Design and Computational Investigation of Double Piston U-Shaped Single Connecting Rod in Remodelled Internal Combustion Engines

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Abstract

Objectives: This paper aims at studying force distribution characteristics and load with standing capability of a remodelled IC engine piston connecting rod arrangement where the conventional single piston single connecting rod arrangement is replaced by linking two pistons with a single connecting rod. Methods\Statistical Analysis: 3D Modelling of the arrangement is carried out using Solid works while force analysis of the model is done using ANSYS workbench. Parallel twin cylinder 4 stroke petrol engine is utilized as reference for creating the model and analysis purpose. Findings: The results gives the theoretical evidence that there can be a considerable reduction in engine weight and complexity with this new arrangement with stress, deformation and strain values lying within the boundary. Applications\Improvements: This arrangement gives extra room for lubricants thereby indeed indirectly increasing performance characteristics.

Keywords: Aluminium Alloy, Brake Power, Connecting Rod, Piston, Internal Combustion Engine, Solid Works and Ansys

1. Introduction

A connecting rod has got the function of converting reciprocating motion of the piston to rotary motion of the crankshaft. The most important is to ensure the proper cyclic repetition of the process which indeed controls most of the operations happening inside an IC engine starting from admittance of fuel to pushing out the burnt gases. The effective swept area has to secure from the low to high engine speeds. The achievement of a feasible, reliable and accurate reciprocating motion and transmittance of force, conversion of it into shaft work and long durability together with low friction loss is a complicated task which needs a comprehensive approach. There are some historically verified criteria for good design of connecting rod piston arrangement which is a pin joint mechanism from which result a necessity to do a lot of compromises. The development of simulation tool helps to reach the
best feasible reliable result which compliments connecting rod design. This effort is aided by the enlargement of computational capacity, speed and lower cost of common computers. Helpful is also the demands on the computational power rises slower than the hardware developments. This enables to compute more sophisticated do the design and optimization process more effective. Further physical properties can be added into models which results in better representation of critical points. In this model, the pistons are treated as flexible bodies to account for mass effects. This allows to prediction of load distribution more precise. The interactions of the piston, connecting rod and the pin are modeled as a force contact relation to allow their separation which might cause a jump or a bounce. The authors selected modeling strategy which is common in simulations in recent years and this approach fully takes advantage of the developments in the simulation software. The part of the connecting rod is in direct contact with the piston is the gudgeon pin. Generally there are two kinds of connecting rod arrangement. The big end of the connecting rod attached the crankpin of the crankshaft is divided into halves to make it possible to assemble them around the crankpin. The first way of arrangement is of splitting the big end at right angles to its length and the second one at any angle. The first arrangement is chosen as studies have shown that the second arrangement requires thick and heavy section to avoid excessive deflections of the long arm which may increase the self-weight of the connecting there by adding complexity for analyzing and balancing. The main section of the rod is U-shaped along with a link that connects the connecting rod to the crankshaft through a crank pin. The link end towards the crankshaft is taken as the big end and split into halves at right angles to its length. The thickness of the link remains constant throughout.

2. Methodology of Work

The overall project is divided into the no of sub steps. The following Figure 1 and 2 shows the stages in the design and analysis of connecting rod, link and pin.

3. Connecting Rod Materials

The other cam lobe surface is not designed appropriately, then the valve cannot accurately follow the contour and this will result in irregular motion. The camshaft and crank shaft material should combine a strong shaft with camshaft having hard cam lobes. The most widely used material for camshafts and crank shafts at present are chilled cast iron Chilled Cast iron, hardened cast iron or JIS-SCM420 forging followed by carburizing for Improving Wear resistance of the cam lobe. Lighter moving parts in the valve train will enable high-speed revolutions.

Increasing the tension of the valve spring will increase reactive force, help to prevent irregular motion of the
valves. However, the high reactive force will result in high contact pressure on the cam lobe, so the cam lobe should have high wear resistance. It is essential to supply adequate amounts of lubricating oil to the cam lobe. The contact between the curved surface of the cam lobe and the flat face of the valve lifter (bucket tappet) generates high stress, and therefore both parts require high wear resistance where contact occurs.

Mostly used materials are high speed steel, steel bar, Grey cast iron, Spheroidal graphite cast iron, Carbon epoxy.

3.1 Selection of Connecting Rod Materials
Recently developed aluminium alloys can provide nearly custom-engineered strength, fracture toughness, fatigue resistance, and corrosion resistance for aircraft forgings and other critical components. The rapid-solidification process is the basis for these new alloy systems, called wrought P/M alloys. The term wrought P/M is used to distinguish this technology from conventional press-and-sinter P/M technology. Grades 7090 and 7091 are the first commercially available wrought P/M aluminium alloys.

3.2 Properties of Aluminium 1100-H26
In our selection of Aluminium 1100-H26 chemical composition is shown in Table 1.

Table 1. Chemical composition of Al 1100-H26

| Chemical composition (%) |  |
|--------------------------|--|
| Aluminum                 | 99 |
| Iron                     | 0.95 |
| Silicon                  | 0.095 |
| Copper                   | 0.15 |
| Manganese                | 0.05 |
| Chromium                 | Balance |

These alloys can be handled like conventional aluminium alloys on existing aluminium-fabrication facilities. In this kind of Wrought Aluminium alloys we have choose Aluminium 1100-H26 type.

4. Load Acting on the Connecting Rod
The connecting rod has to withstand compressive loads during compression stroke when gas pressure is greater than the inertia forces of the reciprocating parts and

| S. No | Parameters     | Design Values                                      |
|-------|----------------|----------------------------------------------------|
| 1     | Manufacturer   | Yamaha Motor Company                               |
| 2     | Engine         | 654 cc, 4-stroke, parallel twin                    |
| 3     | Compression ratio | 8.4:1                                            |
| 4     | Torque         | 54 Nm @ 6800 rpm                                   |
| 5     | Cylinder diameter | 50mm                                         |
| 6     | Cylinder length  | 90mm                                                |
| 7     | Stroke length   | 60mm                                                |
| 8     | Brake power    | 36.4 kW @ 7200 rpm                                 |

Table 2. Specification of engine
tensile loads during exhaust stroke when inertia forces dominates gas pressure. These two are taken into consideration along with bending loads acting on the connecting rod due to combined action of inertia loads as well as the centrifugal forces.

5. Engine Specification
In this research work the specification of engine is shown in Table 2. 3D drawing is shown as Figure 3.

6. Material Properties
6.1 Aluminium 1100-H26
For this work taken material Aluminium 1100-H26 specification is shown in Table 3.

7. Calculations
To calculate mean effective pressure using brake power formula:

\[ \text{B.P} = \frac{n \times P_{mi} \times L \times A \times N \times K_b \times 10/6}{\text{KW}} \]

\[ 36.4 = \frac{2 \times 26 \times 0.06 \times 0.00196 \times 0.5 \times 10 \times 7200}{6} \]

\[ P_{mi} = 26 \text{ bar.} \]

For aluminium operating pressure,

\{Compression - 7 to 15 bar\}
\{Max- pressure - 45 to 60 bars\}

8. Finite Element Analysis
8.1 Nodes and Elements
- Nodes and elements arrangement is shown in Figure 1.
- Red dots represent the element’s nodes.
- Elements can have straight or curved edges.
- Each node has three unknowns, namely, the translations in the three global directions.
- The process of sub dividing part into small elements is called meshing. In general smaller element gives more accurate results but require more computer and resource and time.

Table 3. Specification of Aluminium 1100-H26

| S. No | Parameters                  | Design Values |
|-------|-----------------------------|---------------|
| 1     | Young's modulus             | 69000 N/mm²   |
| 2     | Poisson’s ratio             | 0.33          |
| 3     | Density                     | 2700 kg/mm³   |
| 4     | Thermal expansion           | 1.1e-005 1/°C |
| 5     | Tensile yield strength      | 150 MPa       |
| 6     | Thermal conductivity        | 230 w/m K     |
| 7     | Specific heat               | 450 J/kg F    |
• Ansys suggest a global element for tolerance for meshing. The size is only an average value, actual element vary from one location to other depending on geometry.
• It is recommended to use default setting of meshing for initial run. For a more accurate solution use smaller element size.

9. Analysis Procedure

9.1 Static and dynamic Structural
A static-structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects while dynamic loading causes negligible damping effects with inertia effects. Steady, continuous and cyclic loading and response conditions are assumed; that is, the loads and the structure's response are assumed
**Figure 7.** Total stress result for U-rod when moving downwards direction.

**Figure 8.** Load Diagram for piston pin when piston moving upwards.

**Figure 9.** Total Displacement for piston pin when piston moving upwards.

**Figure 10.** Total Stress when piston moving upwards.
**Figure 11.** Load diagram for crank pin slot when piston moves upwards.

**Figure 12.** Stress on crank pin when piston moves upwards.

**Figure 13.** Stress on crank pin when piston moves downwards.

**Figure 14.** Total Load diagram for piston pin.
10. Results and Discussion

The Figures shows results of respective computational experiments carried on U shaped double piston rod where the force direction are in two plane depending on the direction of motion of the rod for compression and expansion process happening inside the internal combustion engine. Figure 4 shows the grid formation while rest of the figures show analysis results. Figure 5, 6, 7 shows to vary respect to time. The types of loading that can be applied in a static analysis include:

- Externally applied forces and pressures.
- Steady-state inertial forces (such as gravity or rotational velocity).
- Imposed (Non zero) displacements.
- Temperatures (Thermal strain).

Figure 15. Total stress distribution for piston pin.

Figure 16. Total Load Diagram for link.

Figure 17. Total Stress distribution for link.
respectively load applied, total displacement, total stress for U-shaped connecting rod while it is forced downward. Figure 8, 9, 10 depicts respectively the load applied, total displacement, total stress distribution in the same connecting rod while it is imparted with a upward motion. Load taken by the crank pin is shown in Figure 11 while Figure 12, 13 depicts its stress distribution while having upward and downward motion respectively. For piston pin load diagram is Figure 14 and stress distribution is shown with the help of Figure 15 while for the link load diagram and stress distribution diagram are Figure 16 and 17 respectively.

11. Conclusion

Experimental results from testing the U-shaped connecting rod supporting and transmitting force from two pistons under static and dynamic load containing the stresses displacement are listed in the Table 4 for the present material Aluminium 1100-H26.

- Testing has been done Bidirectional.
- From the results listed above it is evident that the proposed U-shaped connecting rod can transmit force and while it can also act as strut, beam and tie under various loading conditions with stress, strain build within the limit for the selected material thereby the current design and can be replaced in future with this new proposed one which will serve the purpose successfully with minimum space utilization providing better movement of lubricating oil through the crank case and piston wall.

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14. References

1. Zhang H, Lin Z, Xu D. An analysis to thermal load and mechanical load coupling of a gasoline engine piston. Journal of Theoretical and Applied Information Technology. 2013 Feb 20; 48(2):2005-13.
2. Silva F. Analysis of a vehicle crankshaft failure. Engineering Failure Analysis. 2003; 10(5):605-16.
3. Wang C, Zhao C, Wang D. Analysis of an unusual crankshaft failure. Engineering Failure Analysis. 2005; 12(3):465-73.

### Table 4. Stress, displacement and strain values

| Components   | Displacement (mm) | Stress (N/mm²) | Strain |
|--------------|-------------------|----------------|--------|
| Connecting rod | 0.00686           | 82.336         | 0.0021 |
| Pin          | 0.0002312         | 54.249         | 0.0023 |
| Link         | 0.00031           | 81.17          | 0.0046 |
4. Taylor CM. Automobile engine Tribology-design considerations for efficiency and durability. Wear. 1998; 221(1):1-8.
5. Kim D, Ito A. Friction characteristics of steel pistons for diesel engines. Journal of Materials Research and Technology. 2012 Jul-Sep; 1(2):96-102.
6. Ramjee E, Reddy EK. Performance analysis of a 4-stroke SI engine using CNG as an alternative fuel. Indian Journal of Science and Technology. 2011; 4(7):1-14.
7. Bhandari VB. Design of Machine Elements. 3rd edition. India: McGraw Hill; 2010.