight of aluminum 7075 connecting rod is three times lower than the forged steel connecting rod. Due to light weight of aluminum 7075 connecting has been used in aerospace applications. Whereas deformation would be always lesser in forged steel connecting rods compare to aluminum alloy connecting rods due to their higher stress handling capacity without yielding. Authors has been considered the various factor such as stress handling capacity, weight, cost of material and manufacturing for optimization of connecting rod and it was noticed that forged steel might be better material of connecting rod in the terms of stress handling, manufacturability and cost.

Ali and Haneef et al. (Muhammad, M. A. Ali, and Shanono) performed fatigue analysis was performed on connecting rod to check the fatigue life and alternating stress developed on rod due to service and assembly load with variation in load distribution. For fatigue analysis they considered two load steps at big end, in case 1 considered only assembly loads on shank region and in case 2 all the loads are considered by removing shank region. Gopinath D et al. (Gopinath and Sushma) carried out the optimization analysis on connecting rod to optimize weight and structural of it. They applied two different value of force 100N and 500N at small end of connecting rod for shape and structural optimization, respectively while bigger end subjected as fixed support. Sriharsha B et al. (Sriharsha and Rao) carried out structural analysis of connecting rod for different material as steel, aluminum and titanium and observed von-mises stress and shear stress. They performed an optimization task to minimize mass of connecting rod and structural analysis in each condition and removed excess material. They reduced the initial mass of structural steel connecting rod 482 grams from 539 grams through optimization technique.

The failure analysis of diesel generator set connecting rod has been performed He et al. (He et al.). Shape optimization of structural components has been performed by Upadhyay *et al.* (Upadhyay et al.) using finite element method. Authors compared various numerical methods in the context of shape optimization.

Pani et al. (Pani et al.) compared steel and forged steel connecting rod to minimize the weight, deformation, stresses whereas maximize, factor of safety, stiffness of it. They found that there was increment in the factor of safety and stiffness of forged steel made connecting rod as compare to carbon steel. The weight of forged steel material was less than the existing carbon steel and the number of cycles of forged steel was more than the existing connecting rod. Buckling of various structures has been investigated (Kumari, "Nonlinear Bending Analysis of Cylindrical Panel under Thermal Load" "Free vibration analysis of rotating laminated composite plate type blades with variable thickness" Kumari and Saxena) under various loading conditions uniaxial compression, shear and thermal load. Lee et al. (Lee, Kyu, et al.) carried out finite element analysis by considering three different materials in which one is N-forged steel and other are Al5083 or Al6061. From analysis they concluded that Al5083 have less weight, and weight was reduced by 63.19% and also performed comparison for tensile stresses found that Al5083 has the least stress. Rezvani et al. (Rezvani, Javanmardi, and Mostaghim) considered the three different material such as SAE4340, 42CrMo$_4$, Al7075-T651 to perform finite element analysis on connecting rod. They studied the effect of stresses, strains, deformations, weight and factor of safety on heavy duty vehicles. They concluded that maximum stress was almost same when load applied to piston end, where load applied to crank end maximum stress was almost same; but weight of Al7075-T651 connecting rod was light than other materials and existing carbon steel connecting rod.

Through literature review it is noticed that most of the researchers have been considered the different material properties to investigate the performance of connecting rod. Thus, more work is required to analysis the effect of various cross-section such as I-section, H-section and rectangular section of connecting rod in terms of effect of deformation, Von Mises strain and stress, weight and factor of safety. Therefore, in this article bending and buckling analysis of various cross-section has been performed to optimize the cross-section of connecting rod.

2. Methodology

First we use AUTOCAD to create three-dimensional geometry model considering three different cross-section of connecting rod like I-section, H-section and rectangular-section. Thereafter the created models are converted to standard ACIS file format so as to import the model to ANSYS-Workbench platform to generate the meshed structure. Figure. 3 shows the geometric model of respectively I-section, H-section and rectangular section connecting rod with meshing. All the cross-section of connecting rods is discretised considering three-dimensional four noded tetrahedral element having three degree of freedom u$_x$, u$_y$, u$_z$ along x-axis, y-axis and z-axis. Number of nodes are 15236, 16475, 7973; and elements are 8682, 9631, 3986; respectively for I-section, H-section and rectangular-section connecting rod as presented in Figure. 3(a-c).

After meshing performed the static analysis on connecting load by applying 100 N load on small end of connecting rod whereas bigger end of connecting rod is fixed supported. For static analysis of connecting rod following governing equation are used:

$[K_L]\ \{\delta\} = \{F\}$ .... (1)

Here, $[K_L]$ is linear stiffness matrix; $\{d\}$ displacement vector having three translational displacements u$_x$, u$_y$, u$_z$ along x-axis, y-axis and z-axis; and $\{F\}$ is the force vector.

Thereafter, for the buckling analysis of connecting rod, first switch on the pre-stress command for the static analysis to generate geometric stiffness matric $[K_G]$, than performed the Eigen-buckling analysis; governing equation of motion for Eigen buckling analysis may be written as:

$[K_L]\ \{\delta\} + \lambda\ [K_G]\ \{\delta\}\ =\ 0$ .... (2)

Here, λ is Eigen buckling frequency.

The major design parameters of all type of cross-section of connecting rod geometric parameters are given in Table 1. and material properties are presented in Table2.

3. Result and Discussion

Now we perform static structural analysis for total deformation, elastic strain (von-mises), von-mises stress, life, and safety factor under the boundary condition for all types of connecting rod and compare them.

3.1. Static Structural Analysis

For I-section Figure 4. respectively shows the elastic strain, total deformation, von-misses stress, life and safety factor.

For H-section Figure 5. respectively shows the elastic strain, total deformation, von-mises stress, life, and safety factor.

For Rectangular section Figure. 6 respectively shows the elastic strain, total deformation von-mises

TABLE 1. Configuration ofI-section, H-section and Rectangular-section of connecting rod (Pani et al.)

S. NO.	Parameters	I -section	H -section	Rectangular -section	
		mm	mm	PARA.	mm
1	Thickness t	5.13	5.13	-	5.13
2	Width of the section B = 4t	20.52	25.63	B = 2t	10.26
3	Height of the section H = 5t	25.63	20.52	H = 4t	20.52
4	Height at the big end 1.1 to 1.125 of H	28.193	22.572		22.572
5	Height at the small end 0.9 to 0.75 of H	19.2	18.468		18.468
6	Inner diameter of the small end	17	17		17
7	Outer diameter of the small end	19	19		19
8	Inner diameter of the big end	28	28		28
9	Outer diameter of the big end	32	32		32
10	Length	138	138		138

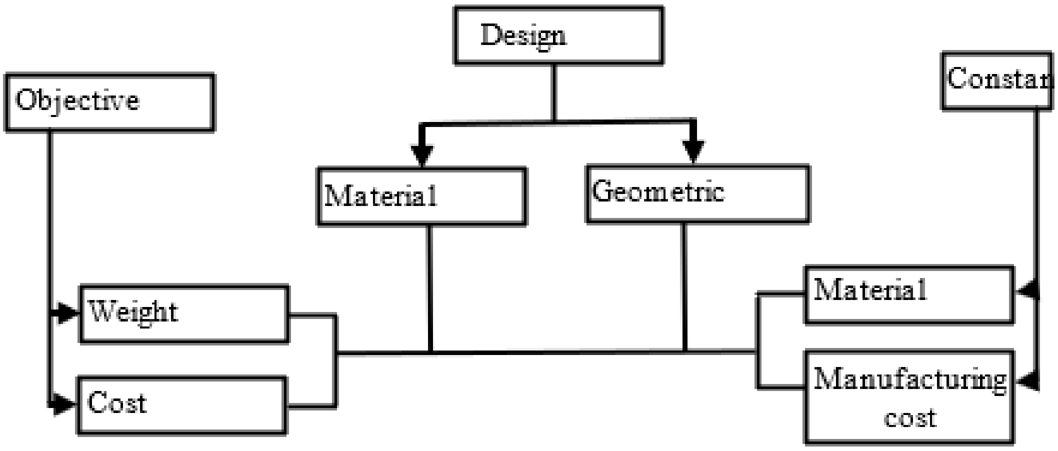

FIGURE 2. Flowchart of Design Variables

TABLE 2. Following material are considered for investigation (Muhammad, M. A. Ali, and Shanono)

Material	Young's modulus (E)	Density (r) kg/m ^{3}	Poisson's ratio (μ)	Thermal conductivity (α)	Shear modulus (G)
Structural Steel	210 GPa	7850	0.3	60.5 W/m $^\circ$C	76.923 GPa

TABLE 3. Minimum and maximum deformations for various cross-sections of connecting rod

Cross section of Connecting Rod	Total Deformation	
	Maximum	Minimum
I-section	0	1.9807 X 10^{-5}
H-section	0	2.4183 X 10^{-5}
Rectangular-section	0	2.2499 X 10^{-4}

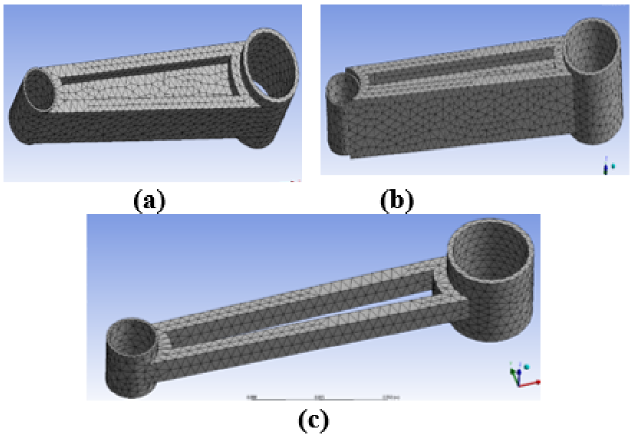

FIGURE 3. **Meshing of various-sections (a) I-section, (b) H-section and (c) Rectangular-Section of connecting rod**

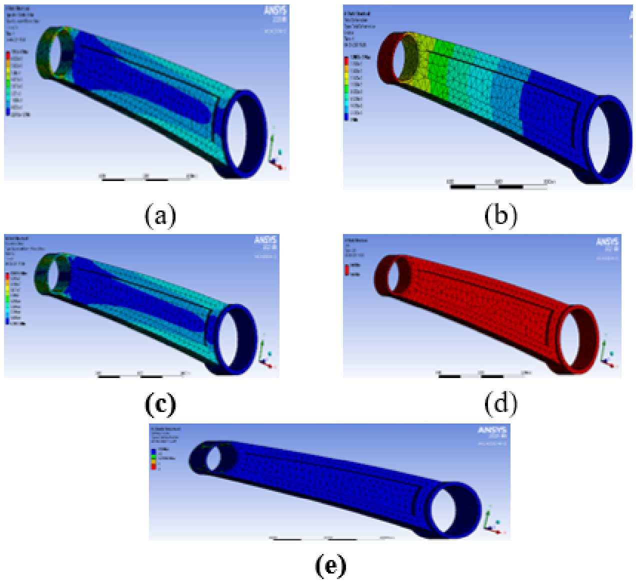

FIGURE 4. **I-section connecting rod (a) equivalent elastic strain, (b) totaldeformation, (c) Equivalent stress, (d)Life and (e) Safety Factor**

stress, life, and safety factor. Table 3. shows us the value of minimum and maximum deformation for all type of connecting rod and from table it concludes that the maximum deformation was found in I-section connecting rod and minimum deformation in I-section connecting rod.

It is noticed from Table 4. that maximum equivalent strain occurs for rectangular section connecting rod compare to I-section and H-section under given boundary condition.

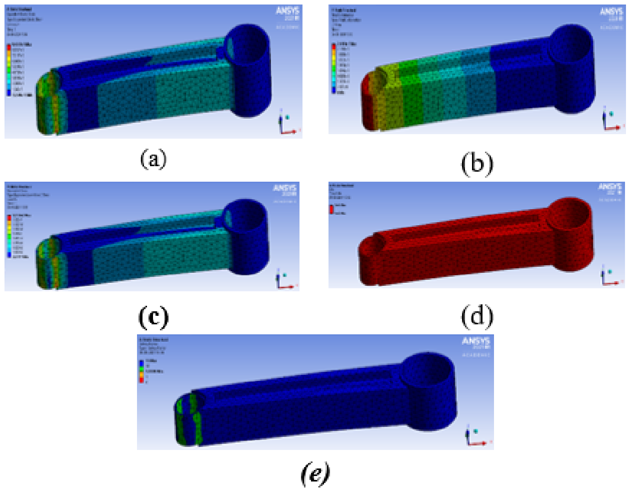

FIGURE 5. **H-section connecting rod (a) equivalent elastic strain, (b) totaldeformation, (c) Equivalent stress, (d)Life and (e) Safety Factor**

It is concluded from Table 5. that maximum equivalent stress occurs for rectangular section connecting rod compare to I-section and H-section under given boundary condition

From Table 6. it concludes that the average safety factor is more in I-section connecting rod so the I-section connecting rod is more safe compare to H and rectangular section connecting rod.

3.2. Eigenvalue Buckling Analysis

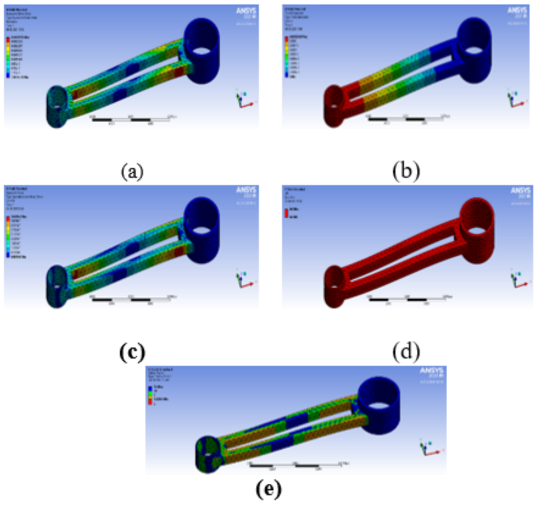

FIGURE 6. **Rectangular-section connecting rod (a) equivalentelastic strain, (b) total deformation, (c) Equivalent stress, (d) Life and (e) Safety Factor**

Buckling is the sudden change in deformation (shape) of a structural component under a load, and that load is called critical buckling load. Critical

TABLE 4. Minimum and maximum equivalent elastic strains for various cross-sections of connecting rod

Cross-sections of connecting rod	Equivalent Elastic Strain	
	Minimum (m/m)	Maximum (m/m)
I -section	$2.2962 \text{ X } 10^{-12}$	$7.563 \text{ X } 10^{-5}$
H -section	$7.2049 \text{ X } 10^{-13}$	$9.4047 \text{ X } 10^{-5}$
Rectangular -section	$7.1011 \text{ X } 10^{-13}$	$2.8359 \text{ X } 10^{-4}$

TABLE 5. Minimum and maximum equivalent stresses for various cross-sections of connecting rod

Cross-sections of connecting rod	Equivalent Stress	
	Minimum (Pa)	Maximum (Pa)
I -section	$0.18863 \text{ X } 10^{-2}$	$1.5028 \text{ X } 10^{7}$
H -section	$7.417 \text{ X } 10^{-2}$	$1.7134 \text{ X } 10^{7}$
Rectangular -section	$8.1849 \text{ X } 10^{-2}$	$5.6468 \text{ X } 10^{7}$

TABLE 6. Comparison of safety factor for various cross-sections of connecting rod

Cross-sections of connecting rod	Safety Factor		
	Minimum	Maximum	Average
I -section	5.7359	15	14.835
H -section	5.0309	15	14.823
Rectangular -section	1.5265	15	10.932

TABLE 7. Buckling and maximum deformation of various sections of connecting rod

Cross-sections of connecting rod		Buckling Modes				
		1	2	3	4	5
I -section	λ	3323	6023	7399	8023	9711
	δ_{max}	1.024	1.08	1.051	1.076	1.201
H -section	λ	5162	5840	6444	7251	8325
	δ_{max}	1.063	1.032	1.054	1.129	1.09
Rectangular -section	λ	170	265	269	654	706
	δ_{max}	1.000	1.020	1.002	1.005	1.009

load may be derived by Euler formula that is written as:

$P_{cr} = \pi^2 EI / L_e^2$ .....(3)

Where, P_{cr}= Critical load in N; E = Youngs modulus of material in MPa; I = Moment of inertia for the principal axis about which buckling occurs mm^4; L_e= Effective length of column in mm

In order to analysis the Eigen buckling we considered the load and boundary conditions as same as structural analysis. For total deformation due to buckling extract the modes number to 5.

For every buckling mode there are two conditions that either it is positive or negative. For every mode check the minimum and maximum deformation value and compare them for all type of section of connecting rod.

Figure 7. shows the deformation in I-section, H-section and rectangular-section connecting rod due to buckling load. First-four buckling modes 1st Bending, 1st Torsion, 2nd Bending and 2nd Torsion for the I-section, H-section; and 1st, 2nd, 3rd, 4th Bending modes of rectangular-section are presented here.

From Table 7. it noticed that the value of first buckling mode is maximum in H-section and value of maximum deformation is also greater than I-section and rectangular-section. For rectangular section connecting rod value of buckling mode is very less.

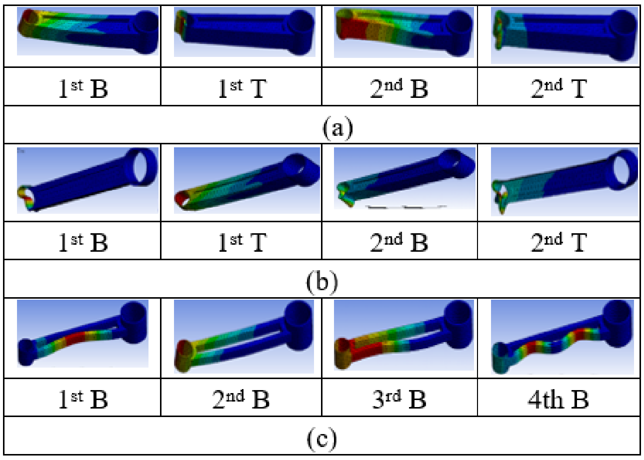

FIGURE 7. **First four buckling modes of (a) I-section, (b) H-section and (c) Rectangularsection of connecting rod**

4. Conclusion

In this paper the structural and buckling analysis of different cross-section type of connecting rod based on finite element method is done using ANSYS-WORKBENCH. Three different cross-section I-section, H-section, rectangular-section are select. On comparing the result for all type of connecting rods, it is observed that the value of total deformation, equivalent elastic strain and von misses stress are less for I-section, moderate for H-section and high for rectangular section and also the safety factor is high for I-section. From buckling analysis it is observed that first buckling load is high for H-section and very less for rectangular section.

ORCID iDs

Emarti Kumari https://orcid.org/0000-0002-3339-8153

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