STATIC ANALYSIS OF CONNECTING ROD

Mulukuntla Vidya Sagar1, Kanjarla Shyam Kumar2, Nalla Suresh3 and Ch Radhika4

1,2,3Department of Mechanical Engineering, WITS Engineering College
4Department of Mechanical Engineering, UCE, Kakatiya University

Abstract—Connecting rod is one of the most important part in automotive engine. Connecting rod is the link between piston and crank shaft. Which it converts reciprocating motion of piston into rotary motion of crank shaft. In internal engines connecting rod is mainly made of steel and aluminum alloys (for light weight and absorb high impact loads) or titanium (for higher performance engines and for higher cost) or composite materials, composite materials is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons: common examples include materials which are stronger, lighter, or less expensive when compared to traditional materials. As a connecting rod is rigid, it may transmit either a push or a pull and so the rod may rotate the crank through both halves of a revolution, i.e. Piston pushing and piston pulling. Earlier mechanisms, such as chains, could only pull. In a few two-stroke engines, the connecting rod is only required to push. In which it undergoes structural deformations. Thus in this project we are modeling a connecting rod in CATIA V5 design software and doing static structural analysis in ansys work bench 14.5 software by using advance materials. Thus the part which is modeled is converted into IGES file to import in ansys work bench and static structural analysis is carried out at 16MPa of pressure load by applying various materials such as Aluminum Alloy, Al6061 + B4C (Aluminum boron carbide) and 42Cr2Mo4 (special alloy steel) materials used in this project. By applying these boundary conditions on connecting rod the unknown variables such as stress, deformation, and strain are found using the FEM Analysis based software (ANSYS14.5).

Keywords— Connecting rod, CATIA V5, Ansys, Aliminium, 42CrMo4, Al6061 + B4C, IGES.

I. INTRODUCTION

In a reciprocating position engine to the connecting rod or conrod connects the piston to the crank or crankshaft, alongside the crank they form a simple mechanism converts reciprocating motion into rotating motion.

Connecting rod might also converts rotating motion into reciprocator motion. Traditionally to development of engines they were first using this manner.

II. PROJECT BACKGROUND

As a connecting rod is rigid, might transmit either push or pull and then the rod might rotate each halves of a revolution i.e. Piston pushing and piston pulling. Earlier mechanisms used like chains, may solely pull in a very few two-stroke engines, the connecting rod is barely needed to push. Now days, connecting rods are best well-known through their use in a internal combustion piston engines like automotive engines. These are clearly different forms earlier types of the connecting rods utilized in stream engines and steam locomotives.
Importance of Con Rod in Engine

The connecting rod is that the main part of the engine, additionally backbone of the engine. There is most significant of the connecting rod in an engine.

Connecting rod rotates the crank shaft that helps the engine to maneuver on or any of the vehicles to rotate its wheels. It is designed to resist stresses from combustion and piston movement.

Connecting rods is toward lighter weight components. 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.

HISTORY

The earliest proof of a connecting rod seems within the late third century ad roman hierapolis sawmills. It additionally seems in two 6th century eastern roman saw mills excavated at ephesus respectively gerasa.
The crank and connecting rod mechanism of those Roman watermills regenerate the rotary motion of the waterwheel into the linear movement of the saw blades. Someday between 1174 and 1206, the Arab inventor and engineer al-Jazari described the machine that incorporated the connecting rod with a crankshaft to pump water as a part of a water-raising machine, however the device was unnecessarily complicated indicating that he still failed to fully understand the concept of power conversion. Compound crank and connecting-rod is found within the sketch books of Taccola. A sound understanding of the motion concerned displays the painter Pisanello (d. 1455) world health organization showed a piston-pump driven by a water-wheel and operated by two simple cranks and two connecting-rods. By the sixteenth century, evidence of cranks and connecting rods within the technological treatises and design of Renaissance Europe becomes abundant; Agostinoramelli’s the various and artifactitious machines of 1588 alone depicts eighteen examples, a number that rises within theatrum machinarum novum by Georg Andreas Bockler to 45 different machines.

III. LITERATURE REVIEW

The connecting rod is subjected to a complex state of loading; it undergoes high cyclic loads and the order of 10^8 - 10^9 cycles range from high compressive loads due to combustion and high tensile loads due to inertia. Therefore, durability of this component is of critical importance. Due to above factors the connecting rod has been the topic of research for different aspects such as production technology, materials, performance simulation, fatigue, etc. For the current study it was necessary to investigate finite element modeling techniques, optimization techniques, developments in production technology, new materials, fatigue modeling, and manufacturing cost analysis. This brief literature survey reviews some of these aspects.

Webster et al. (1983) performed three dimensional finite element analysis of a high-speed diesel engine connecting rod. In this analysis there used the maximum compressive load how much was measured experimentally, and the maximum tensile load which is essentially in the inertia load of the piston assembly mass and the load distributions on the piston pin end and crank end were determined experimentally. They modeled the connecting rod cap separately, and also modeled the bolt pretension using beam elements and multi point constraint equations.

Repgen (1998), based on fatigue tests carried out on identical components made of powder metal and c-70 steel (fracture splitting steel), in this paper he writes the fatigue strength of the forged steel part is 21% higher than the powder metal component and using the fracture splitting technology results in a 25% cost reduction over the conventional steel forging process. These main factors suggest that a fracture splitting material would be the material of choice for steel forged connecting rods and also mentions two other steels are tested, a modified micro-alloyed steel and a modified carbon steel. Other
issues discussed by repgen are the necessity to avoid jig spots along the parting line of the rod and the cap, need of 4 consistencies in the chemical composition and manufacturing process to reduce variance in microstructure and production of near net shape rough part.

Park et al. (2003) investigated microstructural behavior at various forging conditions and recommend fast cooling for finer grain size and lower network ferrite content. From their research they concluded that laser notching exhibited best fracture splitting results, when compared with broached and wire cut notches. They optimized the fracture splitting parameters as, applied hydraulic pressure, jig set up and geometry of cracking cylinder based on delay time. They compared fracture splitting high carbon micro-alloyed steel (0.7% c) with carbon steel (0.48% c) using rotary bending fatigue test and concluded that the former has the same or better fatigue strength than the later and comparison of these fracture splitting high carbon micro-alloyed steel and powder metal and based on tension-compression 18% higher than the later fatigue.

Sarihan and song (1990), for the optimization of the wrist pin end, used a fatigue load cycle consisting of compressive gas load corresponding to maximum torque and tensile load corresponding to maximum inertia load they used the maximum loads in the whole operating range of the engine after a design for fatigue, modified Goodman’s equation with alternating octahedral shear stress and mean octahedral shear stress was used, optimization they generated an approximate design surface, and performed optimization of this design surface and the objective and constraint functions were updated to obtain precise values in this process was repeated till convergence was achieved also included constraints to avoid fretting fatigue. The mean and the alternating components of the stress were calculated using maximum and minimum 5 values of octahedral shear stress. In this exercise reduced the connecting rod weight by nearly 27%.

Hippoliti (1993) reported design methodology in use at piaggio for connecting rod design, which incorporates an optimization session moreover neither the details of optimization nor the load under which optimization was performed were discussed. Two parametric fe using 2d plane stress and 3d approach developed by the author were compared with experimental results and have good agreements and optimization procedure they developed was based on the 2d approach.

In a published sae case study (1997), a replacement connecting rod with 14% weight savings was designed by removing material from areas that showed high factor of safety. Factor of safety with respect to fatigue strength was obtained by performing fea with applied loads including bolt tightening load, piston pin interference load, compressive gas load and tensile inertia load. The study lays down certain guidelines regarding the use of the fatigue limit of the material and its reduction by a certain factor to account for the as-forged surface. They also indicate that buckling and bending stiffness are important design factors that must be taken into account during the design process. On the basis of the stress and strain measurements performed on the connecting rod, close agreement was found with loads predicted by inertia theory. The study also concludes that stresses due to bending loads are substantial and should always be taken into account during any design exercise.

IV. PROBLEM STATEMENT

Problem statement:

Connecting rod is one of the most critical components internal combustion. Connecting rod is connected in between the piston and crank shaft. While the crank shaft rotates piston moves from bottom dead Centre to top dead Centre vice versa. In this process connecting rod undergoes stress and deformation. Hence for the connecting rod when the load is applied, how the stresses and strain are induced in the component and deformation value, due to applied load are analyzed.

Decreasing these stresses and increasing stability depends upon the materials applied. Thus in industrial purpose optimization of connecting rod had already started. Optimization is really important
for automotive industry especially. Optimization of the component is to make the less time to produce the product that is stronger, lighter and less total cost productions. The design and weight of the connecting rod influence on car performance. Hence, it effects on the car manufacture credibility. Change in the design and material results a significant increment in weight and also performance of the engine. The structural factors considered for weight reduction during the optimization include the buckling load factor, stresses under the loads, bending stiffness, and axial stiffness. Thus, the component can give the higher strength, efficient design and lighter that would create a major success in the automotive and manufacturing industry. Among the main objectives is to improve the engine performance and also to strengthen the product that ensure the safety of human being.

Connecting rod failed due to insufficient strength to hold the load. Increasing the strength, automatically it will longer the life cycles of the connecting rod. In this study, the design of the connecting rod will be modeled and at the same time increase the strength. And different materials composites are applied for gaining more stability and decrease weight. The study will be focus on the finite element method and analysis. From the analysis results, the decision whether connecting rod needs to change in material, load, design etc factors which induces stress in the component.

V. OBJECTIVES OF PROJECT

The objectives of the project are as follows
(i) To develop structural modeling of connecting rod
(ii) To perform finite element analysis of connecting rod

Scope of the project:
The structural modeling of the connecting rod needs to be developed by using CATIA V5 design software. Then structural analysis is carried out in Ansys and suitable materials such as general and composite materials are applied and began the meshing on the connecting rod. The finite element modeling (fem) processes were performed. One end is fixed and loading is selected and placed at the other end of connecting rod. The finite element analysis (FEA) then carried out on the connecting rod by dividing the larger solutions into smaller solutions in the form of partial differential equations. Thus, producing the result of stress, strain and displacement where it will be used to analyze the critical area of the connecting rod. Finally the optimization will take place according to stress and deformation developed in the connecting rod.

THEORITICAL CALCULATIONS

Pressure calculation:
Consider a 220cc engine,
Engine type air cooled 4-stroke
Bore × Stroke (mm) = 67×62.4
Displacement=220 cm³
Maximum Power = 20.8 Bhp at 8500rpm
Maximum torque= 19.12 Nm at 7000rpm

Mechanical efficiency of the engine (η) = 80 %.

\[
\eta = \frac{\text{Brake Power (B.P)}}{\text{Indicated Power (I.P.)}}
\]
B.P. = \frac{2\pi NT}{60} = \frac{2\pi \times 19.12 \times 7000}{60} = 14.015 \text{ kW}

I.P. = \frac{8P}{\eta} = \frac{14.015}{0.8} = 17.518 \text{ kW}

I.P. = P \times A \times L \times \frac{N}{2}

I.P. = P \times \frac{\pi}{4} \times D^2 \times L \times \frac{N}{2}

17.518 \times 1000 = P \times \frac{\pi}{4} \times (0.067)^2 \times (0.0624) \times \frac{7000}{2 \times 60}

So, P = 13.65 \times 10^5 \text{ N/m}^2 \text{ or } P = 1.365 \text{ MPa}

Maximum Pressure, P_{max} = 10 \times P

= 10 \times 1.365

= 13.65 \text{ MPa}

So approx 16 \text{ MPa} is taken as pressure applied on connecting rod

Design Calculation of connecting rod

From standards,

\begin{itemize}
  \item Thickness of flange and web of the section = t
  \item Width of the section B = 4t
  \item Height of the section H = 5t
  \item Area of the section A = 11t^2
  \item Moment of inertia about x axis I_{xx} = 34.91t^4
  \item Moment of inertia about y axis I_{yy} = 10.91t^4
  \item Therefore I_{xx}/I_{yy} = 3.2
\end{itemize}

So, in the case of this section (assumed section)

Proportions shown above will be satisfactory.

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

L = 124.8 \text{ mm}

Fc = (\pi d^2/4) \times \text{ gas pressure}

Fc = 48125.154 \text{ N}

WB = FC \times F. S. = 48125.154 \times 1.78 = 85662.77 \text{ N}
We know that radius of gyration of the section about X-axis,

\[ K_{xx} = \sqrt{\frac{l_{xx}}{A}} = \sqrt{\frac{34.91t^4}{11t^2}} = 1.78 \ t \]

Radius of crank,

\[ r = \frac{\text{stroke length}}{2} = \frac{62.4}{2} = 31.2 \ mm \]

Length of Connecting Rod = 2\times\text{stroke} = 2\times62.4 =124.8 \ mm

Equivalent length of the connecting rod for both Ends hinged, \( L = l = 124.8 \ mm \)

For generally used aluminium alloy material

Now according to Rankine’s formula, we know that Buckling load (WB),

\[ 85662.77 = 7.35 \ mm \ (\alpha = 0.002) \]

Thus, the dimensions of I-section of the Connecting rods are:

\[ \frac{170\times11t^2}{1+\alpha\left(\frac{L}{K_{xx}}\right)} \]

Thickness of flange and web of the section

\[ t = 7.35 \ mm \]

Width of the section, \( B = 4 \ t = 4 \times 7.35 = 29.4 \ mm \)

Height of the section, \( H = 5 \ t = 5 \times 7.35 = 36.75 \ mm \)

Depth near the big end,

\( H_1 = 1.2H = 1.2 \times 36.75 = 44 \ mm \)

Depth near the small end,

\( H_2 = 0.85H = 0.85 \times 36.75 = 31.23 \ mm \)

For Aluminium 6061 SIC-15% composite material

Now according to Rankine’s formula, we know that Buckling load (WB),

\[ 85662.77 = \]

\[ \frac{363\times11t^2}{1+\alpha\left(\frac{L}{K_{xx}}\right)} = 5.254 \ mm \]

Width of the section, \( B = 4 \ t = 4 \times 5.254 = 21.01 \ mm \)

Height of the section, \( H = 5 \ t = 5 \times 5.254 = 26.27 \ mm \)

Depth near the big end,

\( H_1 = 1.2H = 1.2 \times 26.27 = 31.52 \ mm \)

Depth near the small end,

\( H_2 = 0.85H = 0.85 \times 26.27 = 22.32 \ mm \)
VI. DESIGNING OF A CONNECTING ROD BY USING CATIA V5

Sketch of a connecting rod

ANALYSIS IN ANSYS (FEM Model)

Analyses on connecting rod by using Ansys 14.5 software

Figure 5 structural analysis
VII. MATERIALS AND THEIR PROPERTIES

| Material            | Density (kg/m³) | Young’s modulus (pa) | Poisons ratio | Shear modulus (pa) | Bulk modulus (pa) |
|---------------------|-----------------|----------------------|---------------|--------------------|------------------|
| Aluminum Alloy      | 2.77e-006       | 71000                | 0.33          | 69608              | 26692            |
| 42CrMo4             | 7830            | 2.1E+11               | 0.30          | 8.0769E+10         | 1.75E+11         |
| Al6061+B4C          | 2680            | 1.97E+11              | 0.32          | 7.4621E+10         | 1.8241E+11       |

Boundary Conditions
- Fixed support is at head which is connected to crank shaft.
- Load applied is pressure exerted during piston movement i.e 16mpa has taken

Static Structural Analyses
Material: 42CrMo4 (steel alloy)
Material is applied as 42CrMo4 from engineering data library.

| PROPERTY |      |
|----------|------|
| Volume   | 53399 mm³ |
| Mass     | 0.41811 kg |

Total Deformation | Equivalent Elastic Strain | Equivalent (von-Mises) Stress

7.1 Material: Al6061+B4C (Aluminum alloy boron carbide)
Material is applied as Al6061+B4C from engineering data library.

| PROPERTY |      |
|----------|------|
| Volume   | 53399 mm³ |
| Mass     | 0.14311 kg |
7.2 Material: Aluminum Alloy
Material is applied as Aluminum Alloy from engineering data library.

| Properties | Volume | Mass |
|------------|--------|------|
|            | 25171 mm³ | 6.9724e-002 kg |

VIII. RESULTS AND DISCUSSION

Modeling of the connecting rod has done by using CATIA V5 software and therefore the model is saved in initial graphics exchange specification (iges) and is imported into the ansys work bench to perform static structural analysis. The results of the analysis have shown below.

**Results applied load 16 mpa with different materials**

**Total Deformation (mm):**

| Materials        | Max      | Min      |
|------------------|----------|----------|
| Aluminum Alloy   | 1.2505e-002 | 0        |
| 42CrMo4          | 4.1742e-003 | 0        |
| Al6061+B4C       | 4.4827e-003 | 0        |

**Equivalent Elastic Strain (mm/mm):**

| Materials        | Max      | Min      |
|------------------|----------|----------|
| Aluminum Alloy   | 9.871e-004 | 8.5e-014 |
| 42CrMo4          | 3.3509e-00 | 1.3394e-012 |
| Al6061+B4C       | 3.5721e-004 | 1.2039e-012 |

**Equivalent (von-Mises) Stress (MPa):**
IX. CONCLUSION

- Modeling and analysis of connecting rod is done.
- Modeling of connecting rod is done in CATIA V5 software.
- The file is saved as iges to import in Ansys workbench.
- The static structural, thermal and modal analysis has carried out in the ansys 14.5 software package for connecting rod by different materials. In which, one generally used material i.e. alloy steel (42CrMo4), aluminum boron carbide (Al+B4C), Aluminum alloy.
- The utmost stress, strain, deformation values and mass based upon respective materials are noted and tabulated in static structural analysis.
- From the above results we can conclude that from 16mpa i.e., load condition on connecting rod that are applied on the connecting rod by assigning different materials, composite materials such as Al+B4C and Al Si Mg alloy less stress compare to generally used alloy steel material.
- Hence we can conclude that Aluminum Boron Carbide (Al+B4C) is the best composite material for connecting rod, due to its high weight to strength ratio and dynamic behavior and economically too.

REFERENCES

[1] Webster W D, Coffell R and Alfaro D (1983), “A Three Dimensional Finite Element Analysis of a High Speed Diesel Engine Connecting Rod”, SAE Technical Paper Series, Paper No. 831322.
[2] Repgen, B., 1998. “Optimized Connecting Rods to Enable Higher Engine Performance and Cost Reduction,” SAE Technical Paper Series, Paper No. 980882.
[3] Park, H., Ko, Y. S., Jung, S. C., Song, B. T., Jun, Y. H., Lee, B. C., and Lim, J. D., 2003, “Development of Fracture Split Steel Connecting Rods,” SAE Technical Paper Series, Paper No. 2003-01-1309.
[4] Sarihan, V. and Song, J., 1990, “Optimization of the Wrist Pin End of an Automobile Engine Connecting Rod With an Interference Fit”, Journal of Mechanical Design, Transactions of the ASME, Vol. 112, PP. 406-412 and “Optimization of the Wrist Pin End of an Automobile Engine Connecting Rod with an Interference Fit,” Journal of Mechanical Design, Transactions of the ASME, Vol. 112, pp. 406-412.
[5] Yoo Y M, Haug E J and Choi K K (1984), “Shape Optimal Design of an Engine Connecting Rod”, Journal Of Mechanics, Transmissions, and Automation in Design, Transactions of ASME, Vol. 106, pp. 415-419.
[6] Hippoliti R (1993), “FEM Method for Design and Optimization of Connecting Rods for Small Two-Stroke Engines”, Small Engine Technology Conference, pp. 217-231.
[7] El-Sayed, M.E.M. and E.H. Lund, 1990. “Structural optimization with fatigue life constraints,” Engineering Fracture Mechanics, 37(6): 1149-1156.
[8] Tai, C. L., 1996, “The Shape Optimization of a Connecting Rod with Fatigue Life Constraint”, Int. J. of Materials and Product Technology, Vol. 11, No. 5-6, PP. 357-370.
[9] Somsino, C. M. and Esper, F. J., 1994, “Fatigue Design for PM Components,” European Powder Metallurgy Association (EPMA).
[10] Serag, S., Sevien, L., Sheha, G., and El-Beshawi, I., 1989, “Optimal Design of the Connecting Rod”, Modelling, Simulation and Control, B, AMSE Press, Vol. 24, No. 3, PP. 49-63.
[11] Athavale S, Sajanpawar PR. Studies on somemodelling aspects in the finite element analysis ofsmall gasoline engine components. No. 911271.SAETechnical Paper 1991.