Design and Analysis of Connecting Rod for Weight and Stress Reduction

Dr. B S N Murthy[1], K. Adarsh Kumar[2] , Mohammed Abdul Shafeeq[3], S. Sai Sundara Praveen[4]
[1]Associate Professor, [2]Assistant Professor, [3,4] Student,
[1,2,3,4]Dept. of Mechanical Engineering,
GIT, GITAM,
Visakhapatnam-530 045, Andhra Pradesh, India.

***Abstract*—The main objective in the "Design and analysis of connecting rod using weight reduction" is to achieve suitable design of the connecting rod for stresses produced under loading and suggest weight reduction opportunities. That can be achieved by changing such design parameters in the existing design. Finite element analysis of single cylinder four stroke petrol engines is taken for the study; Structural systems of Connecting rod can be easily analysed using Finite Element techniques. The static analysis is done to determine the von Misses stress, shear stress, elastic strain, total deformation in the present design connecting rod for the given loading conditions using Finite Element Analysis Software ANSYS 18.1. In the first part of the study, the static loads acting on the connecting rod, after that the work is carried out for safe design. Based on the observations of the static FEA and the load analysis results, the load for the optimization study was selected. The results were also used to determine of various stress and the fatigue model to be used for analysing the fatigue strength. Outputs of the fatigue analysis of include fatigue life, damage, factor of safety, stress biaxiality indication. Then results of present model in ANSYS are compared with the results of existing design in the reference paper.**

***Keywords**:- Stress reduction, connecting rod, finite element analysis.*

I. INTRODUCTION

The connecting rod is the main part of the engine. It rotates the crank shaft that helps the engine of any vehicle to rotate it's wheels .It is situated between crank and piston of the engine. It is designed to resist stresses from combustion and piston movement. It is a light weight component. It should withstand with greater power loads though it is lower in weight. The main purpose of a connection rod is to provide fluid movement between pistons and a crankshaft and therefore the connecting rod is beneath tremendous stress from the load represented by the piston. When building a high performance engine, great attention is paid to the connecting rods. The most effective feature of a connecting rod ought to be the uniform shape.

The cross section of rod beam design ought to be spread and minimize stress load over massive uniformly shaped areas. In operation stress are generated and radiate from one or more source on a component because the rod functions. The structure of connecting rod in an engine is shown in the Fig. 1

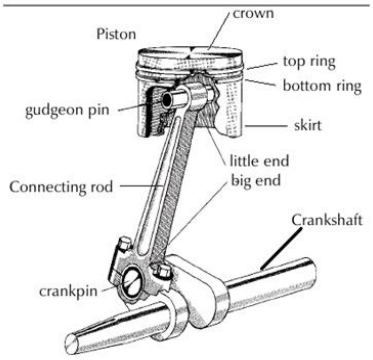

Fig. 1: Connecting rod in engine

The main finction of connecting rod is to convert reciprocating Motion into rotating motion and vice versa as shown in Fig. 2. Pushing and pulling a piston which can transmit the energy. That rotates the rod and crank. It is known as the heart of the engine. It performs piston pushing and piston pulling operations mainly so that the mechanism of an engine works. This provides power to engine to start and move the equipment within which it is used. It is most commonly used in the engines of automobiles. Connecting rod employed in all kinds of vehicles like cars, trucks and bikes wherever combustion engine is employed. All commercial vehicles will have this kind of engine, where connecting rods are used. Even construction vehicles like bulldozers, road rollers (earth movers) use internal combustion engines. Thus, all quite machines essentially depend on piston, connecting rods and crank shafts.

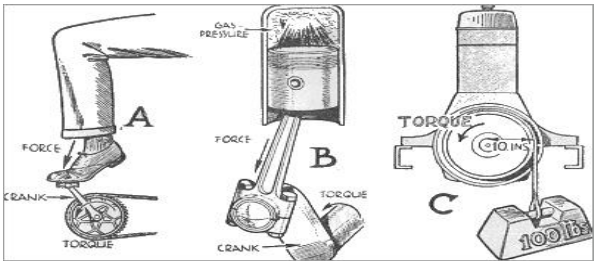

Fig. 2: Working of a connecting rod

Suraj Pal et al. [1] studied finite element analysis of single cylinder four stroke petrol engines. Structural systems of Connecting rod can be easily analysed using Finite Element techniques. So firstly a proper Finite Element Model is developed using Cad Software Pro/E Wildfire 4.0. Then static analysis is done to determine the von Misses stress, shear stress, elastic strain, total deformation in the present design connecting rod for the given loading conditions using Finite Element Analysis Software ANSYS v 12. In the first part of the study, the static loads acting on the connecting rod, after that the work is carried out for safe design.

Naga Malleshwara Rao et al. [2] have explored weight reduction opportunities in the connecting rod of an I.C. engine by examining various materials such as Genetic Steel, Aluminium, Titanium and Cast Iron. This was entailed by performing a detailed load analysis. This study has dealt with two subjects, first, static load and stress analysis of the connecting rod and second, design optimization for suitable material to minimize the deflection. Sudarshan Kumar et al. [3] describes modelling and analysis of connecting rod. In this project connecting rod is replaced by Aluminium reinforced with Boron carbide for Suzuki GS150R motorbike. A 2D drawing is drafted from the calculations. A parametric model of connecting rod is modelled using PRO-E 4.0 software. Analysis is carried out by using ANSYS software.

Julie saahu and Jitendra Jayanth[4]designed connecting rod with aluminium alloy by replacing iron alloy and analysed it by FEA approach to determine the various stresses. James [5] focused on using FEA analysis to show where and how the original connecting rod design could be reconfigured to reduce weight. Vivek et al [7] done stress analysis of connecting rod by designing it in CREO software. Raman preet singh [8] conducted simulation on a model of a connecting rod of a single cylinder four stroke engine. Doshi[9]simulated the model of connecting rod to determine the best material for connecting rod. Sanjay et al[15]studied effect of geometric parameters on stiffness in the big end structure of connecting rod. Shaari et al[18]designed connecting rod of an I.c.engine by using topology optimization and analysed by using FEA approach. A Mirehei et al. [13] investigated the connecting rod fatigue of the universal tractor by ANSYS. Vijayabhaskarreddy et al[19] done static analysis of a connecting rod to determine Von-misses stresses,strains,shear stresses and total deformation by selecting two materials and compared them. Omparkash et al. [10] re-optimized the existing design of the connecting rod of universal tractor (U650) by changing some of the design variables. Silvaa [11] investigated the stress distribution and deformation for two different materials of a crank shaft. Franscisco et al. [16] optimized the connecting rod big end bearings with meta model assistance. Firstly, the theoretical background is analysed then the finite element analysis was performed.

It is observed that in many cases weight reduction of connecting rod was obtained by removing materials from certain regions. The widely used materials in connecting rod manufacturing are carbon steel, cast iron, wrought steel or powder metal etc. So there is a scope to try other materials like Titanium alloy, carbon fiber, aluminum alloy, glass fiber etc. to produce light weight alternative. As these are light in weight, mass of the part will reduce. Therefore, we can optimize the connecting rod for weight reduction with the use of such materials. The connecting rod in any engine determines the efficiency of the engine. There are many factors of a connecting rod which effect the efficiency and performance of the engine. The factors which effect the performance of an engine with respect to the connecting rod are: the material of the connecting rod and the weight of the connecting rod. The amount of power used up to move the connecting rod in the power stroke determines the efficiency of the engine. More the power used up to set the connecting rod into motion, less is the efficiency.

The main objective of the paper is to study various materials and analyze the different forces acting on different materials so as to analyse each material and find the best material suitable for manufacturing of the connecting rod. The other objectives are to design and develop a structural model of a connecting rod and to perform a finite element analysis of a connecting rod and to study the all load factors acting on the connecting rod and to study the stress and strain deformations induced in the connecting rod and to develop a structural optimisation model of connecting rod.

II. METHODOLOGY

A. Design of a Connecting rod

A connecting rod is a machine member which is subjected to alternating direct compressive and tensile forces. Since the compressive forces are much higher than the tensile force, therefore the cross-section of the connecting rod is designed as a strut and the Rankine formula is used. A connecting rod subjected to an axial load W may buckle with x-axis as neutral axis in the plane of motion of the connecting rod, {or} y-axis is a neutral axis. The connecting rod is considered like both ends hinged for buckling about x-axis and both ends fixed for buckling about y-axis. A connecting rod should be equally strong in buckling about either axis.

Let,

A = cross sectional area of the connecting rod.

L = length of the connecting rod.

c =compressive yield stress.

Wcr =crippling or buckling load.

I_{xx} = moment of inertia of the section about x-axis

I_{yy} = moment of inertia of the section about y-axis

k_{xx} = radius of gyration of the section about x-axis

k_{yy} = radius of gyration of the section about y- axis

D = Diameter of piston

r = Radius of crank Rankine formula = (Ixx=4Iyy)

B. Pressure Calculation for 150 cc Engine

Engine type: Air cooled 4-stroke

Bore × Stroke (mm) = 57*58.6

Displacement = 149.5cc

Max. Power = 13.8bhp at the rate of 8500 rpm

Max. Torque = 13.4Nm at the rate of 6000 rpm

Compression Ratio = 9.35/1

Density of Petrol [C8H18] = 737.22 kg/m^3

Temperature = 60F = 288.855K

Mass = Density × Volume = 0.11Kg

Molecular Weight of Petrol= 114.228 g/mole

From Gas Equation,

PV= Mrt

R = R*/Mw = 8.3143/114.28 = 72.76

P = (0.11*72.786*288.85) / 149.5E 3
P = 15.469 MPa.

C. Design Calculation for Carbon Steel

Thickness of flange & web of the section = t

Width of section (B) = 4t

The standard dimension of I-SECTION is shown in the Fig. 3.

Height of section H = 5t

Area of section A= 2(4t*t) +3t*t = 11t^2

MI of section about x axis:

I_{xx} = 1\12 (4t (5t) ^{3} -3t (3t)^3) = 419\12t^4

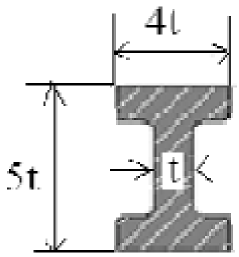

Figure 3: Standard dimension of I-section

MI of section about y axis:

I_{yy} = (2+1\12t (4t)^3 +1\12(3t)t^3) = 131\12 t^4

I_{xx}/I_{yy} = 3.2

Length of connecting rod (L) = 2 times the stroke

L = 117.2 mm

Buckling load W_b = maximum gas force × F.O.S

W_b = (σc*A) /1+ [a*(L\Kxx) 2] = 37663

σc = compressive yield stress = 415MPa

k_{xx} = I_{xx}\A k_{xx} = 1.78t A = σc/π 2 E a = 0.0002

By substituting σc, A, a, L, k_{xx}

$4565t^4 - 37663t^2 - 81639.46 = 0$

t_2=10.03

t=3.2 mm

Width of section B = 4t =12.8mm

Height of section H = 5t = 16mm

Area A = 11t^2 = 112.64mm^2

Radius of crank(r) =stroke length/2 = 58.6/2 = 29.3

Maximum force on the piston due to pressure Fl = π/4*D2 *p = (π/4)*(57)2 *15.469 = 39473.16N

Maximum angular speed Wmax = [2πNmax]/60 = [2π*8500]/60, = 2 =768 rad/sec

Ratio of the length of connecting rod to the radius of crank N= L/r =112/ (29.3) = 3.8

Maximum Inertia force of reciprocating parts

F im = Mr (Wmax) 2 r (cosθ + COS2θn) (Or)

F im = Mr (Wmax)*2 r (1+1/n) = 0.11x (768)2 * (0.0293) * (1+ (1/3.8))

F im = 2376.26N

Inner diameter of the small end d1 =fg /Pb1*l1

= 6277.167/12.5*1.5d1

= 17.94mm

where,

Design bearing pressure for small end pb1=12.5 to 15.4N/mm^2

Length of the piston pin l1= (1.5to 2) d1

Outer diameter of the small end = d1+2tb+2tm = 17.94 + [2*2] + [2*5] = 31.94mm

where,

Thickness of the bush (t_b) = 2 to 5 mm

Marginal thickness (t_m) = 5 to 15 mm

Inner diameter of the big end d_2= 23.88mm

where,

Design bearing pressure for big end pb_2 = 10.8 to 12.6 N/mm
Length of the crank pin l_2 = (1.0 to 1.25) d_2

Root diameter of the bolt = ((2Fim) (π*St))1/2 = (2*6277.167π*56.667)1/2= 4 mm

Outer diameter of the big end = d2 + 2tb + 2db +2tm = 23.88+2*2+2*4+2*5= 47.72mm

where,

Thickness of the bush [t_b] = 2 to 5 mm

Marginal thickness [t_m] = 5 to 15 mm

Nominal diameter of bolt [d_b] = 1.2 x root diameter of the bolt = 1.2×4 = 4.8 mm

Height at the big end (crank end) = H_2 = 1.1H to 1.25 H =17.6 mm
Height at the small end (piston end) =H_1= 0.9H -0.75H =14.4 mm

III. RESULTS AND DISCUSSIONS:

A. Modelling of the Connecting Rod

The connecting rod was modelled by using solid works software as shown in the Fig. 4

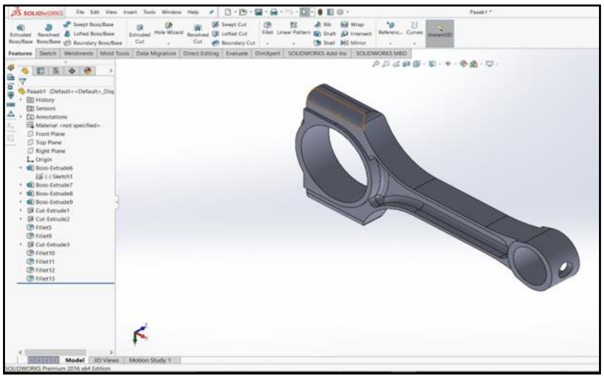

Fig. 4: 3D-Solid model of the connecting rod

The configuration of the engine to which the connecting rod belongs is stated in the table 1.

TABLE 1: CONFIGURATION OF THE ENGINE

Crankshaft radius	48.5 mm
Connecting rod length	141.014 mm
Piston diameter	86 mm
Mass of the piston assembly	0.434 kg
Mass of the connecting rod	0.439 kg
Izz about the center of gravity	0.00144 kg m^2
Distance of C.G. from crank end center	36.44 mm
Maximum gas pressure	37.29 Bar

B. Finite Element Analysis of Connecting Rod

The model designed in the solid works software is imported to ANSYS 18.1 workbench software and meshing of the model is done as shown in the fig. 5.

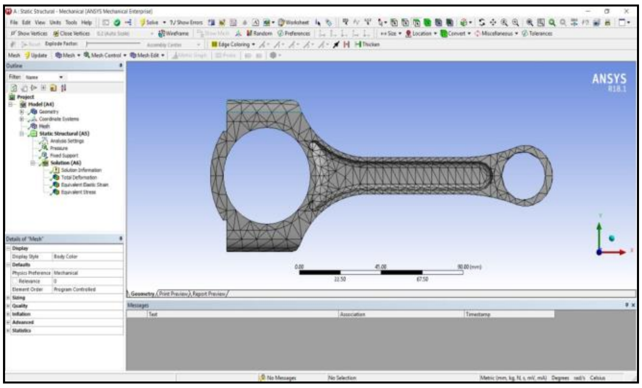

Fig. 5: Meshing of the connecting rod

The Equivalent stress of structural steel is calculated by fixing piston end and applying a pressure of 22.2 Mpa at crank as shown in the Fig. 6 and minimum and maximum stresses are shown in the Table II.

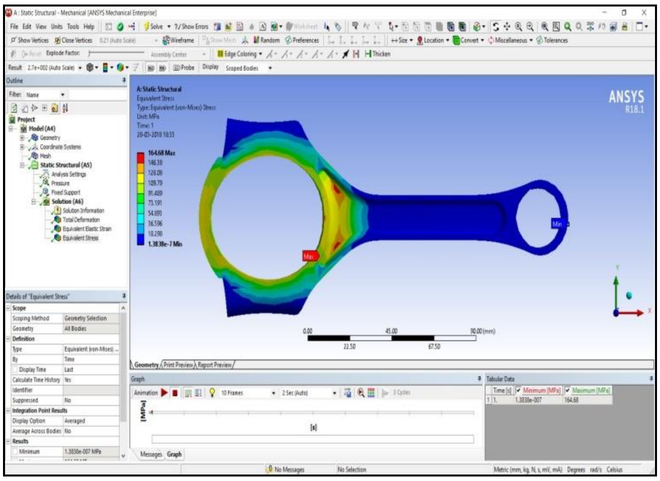

Fig. 6: Equivalent stress of structural steel

TABLE II: VALUES OF MINIMUM AND MAXIMUM STRESSES IN STRUCTURAL STEEL

Time [s]	Minimum [MPa]	Maximum [MPa]
1	1.3838e-007	164.68

Equivalent stress of titanium is calculated by fixing piston end and applying a pressure of 22.2 Mpa at crank end as shown in the Fig. 7 and minimum and maximum stresses are shown in the Table III.

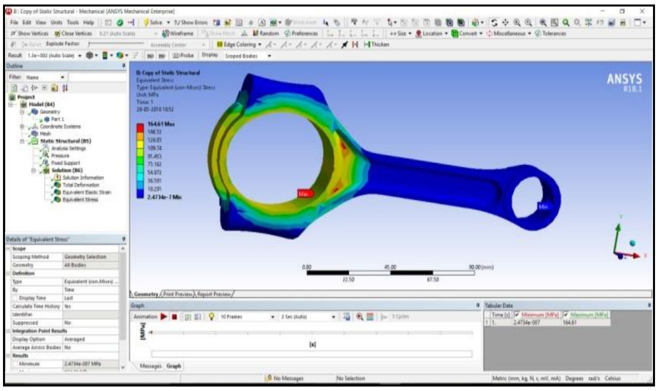

Fig. 7: Equivalent stress of Titanium

TABLE III: VALUES OF STRESSES IN TITANIUM

Time [s]	Min. [MPa]	Max. [MPa]
1	2.4734e-007	164.61

The Equivalent stress of titanium is calculated by fixing crank end and applying a pressure of 23.2Mpa at piston end as shown in the Fig. 8 and minimum and maximum values of stresses are tabulated in the table IV.

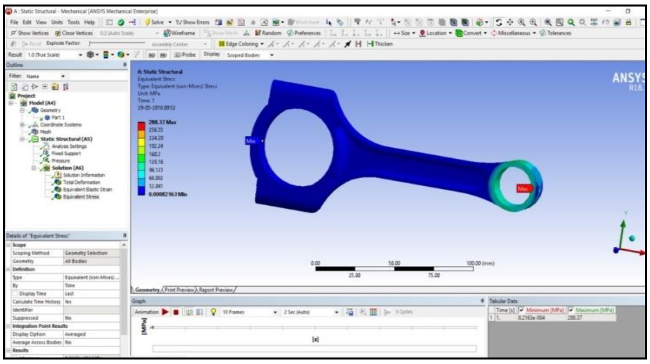

Fig. 8: Equivalent stress of Titanium

TABLE IV: VALUES OF STRESSES IN TITANIUM

Time [s]	Min. [MPa]	Max. [MPa]
1	6.2465e-004	290.59

The Equivalent stress of structural steel is calculated by fixing crank end and applying a pressure of 23.2Mpa at piston end as shown in the Fig. 9 and the values of minimum and maximum stresses are tabulated in the table V.

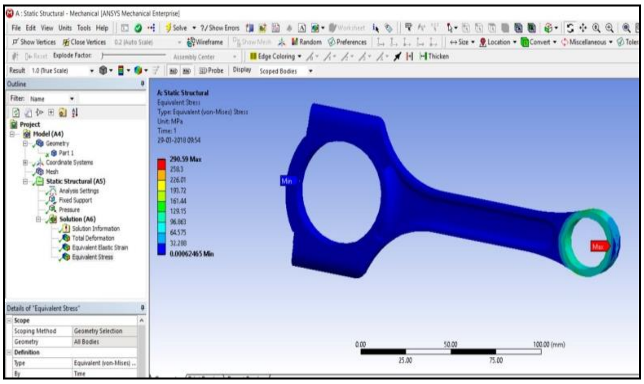

Fig. 9: Equivalent stress of structural steel

TABLE V: VALUES OF STRESSES IN STEEL

Time [s]	Min. [MPa]	Max. [MPa]
1	8.2163e-004	288.37

IV. CONCLUSION

This overview research report studies the possibilities of weight reduction in forged steel connecting rod. For weight reduction process, static strength was considered as a structural factor. First, the connecting rod was 3D modelled. After that load analysis was performed using ANSYS software. From the results of the study, following conclusions can be made.

It was observed that connecting rod is designed at its maximum engine speed and maximum gas pressure. As per the results received from the finite element analysis, There is a large margin of material removal from big end area, small end area and area connecting to the small end of the connecting rod. As per the results received from the analytical calculations, there may be a scope of reduction in it's I-section thickness. It was observed that the new connecting rod geometry is lighter than the original connecting rod. It was also observed that the Titanium material has higher mechanical properties and better machinability and lower ductility and mainly has less weight compared to the steel

REFERENCES

[1] Suraj pal, Sunil Kumar "Design Evaluation and Optimization of Connecting Rod Parameters Using FEM" International Journal of Engineering and Management Research, Vol.-2, Issue-6, December 2012.

[2] G. Naga Malleswara rao "Design Optimization and Analysis of a Connecting Rod using ANSYS" International Journal of Science and Research (IJSR),july-2013

[3] K.Sudarshan kumar, K.tirupathi reddy, Syed Altaf Hussain, "Modelling and analysis of two-wheeler connecting rod" International journal of modern engineering research, October-2012.

[4] Julee Sahu, Jitendra Jayanth, "Design and analysis of Connecting rod with Aluminium Alloys Replacing cast iron and steel for Internal combustion engines with the help of ANSYS", International journal of multi-disciplinary research centre December-2015.

[5] James. R. Dale "Connecting rod evaluation" Metal Powder Industries Federation, Jan-2005.

[6] T.G.Thomas ,S.Srikari,M.L.J.Suman "Design of Connecting Rod for Heavy Duty Applications Produced by Different Processes for Enhanced Fatigue Life", SASTECH Journal Volume 10, Issue 1, May 2011.

[7] Vivek C Pathade, Bhumeshwar Patle. "Stress Analysis of IC Engine Connecting Rod by FEM", International Journal of Engineering and Innovative Technology (IJEIT) Volume 1, Issue 3, March 2012.

[8] Ramanpreet Singh, "Stress analysis of orthotropic and isotropic connecting rod using finite element method, International Journal of Mechanical Engineering & Robotics Research, Vol. 2, No. 2, April 2011.

[9] N.P.Doshi, N.K.Ingole "Analysis of Connecting Rod Using Analytical and Finite Element Method", International Journal of Modern Engineering Research (IJMER), pp-65-68, Vol.3, Issue.1, Jan-Feb. 2013.

[10] Om Parkash, Vikas gupta, Vinod mittal " Optimizing the Design of Connecting Rod under Static and Fatigue Loading", International Journal of Research in Management, Science & Technology, Vol. 1; No. 1, June 2013.

[11] F.S. Silva, "Analysis of a vehicle crankshaft failure" Engineering Failure Analysis, Vol.10, pp. 605–616, 2003.

[12] F.S. Silva, "Fatigue on engine pistons – A compendium of case studies" Engineering Failure Analysis, Vol.13, pp.480–492, 2006.

[13] Mirehei e, M hedayati Zadeh,A.jafari,M.omid "Fatigue analysis of connecting rod of universal tractor through finite element method (ANSYS)" , Journal of Agricultural Technology 2008

[14] Gudimetal P and Gopinadh C.V "Finite Element Analysis of Reverse Engineered Internal Combustion Engine Piston", AIJSTPME, 2009.

[15] Sanjay B Chikalthankar, Vilas Madhaorao "FEA Analysis of Geometric Parameters of connecting rod big end", International Journal of Engineering Science and Technology, Vol.04, No.04, April 2012.

[16] Arthur Francisco, Thomas Lavie, Aurelian Fatu and Bernard Villechaise, J. Tribol "Metamodel-assisted optimization of connecting rod big-end bearings"135(4), 041704, Jun 24, 2013.

[17] Bhuptani K. M "Structural analysis of bush bearing for small end connecting rod using promechanica", International journal of information, knowledge and research in mechanical engineering, volume – 02. 2344-02.

[18] S. Shaari, M.M. Rahman, M.M. Noor, K. Kadirgama and A.K. Amirruddin "Design of connecting rod of internal combustion engine: atopology optimization approach" National Conference in Mechanical Engineering Research and Postgraduate Studies, December 2010, pp.155-166.

[19] International Journal of Engineering Trends and Technology (IJETT) – Volume 4 Issue 9- Sep 2013 " Comparision Of Materials For Two-Wheeler Connecting Rod Using Ansys" B. Anusha#1, Dr.C.Vijaya Bhaskar Reddy

[20] P. Brabec, P.kefurt,C.Scholz,R.Vozenilek "FEM analysis of connecting rod for stationary engine" XIIIth International Scientific Meeting Motor Vehicles & Engines, Kragujevac 2004. Serbia ISSN 0352 292X