Design Analysis and Optimization of Various Parameters of Connecting Rod using CAE Softwares

DR.B.K.Roy
Director-Principal
OM Institute of Technology and Management, Hisar, Haryana.

Abstract - 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.

As the purpose of the connecting rod is to transfer the reciprocating motion of the piston into rotary motion of the crankshaft. 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 (Gupta, 1993). Various designs of connecting rod have been analysed in this report and finally an optimal design has been selected for Finite Element Analysis. Using ANSYS-12.0 Workbench and CATIA V5R19, Various results are found out and compared with the existing results. It has been found out that the study presented here has came up with better results as well as safe design of connecting rod under permissible limits of various parameters and safe stresses.

KEY WORDS: Connecting rod, rotating crankshaft, optimum design

I. 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.
As the purpose of the connecting rod is to transfer the reciprocating motion of the piston into rotary motion of the crankshaft. The main parts of the connecting rod are shown in the figure- 1. This type of connecting rod is most widely used in multi cylinder engine.

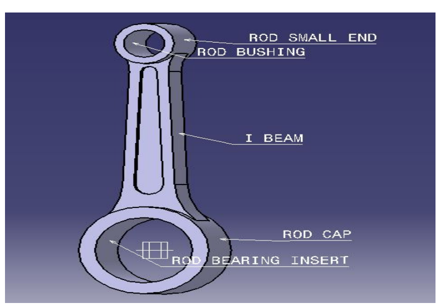


Fig.1- Different parts of a Connecting Rod

The working model of connecting rod is shown in fig -2, small end of connecting rod is in contact with the piston with the help of gudgeon pin. And the larger end is in contact with the crankshaft.

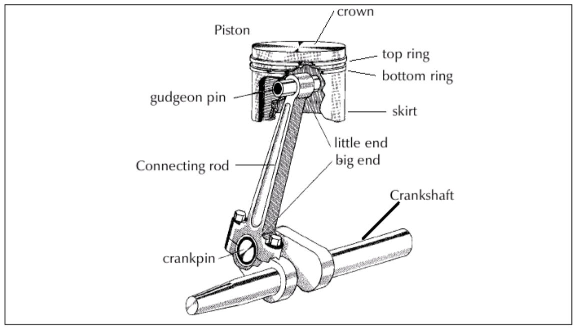


Fig.2 - Connecting rod with piston and crankshaft assembly

II. TYPES OF CONNECTING ROD

There are many types of connecting rod with different I section and H section. But there are basically two types of connecting rod.

1.Connecting rod with nut and bolt- The connecting rod with cap at the larger end is joined by means of bolt and nut as shown in fig.3. This type of connecting rod is most widely used in multi cylinder engines. For example trucks, tractor etc.

Fig.3 - Connecting rod with nut and bolt

2 Connecting rod without nut and bolt – This type of connecting rod consist of single parts itself. And mostly used in single cylinder engine. For example bikes, scooter etc. This is shown in fig.4.

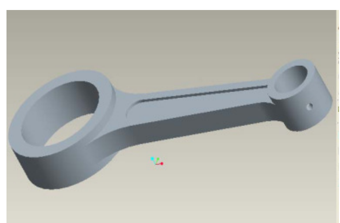


Fig.4 - Connecting rod without nut and bolt

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 (Gupta, 1993).

Between the forging processes, powder forged or drop forged, each process has its own pros and cons. However, the cost of the blank is high due to the high material cost and sophisticated manufacturing techniques (Repgen, 1998). With steel forging, the material is inexpensive and the rough part manufacturing process is cost effective. Bringing the part to final dimensions under tight tolerance results in high expenditure for machining, as the blank usually contains more excess material (Repgen, 1998). A sizeable portion of the US market for connecting rods is currently consumed by the powder metal forging industry. A comparison of the European and North American connecting rod markets indicates that according to an unpublished market analysis for the year 2000 (Ludenbach, 2002), 78% of the connecting rods in Europe (total annual production: 80 million approximately) are steel forged as opposed to 43% in North America (total annual production: 100 million approximately. In order to recapture the US market, the steel industry has focused on development of production technology and new steels. AISI (American Iron and Steel Institute) funded a research program that had two aspects to address. The first aspect was to

investigate and compare fatigue strength of steel forged connecting rods with that of the powder forged connecting rods. The second aspect was to optimize the weight and manufacturing cost of the steel forged connecting rod.
Due to its large volume production, it is only logical that optimization of the connecting rod for its weight or volume will result in large-scale savings. It can also achieve the objective of reducing the weight of the engine component, thus reducing inertia loads, reducing engine weight and improving engine performance and fuel economy.

III. THE DESIGN PROCESS

The basic five-step process usually used in a problem-solving works for design problems as well. Since design problems are usually defined more vaguely and have a multitude of correct answers, the process may require backtracking and iteration. Solving a design problem is a contingent process and the solution is subject to unforeseen complications and changes as it develops. Until the Wright brothers actually built and tested their early gliders, they did not know the problems and difficulties they would face controlling a powered plane.
The five steps used for solving design problems are:

1. Define the problem
2. Gather pertinent information
3. Generate multiple solutions
4. Analyze and select a solution
5. Test and implement the solution

The first step in the design process is the problem definition. This definition usually contains a listing of the product or customer requirements and specially information about product functions and features among other things. In the next step, relevant information for the design of the product and its functional specifications is obtained. A survey regarding the availability of similar products in the market should be performed at this stage. Once the details of the design are clearly identified, the design team with inputs from test, manufacturing, and marketing teams generates multiple alternatives to achieve the goals and the requirements of the design. Considering cost, safety, and other criteria for selection, the more promising alternatives are selected for further analysis. Detail design and analysis step enables a complete study of the solutions and result in identification of the final design that best fits the product requirements. Following this step, a prototype of the design is constructed and functional tests are performed to verify and possibly modify the design.

When solving a design problem, you may find at any point in the process that you need to go back to a previous step. The solution you chose may prove unworkable for any number of reasons and may require redefining the problem, collecting more information, or generating different solutions. This continuous iterative process is represented in the following Figure.

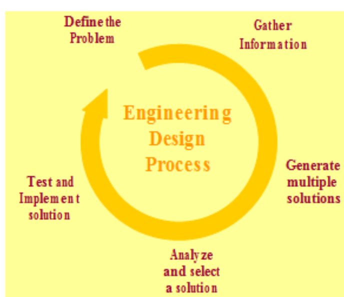


Fig. 5 - Design Process

The objective of the connecting rod is to connect the piston to the crank or crankshaft together with the crank; they form a simple mechanism that converts linear motion into rotating motion. The work described here carried out the design optimization of connecting rods using the ANSYS software. Due to market competitiveness it is important for clients to be able to produce an optimized preliminary design (with minimum weight in as short a time as possible). The optimization procedure was performed in two phases. Phase 1, was used to optimize the small end and shank of the rod while Phase 2, was used for the big end. Typical design variables for Phase 1 were the width, depth and taper ratios of the shank, and the wall thickness of the small end. Typical design variables for Phase 2 were the radius of the big end , and the objective function was to give the optimum design parameter . A

number of random designs would be generated by varying the values of the design variables within the specified limits before the Optimizer 'homed' in to the best design.
As connecting rod is subjected to stresses caused by

- combined effect of gas pressure on the piston and the inertia of the reciprocating parts,
- friction of the piston rings and of the piston force and
- Inertia of the connecting rod.

Which leads to stresses and deformation in connecting rod so a structural analysis of connecting rod has been carried out. The main objective of work is to suggest the optimum design parameter for the connecting rod. The strain and stress contours have been plotted and patterns are studied. The results are compared and verified with available existing results. The optimization of connecting rod also achieve reducing the weight of the engine component, thus reducing inertia load, reducing engine weight and improving the engine performance and fuel economy. The main design parameter of the connecting rod is shown in the figure-6

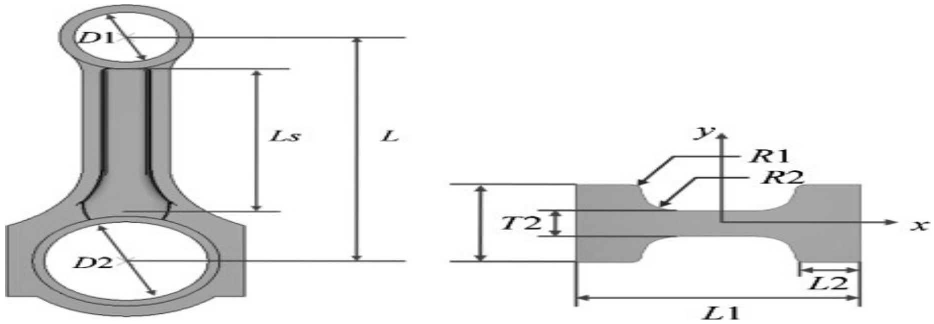


fig-6 design parameter of the connecting rod

IV. LITERATURE REVIEW

There is a vast amount of literature related to Finite Element Analysis. Many research publications, journals, reference manuals, newspaper articles, handbooks; books are available of national and international editions dealing with basic concepts of FEA. Many other publications indicate the success story of implementation of FEA on various components. The literature review presented here considers the major development in implementation of FEA.

Pravardhan S. Shenoy, the University of Toledo [14] carried out the dynamic load analysis and optimization of connecting rod. The main objective of this study was to explore weight and cost reduction opportunities for a production forged steel connecting rod. This has entailed performing a detailed load analysis. James R. Dale (2005) [4] presented a paper which gave the idea of Connecting Rod Evaluation in which he summarized up with Most forging grade alloy powders use nickel and molybdenum and small amounts of manganese to enhance iron hardenability without developing stable oxide formation. A. Mirehei, M. Hedayati Zadeh, A. Jafari, M. Omid (2008) [10] carried out the fatigue analysis of connecting rod .The connecting rod fatigue of universal tractor (U650) was investigated through the ANSYS software application and its lifespan were estimated. The reason for performing this research showed the connecting rod behaviour affected by fatigue phenomenon due to the cyclic loadings and to consider the results for more savings in time and costs, as two very significant parameters relevant to manufacturing. The results indicate that with fully reverse loading, one can estimate longevity of a connecting rod and also find the critical points that more possibly the crack growth initiate from. Xianjun Hou, Cuicui Tian,Dan Fang, et.al (2009) [7] carried out the Sensitivity Analysis and Optimization for Connecting rod of LJ276M Electronic Gasoline Engine. Sensitivity analysis and optimization based on the combination of Pro/MECHANICAL and ANSYS are applied to designing of the connecting rod of LJ276M electronic gasoline engine. The maximum stress of connecting rod on the largest compression condition is reduced by 4.9% after the optimization is applied, static intension safety coefficient is increased by 5.4% and mass of connecting rod is also reduced.

V. CAE TOOLS AND SOFTWARE

Computer-Aided Technologies is a broad term that means the use of computer technology to aid in the design, analysis, and manufacture of products.

Advanced CA tools merge many different aspects of the product lifecycle management (PLM), including design, finite element analysis (FEA), manufacturing, production planning, product testing with virtual lab models and visualization, product documentation, product support, etc. CA encompasses a broad range of tools, both those commercially available and those proprietary to individual engineering firms.

Computer- Aided Design (CAD), also known as Computer Aided Design and Drafting (CADD), is the use of computer systems to assist in the creation, modification, analysis, or optimization of a design. Computer Aided Drafting describes the process of creating a technical drawing with the use of computer software. CADD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. CADD output is often in the form of electronic files for print or machining operations. CADD software uses either vector based graphics to depict the objects of traditional drafting, or may also produce raster graphics showing the overall appearance of designed objects.

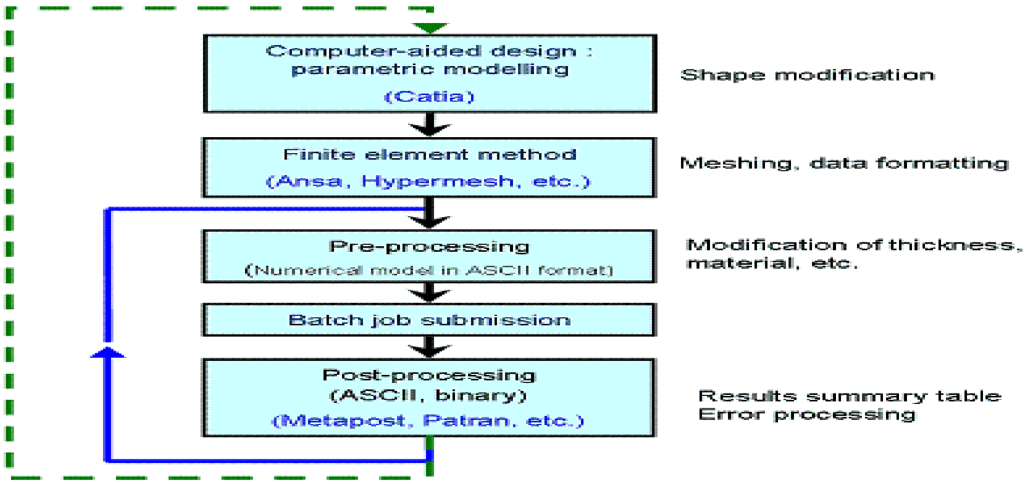
Computer-Aided Engineering (CAE) is the broad usage of computer software to aid in engineering tasks. It includes computer aided design (CAD), computer aided analysis (CAA), computer integrated manufacturing (CIM), computer aided manufacturing (CAM), material requirements planning (MRP) and computer-aided planning (CAP). CAE embraces the application of computers from preliminary design (CAD) through production (CAM). Computer Aided Design, which is usually associated with computerized drafting applications, also includes such diverse application programs such as those for calculating the dimensional stack-ups due to tolerances, ergonomic studies with virtual people and design optimization. Computer Aided Analysis includes finite element and finite difference method for solving the partial differential equations governing solid mechanics, fluid mechanics and heat transfer, but it also includes diverse program for specialized analyses such as rigid body dynamics and control system modeling.

Computer aided manufacturing (CAM) includes programs for generating the instructions for computer numerically controlled (CNC) machining to production and process scheduling and inventory control. Recently, manufactures have been asked to design their products for eventual recycling, and this aspect of engineering will undoubtedly fall under the umbrella of CAE, but as of yet it doesn't have its own acronym. CAE tools are being used, for example, to analyze the robustness and performance of components and assemblies. The term encompasses simulation, validation, and optimization of products and manufacturing tools. In the future, CAE systems will be major providers of information to help support design teams in decision making.

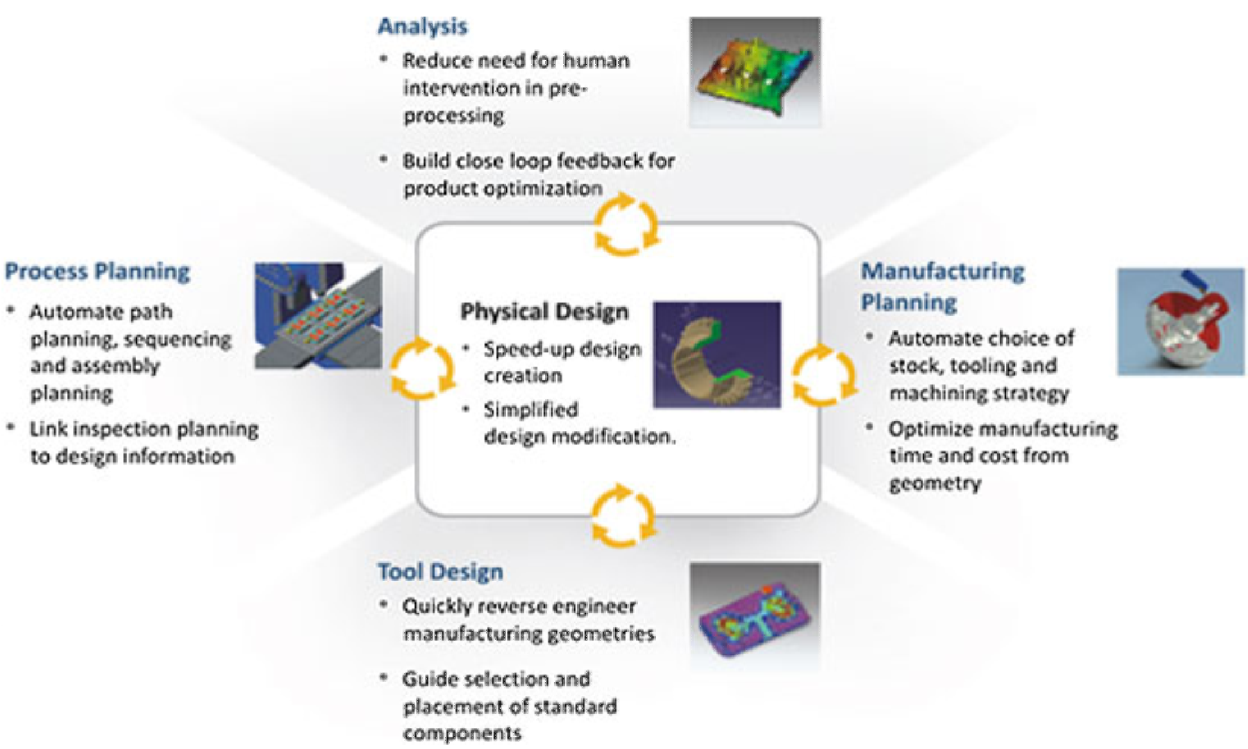
CAE areas covered include:

1. Stress analysis on components and assemblies using FEA (Finite Element Analysis);
2. Thermal and fluid flow analysis Computational fluid dynamics (CFD);
3. Kinematics;
4. Mechanical event simulation (MES).
5. Analysis tools for process simulation for operations such as casting, molding, and die press forming.
6. Optimization of the product or process.

VI. PHASES IN ANY COMPUTER AIDED ENGINEERING :



VII. APPLICATION AREAS OF CAD/CAM/CAE



VIII. FINITE ELEMENT ANALYSIS

FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. A company is able to verify a proposed design will be able to perform to the client's specifications prior to manufacturing or construction. Modifying an existing product or structure is utilized to qualify the product or structure for a new service condition. In case of structural failure, FEA may be used to help determine the design modifications to meet the new condition.

There are generally two types of analysis that are used in industry: 2-D modeling, and 3-D modeling. While 2-D modeling conserves simplicity and allows the analysis to be run on a relatively normal computer, it tends to yield less accurate results. 3-D modeling, however, produces more accurate results while sacrificing the ability to run on all but the fastest computers effectively. Within each of these modeling schemes, the programmer can insert numerous algorithms (functions) which may make the system behave linearly or non-linearly. Linear systems are far less complex and generally do not take into account plastic deformation. Non-linear systems do account for plastic deformation, and many also are capable of testing a material all the way to fracture.

Engineering analysis of mechanical systems have been addressed by deriving differential equations relating the variables of through basic physical principles such as equilibrium, conservation of energy, conservation of mass, the laws of thermodynamics, Maxwell's equations and Newton's laws of motion. However, once formulated, solving the resulting mathematical models is often impossible, especially when the resulting models are nonlinear partial differential equations. Only very simple problems of regular geometry such as a rectangular of a circle with the simplest boundary conditions were tractable.

The finite element method (FEM) is the dominant discretization technique in structural mechanics. The basic concept in the physical interpretation of the FEM is the subdivision of the mathematical model into disjoint (non-overlapping) components of simple geometry called finite elements or elements for short. The response of each element is expressed in terms of a finite number of degrees of freedom characterized as the value of an unknown function, or functions, at a set of nodal points.

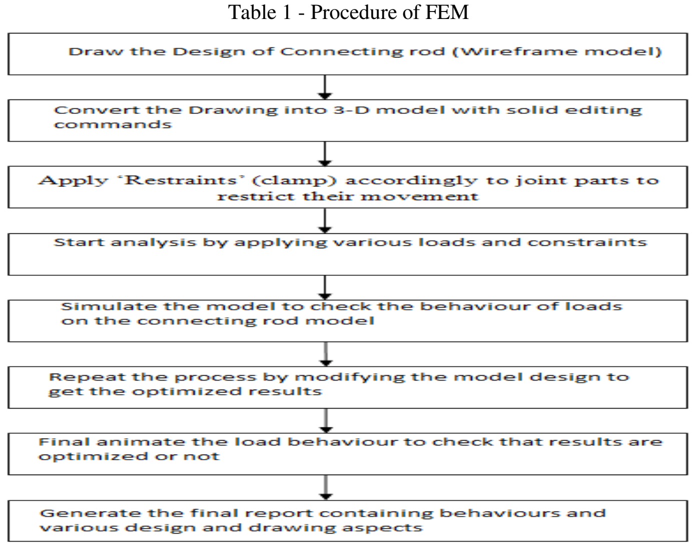
The response of the mathematical model is then considered to be approximated by that of the discrete model obtained by connecting or assembling the collection of all elements.

The disconnection-assembly concept occurs naturally when examining many artificial and natural systems. For example, it is easy to visualize an engine, bridge, building, airplane, or skeleton as fabricated from simpler components. Unlike finite difference models, finite elements do not overlap in space.

A typical finite element analysis on a software system requires the following information:
1. Nodal point spatial locations (geometry)
2. Elements connecting the nodal points
3. Mass properties
4. Boundary conditions or restraints
5. Loading or forcing function details
6. Analysis options

IX. FEM PROCEDURE

Table 1 - Procedure of FEM



X. ANALYSIS AND INTERPRETATION

This paper includes the selection of optimal design of connecting rod which is considered to give better results as compared with the previous results maintaining various parameters which make sure that the optimal design and better results are result of findings and analysis of connecting rod by making various modified designs. Then the Finite Element Analysis method is applied on this design to get the optimized results with the help of various Computer Aided Engineering tools and softwares.

XI. COMPARISON OF EXISTING DESIGN AND SUGGESTED DESIGN

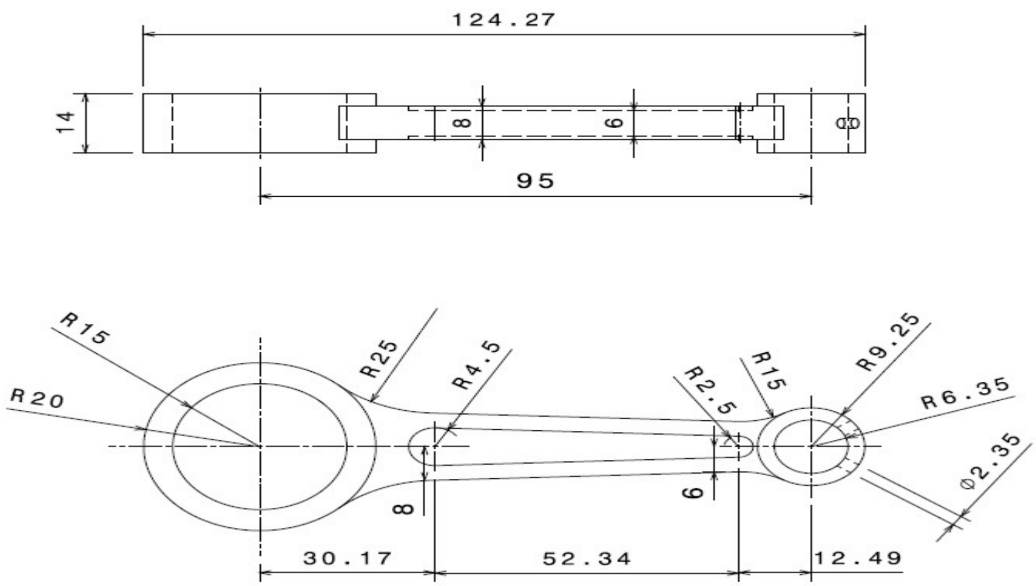


Fig 7.1– Existing Design

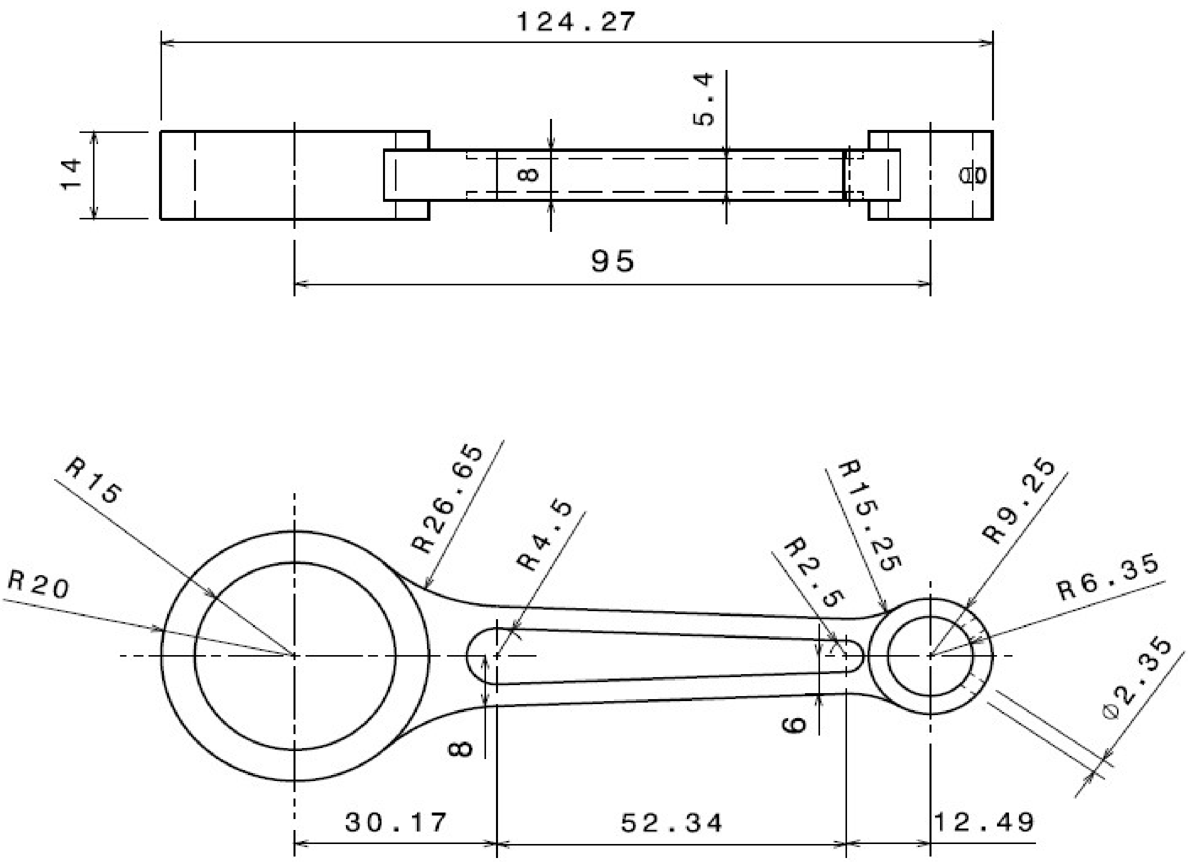


Fig.7.2 – New Suggested Design

CAD Model of connecting rod is made in CATIA V5R19. CAD model used for analysis is shown in fig 8.

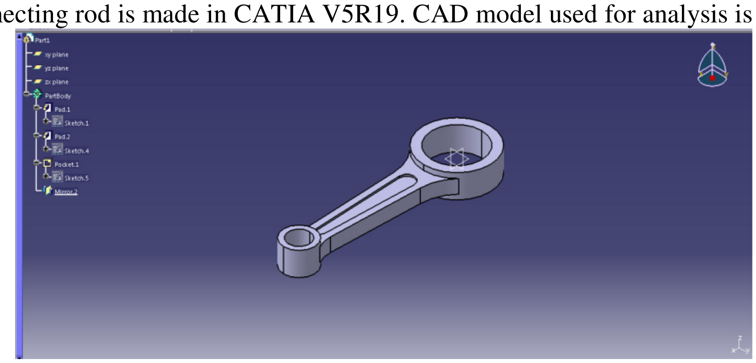


Fig 8 – Model of Connecting Rod in CATIA

Properties and Details of MATERIAL used for Connecting Rod

Table 2- Details of Material Generated in ANSYS

Structural Steel > Constants

Density	7850 kg m^-3
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	434 J kg^-1 C^-1
Thermal Conductivity	60.5 W m^-1 C^-1
Resistivity	1.7e-007 ohm m

Structural Steel > Compressive Yield Strength

Compressive Yield Strength Pa
2.5e+008

Structural Steel > Tensile Yield Strength

Tensile Yield Strength Pa
2.5e+008

Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
4.6e+008

Structural Steel > Isotropic Elasticity

Young's Modulus Pa	Poisson's Ratio
2.e+011	0.3

Snapshots of report generated in ANSYS

Table 3-Properties of Materials

Material selected-	Stainless steel
Young's Modulus, E	$2.0*10^5$ MPa
Poisson's Ratio	0.30
Tensile Ultimate strength	460MPa
Tensile Yield strength	250 MPa
Compressive yield strength	250MPa
Volume	17456 mm^3
Mass	0.13703 kg
Normal Static loading	4319 N
Density	7850kg/m3

After selecting Material, Next step in methodology is Mesh Generation. Meshed Generated model of connecting rod is shown in fig.

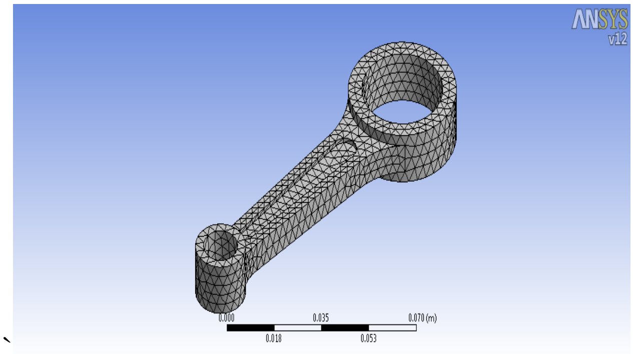


Fig 9 - Meshed model of connecting rod

Constraints and Loading

After preparing the model ready for analysis, various constraints, supports and loads are applied, keeping in mind various boundary conditions. A Fixed Support is applied at crank end and a static load of 4319N is applied.

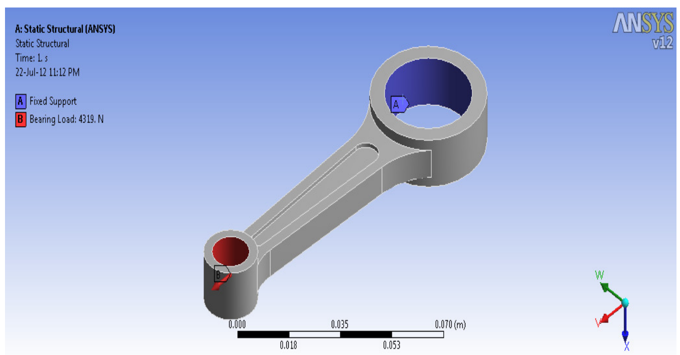


Fig.10- Loading and Fixed Support

In between loading and applying fixed support on connecting rod, various parameters like sizing, shaping, view angles, transition and smoothing of design is studied and analysed to get optimized results in which proper care is needed as any error can cause variation of results in pre-processing phase of Finite Element Method.

XII. COMPARISON OF PRESENT FEA RESULTS WITH EXISTING RESULTS FOR STATIC ANALYSIS

Table 4: Comparative Static Analysis

		For Load 4319N			For Load 21598N		
.No.	Paramters	Ex isting Results	Ne w Results	Va riation	E xisting Results	N ew Results	Var iation
.	Equivalent (Von-Mises) Stress	76. 22MPa	68. 87MPa	9.6 4%	3 81.17 MPa	3 44.44 MPa	9.6 3%
.	Equivalent (Von-Mises)Elastic Strain	3.8 e-4 mm/mm	3.4 e-4 mm/mm	10. 52%	1 .91e-3 mm/mm	1. 72e-3 mm/mm	9.9 4%
.	Total Deformation	-	0.0 261mm	-	-	0. 130mm	-

XIII. COMPARISON OF PRESENT FEA RESULTS WITH EXISTING RESULTS FOR FATIGUE ANALYSIS

Table 5 – Comparative Fatigue Analysis

		For Load 4319N				For Load 21598N			
		Existing Results		New Results		Existing Results		New Results	
.No	Param eter	M in.	M ax.	in.	ax	M in.	M ax.	in.	ax.
.	Safety Factor	1 .13	1 5	.36	5	0 .23	1 5	.27	5
.	Biaxia lity Indication	- 1.0	0. 97	0.99	.73	- 1.0	0 .97	0.99	73
.	Life	1 e6	1e 6	e6	e6	3 138.61	1 e6	570.4	e6
.	Equiv alent Alternating Stress	0 .01 MPa	7 6.22 MPa	.121M Pa	3.31MP a	0 .56 MPa	3 81.17 MPa	.60 Mpa	16.6 Mpa

XIV. CONCLUSION

Various designs of connecting rod have been analysed in this report and finally an optimal design has been selected for Finite Element Analysis. Using ANSYS-12.0 Workbench and CATIA V5R19, Various results are found out and compared with the existing results. It has been found out that the study presented here has came up with better results as well as safe design of connecting rod under permissible limits of various parameters and safe stresses.

- Current work has concluded up with the fact that slight and careful variation in design parameters can give a good design which can be made feasible by a number of analysis using CAE tools and Softwares.
- Static and Fatigue, both analysis are important as both showed up different aspects of factors on which care should be taken before finalizing any part design.
- Stress, Strain, Deformation, Life, Damage, Biaxiality Indication etc. have been studied and analysed to get the good design parameters with taking into account the safe permissible stresses and factors which would have affect the design if not taken into account.

REFERENCES

[1] ANSYS WORKBENCH 12 Reference Manual.

[2] CATIA V19 manual.

[3] Charkha Pranav G , Jaju Santosh B (2009)"Analysis & Optimization of Connecting Rod" Department of Mechanical Engineering, Pankaj Laddhad Institute of Technology & Management Studies, Opp Toll Booth, Chikhali Road,Yelgaon, Buldana, Maharashtra, India, Second international conference of emerging trends in engineering and technology.

[4] Dale James R,(2005) "Connecting Rod Evaluation".

[5] Duffy, James E. Modern Automotive Technology. 1994, Goodheart-Wilcox Company.

[6] Gangwani Dilip G., and Metkar R.M.(2009) "Computer Aided Modelling and Finite Element Analysis of Connecting Rod Fouling on Camshaft of DI Engine of Mahindra and Mahindra Tractor" Second International Conference on Emerging Trends in Engineering and Technology, ICETET-09.

[7] Hou Xianjun, Tian Cuicui, Fang Dan, Peng Fuming and Yan Fuwu(2009) "Sensitivity Analysis and Optimization for Connecting Rod of LJ276M Electronic Gasoline Engine", published by IEEE,2009, pp 978.

[8] Jia Dongkai ,Wu Ke, Wu Shi, Jia Yuntong, Liang Chao (2011), " The Structural analysis and Optimization of Diesel Engine Connecting Rod", ICEMEIT.

[9] LIU Yongfeng, TIAN Hongsen, DING Xiaoliang, LIU Lianda, QIU Tao (2010), "Research on 3-D Design for the Group of Piston Crankshaft Connecting Rod" ICMTMA.

[10] Mirehei, A., Zadeh, M.H., Jafari, A. and Omid, M. (2008). “Fatigue analysis of Connecting rod of universal tractor through finite element method (ANSYS)”. journal of Agricultural Technology 4(1): 21-27.
[11] Rasekh M., Asadi M.R. , A. Golmohammadi , A. Jafari, K. Kheiralipour, and A.M. Borghei,(2010). “Optimization of connecting rod of MF-285 tractor” Journal of Agricultural Technology 6(4): 649-662.
[12] Qinghui Zhou, Yunying Wang and Wei Ji (2010), “The Finite Element Analysis of Connecting Rod of Diesel Engine”.
[13] Ramos, J.I. Internal Combusion Engine Modeling. 1989, Hemisphere Publishing.
[14] Shenoy Pravardhan S,(2004) “Dynamic load analysis and optimization of connecting
a. rod”, Master’s thesis, University of Toledo.
[15] Shenoy Pravardhan S, and Fatemi Ali ,(2005), “Connecting Rod Optimization for Weight and Cost Reduction”, SAE International.
[16] Tong Zhiwei, Liu Hao, and Zhu Fengxia (2009)“Modal Analysis for Connecting Rod of Reciprocating Mud Pump”.
[17] V.B. Bhandari, R.S.Aggarwal “ Books of machine design”.
[18] ZhanGuo Wei, Liu and Ying Yu,(2010), “The Design of Forestry Harvesting Machines Connecting Rod based on Finite Element Analysis” ICMET.