Design and manufacturing of gudgeon pin: A Review Paper

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Abstract- Premature wear of the Gudgeon pin is the major concern for the company Gudgeon pin connects the piston and the small end of the connecting rod of IC engines. This paper deals with Stress analysis and Fatigue analysis of Gudgeon pin used in diesel engine. In stress analysis frictional stresses and Von-Misses stresses coming on Pin are determined using finite element analysis tool ANSYS 16. Effect of different factors on frictional stresses and Von-Misses stresses such as change in internal diameter of pin and application of diamond-like carbon (DLC) coating are analyzed. In Fatigue analysis, fatigue life of Pin is determined using fatigue analysis tool FEMFAT 5.0 b. Effect of change in surface roughness of connecting rod small end bush and change in internal diameter of pin on fatigue life is analyzed.
Keywords- Gudgeon pin,various stresses,ANSYS and CATIA V5

INTRODUCTION

Excessive premature wear of the Gudgeon pins initiated this FEA investigation. The purpose was to develop a design variation that would remove this failure mode. Piston pin or Gudgeon pin or wrist pin connects the piston and the small end of the connecting rod of IC engines. Gudgeon pin is generally hollow and made from case hardening steel heat treated to produce a hard ware resisting surface. Though simple in appearance, without moving parts, it must be recognized as a precision engineered component. This is because it has to satisfy several conflicting requirements: It must combine strength with lightness; it must be close fitting but with freedom of movement, and it must resist wear without scuffing. The Gudgeon pin used in this study is of 24 mm outer diameter and 13 mm internal diameter made of 17Cr3 material. The expected operating life of pins is 3000 hours but the test results showed that the pin diameter gets reduced by 40 microns in merely 475 hours which is not desired.

In this paper finite element analysis is performed on piston assembly which consists of piston, Gudgeon pin and connecting rod small end bush using FEA tool ANSYS 16.

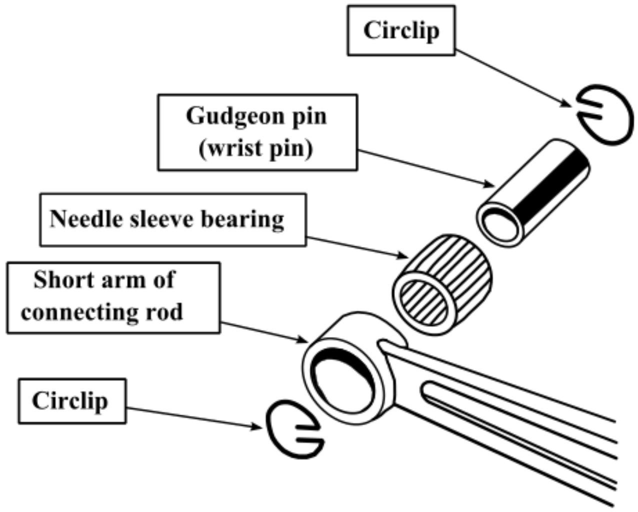
Contact analysis technique is used to analyse pin and bush in which frictional contacts are established in between piston, pin and bush. Piston assembly is then analyzed against the maximum combustion pressure and the frictional stresses and maximum Von-Misses stresses coming on the pin’s outer surface are determined.

Iterations have been performed for redesigning the pin by reducing pin’s internal diameter and by application of diamond-like carbon (DLC) coating on pin. The effects of these redesigns on frictional stresses and on Von-Misses stresses are analyzed.

At last fatigue analysis is performed on piston assembly using fatigue tool FEMFAT5.0b. Fatigue life of pin is determined with rough bush and with increased surface finish of bush. Also effect of reduced internal diameter of pin on the fatigue life is analyzed.

Gudgeon pin:

In internal combustion engines, the gudgeon pin (UK, wrist pin US) connects the piston to the connecting rod and provides a bearing for the connecting rod to pivot upon as the piston moves. In very early engine designs (including those driven by steam and also many very large stationary or marine engines), the Gudgeon pin is located in a sliding crosshead that connects to the piston via a rod. A Gudgeon is a pivot or journal. The origin of the word Gudgeon is the Middle English word gojoun, which originated from the Middle French word goujon. Its first known use was in the 15th century.



Overview:

The gudgeon pin is typically a forged short hollow rod made of a steel alloy of high strength and hardness that may be physically separated from both the connecting rod and piston or crosshead. The design of the gudgeon pin, especially in the case of small, high-revving automotive engines is challenging. The gudgeon pin has to operate under some of the highest temperatures experienced in the engine, with difficulties in lubrication due to its location, while remaining small and light so as to fit into the piston diameter and not unduly add to the reciprocating mass. The requirements for lightness and compactness demand a small diameter rod that is subject to heavy shear and bending loads, with some of the highest pressure loadings of any bearing in the whole engine. To overcome these problems, the materials usedto make the gudgeon pin and the way it is manufactured are amongst the most highly engineered of any mechanical component found in internal combustion engines.

Piston and Connecting-rod Gudgeon-pin Joints:

The gudgeon-pin (piston pin) connects the piston and connecting-rod. It is supported in holes bored in the piston at right angles to the piston axis at about mid-height position, and the centre portion of the gudgeon-pin passes through the connecting-rod small-end eye. This hinged joint transfers directly the gas thrust from the piston to the connecting-rod and allows the rod to pivot relative to the cylinder axis with an oscillating motion.

The gudgeon-pin bosses in the piston experiences a temperature of about 393 to 423 K for both petrol and diesel engines. Also the temperature rise due to friction between the pin and the bosses is in the order of 20 to 30 K. Therefore the gudgeon-pin has to withstand a temperature of about 431 to 453 K. The connecting-rod during its oscillating movement squeezes the oil film alternatively from one side of the pin to the other under semi-boundary-lubrication conditions. In contrast the rotating crankshaft journals operate under full fluid lubrication.

The gudgeon-pins are in tubular shape, which provides adequate strength with minimum weight. They are usually made from low-carbon case-hardened steel of composition 0.15% carbon, 0.3% silicon, 0.55% manganese, and the balance 99% iron. This steel is carburized at a temperature of 1153 to 1203 K, refined at 1143 to 1173 K and then hardened by oil quenching from 1033 to 1053 K. Finally it is tempered at a temperature below 433 K. The finish and size of gudgeon-pins are very closely controlled. A loose gudgeon-pin in the piston or in the connecting rod, causes a rattle during the engine operation. If the pin is too tight in the piston, it restricts piston expansion along the pin diameter which produces piston scuffing. Gudgeon-pin operating clearances are usually about 0.0075 mm, which is critical for quiet running and long life.

The gudgeon-pins are generally lapped to a surface finish of 0.08 to 0.16 \xm for longer service life. A coarser finish produces stress-raisers, which may cause fatigue failure and pick up the softer bearing metal from the pin's rubbing surface. But a smoother finish avoids the oil clinging and wetting the cylindrical working face of the pin. Piston pin holes located in the piston have an offset of approximately 1.57 mm from the piston centre line. Pin offset reduces piston slap and noise, which is created due to crossover action as the large end of the connecting rod swings past both upper and lower dead centres. The piston pins must stay centered in the piston; otherwise, they can move endwise and gouge the cylinder wall.

The method of locating and securing the gudgeon pin in position can be achieved in two ways; (i) semi-floating,
(ii) fully-floating.

Semi-floating Pinch-bolt Small-end-clamped Gudgeon-pin:

In this method of fasten- ing the rod to the pin (Fig. A), the central portion of the pin incorporates a full or partially formed circumferential groove. When the connecting-rod small-end is centrally aligned to this groove, the relative movement takes place only between the gudgeon-pin and the piston bosses. This method allows the use of a narrow small-end due to which the width of the rubbing surface between the piston and the gudgeon-pin boss can be large.

Semi-floating Force-fit Small-end-clamped Gudgeon-pin:
In this arrangement (Fig.B), the connecting-rod small-end faces are polished with emery cloth and heated evenly using an oxyacetylene torch at about 503 to 593 K, until a pale-straw to dark-blue oxide color appears on the bright surface around the eye. Then the gudgeon-pin is forced through both the piston and the small-end eye so that it is centrally positioned. Subsequently the small end cools the shrinks tight over the pin. In this case also the relative rubbing movement is only between the pin and the piston bosses.

Semi-floating Piston-boss-clamped Gudgeon-pin:
In this method (Fig. C), the gudgeon-pin is clamped to one of the piston bosses. The connecting-rod small-end is lined with an interference-fit phosphor-bronze plain bush bearing. This bush locates the gudgeon-pin and provides it with a low-friction surface. Care must be taken not to strip the thread in the relatively soft alloy while tightening the tapered locking bolt. This approach is adopted when the bearing properties of the piston material are not suitable for heavy-duty continuous oscillatory rubbing

Fully Floating Gudgeon-pin End-pads:
If the gudgeon-pins are allowed to float (Fig.D) both in their piston bosses and in the small-end eye, they must not touch the cylinder directly to avoid scoring of the walls by their very hard outer edges. In one of the methods of preventing scuffing, spherical end-pads made from aluminium, brass, or bronze are used to act as buffers between the walls and the pin. During operation, the gudgeon-pin freely revolves both in the small-end and in the piston boss, which has a tendency to improve lubrication.

Fully Floating Gudgeon-pin with Circlip Location.
In this design, the fully floating gudgeonpins (Fig. E) provide the bearing-surface area to the piston-boss bores as well as the small-end bronze bush bearing. Engines with small connecting-rod-to-crank throw ratios and large bore-to-stroke ratios have both large pivoting angular movement and heavy thrust loads on the piston skirt. The double swivel action of the fully floating pin reduce this tendency under heavy-duty conditions. Circlips are used to restrain the gudgeon-pin from sliding from side to side. The clips are positively located in internal circumferential grooves formed near the outer end of each gudgeon-pin-boss bore.

Two types of circlip in use are the heavy rectangular- section Seeger circlip, and the circular-section wire circlip, which is lighter and cheaper but not so secure.

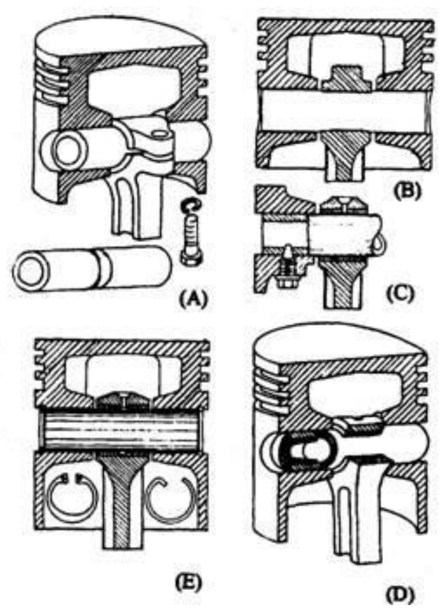


Fig 2. Piston and connecting-rod joints.

The geometries commonly employed in gudgeon pins for internal combustion engines are examined. In particular, various methods for reducing the pin weight are considered. The selection of the appropriate clearance is addressed. The most typical failure modes are classified and interpreted in the light of stress analysis. The available approximate design formulae are assessed versus selected Finite Element forecasts. The fatigue cycles of stress and displacement related parameters are examined. The effect of the initial clearance on the contact pressure and on the pin ovalization is explored for selected clearance values. A typical *Y*–shaped fatigue crack is interpreted with the aid of Mohr circle. An error in a classical design approach based upon the containment of the pin ovalization is hypothesized.

LITERATURE REVIEW:

[1] **Yanxia Wang-** "Due to the fatigue failure and the fracture injury occurs under the alternative mechanical loads, the optimal design of the piston pin and the piston pin boss is presented depending on the FEA static analysis. The optimization is carried out using the Genetic Algorithm (GA), and the piston noncircular pin hole is used to further reduce the stress concentration on the upper end of the piston pin seat."
Points to be note from this: How to make mathematical model of piston for further work.

Vaishali R. Nimbarte "In this paper pressure analysis, thermal analysis and thermo-mechanical analysis is done. The parameter used for the analysis is operating gas pressure, temperature and material properties of piston. In I.C. Engine piston is most complex and important part therefore for smooth running of vehicle piston should be in proper working condition. Piston fails mainly due to mechanical stresses and thermal stresses. Analysis of piston is done with boundary conditions, which includes pressure on piston head during working condition and uneven temperature distribution from piston head to skirt. The analysis predicts that due to temperature whether the top surface of the piston may be damaged or broken during the operating conditions, because damaged or broken parts are so expensive to replace and generally are not easily available."

Points to be note from this:
- Piston & piston pin design consideration
- Base for static design calculation

Dilip Kumar Sonar- "Engine pistons are one of the most complex components among all automotive or other industry field components. The engine can be called the heart of a car and the piston may be considered the most important part of an engine. Notwithstanding all these studies, there are a huge number of damaged pistons. Damage mechanisms have different origins and are mainly wear, temperature, and fatigue related. Among the fatigue damages, thermal fatigue and mechanical fatigue, either at room or at high temperature, play a prominent role. Aluminium alloy have been selected for structural and thermal analysis of piston. An analysis of thermal stress and damages due to application of pressure is presented and analysed in this work. Results are shown and a comparison is made to find the most suited design."

Points to be note from this:
- Alternative method for solution
- Analysis consideration and thermal boundary

R. C. Singh "Piston in the internal combustion (IC) engine is robust, dynamically loaded tribo pair that reciprocates continuously at varying temperature. Study has been made by various researchers on piston design, dynamics, fatigue and wear at the interface with other element in contact along with their effects on IC engines. It was found that the friction coefficient increases with increasing surface roughness of liner surface and thermal performance of the piston increases with increased coating thickness. The free material liberated due to deep scoring between the piston and liner snowballs, leads to seizure failure."

Points to be note from this:
- Various causes of failure of piston & pin
- Location of failure

Bhaumik Patel "In this study, the wok is carried out to measure the distribution of the temperature on the top surface of the piston. Which predicts that due to temperature weather the top surface of the piston may be going to damaged or broken during the operating conditions because damaged or broken parts are so expensive to replace and generally are not easily available. So it is possible to recover the damage or broken parts due to thermal analysis before taking into operations. It can be seen from that the prescribed operating temperature inside the cylinder penetrates the piston crown through nearly 75 % of its thickness before piston ring dissipates some of heat."
Points to be note from this:

- Boundary condition for thermal analysis
- Temperature distribution in piston

Srikanth Reddy "In this work, the main emphasis is placed on the study of thermal behaviour of functionally graded coatings obtained by means of using a commercial code, ANSYS on aluminium and zirconium coated aluminium piston surfaces. The analysis is carried out to reduce the stress concentration on the upper end of the piston i.e. (piston head/crown and piston skirt and sleeve). With using computer aided design NX/Catia software the structural model of a piston will be developed. Furthermore, the finite element analysis is done using Computer Aided Simulation software ANSYS."

Points to be note from this:
- Base for dimension & stress calculation
- Standard material data for design.

Avinash M Wankhde-The finite element analysis is performed using CAD software to investigate and analyze thermal stress distribution at the real engine condition during combustion process. Piston skirt may appear deformation usually causes crack on the upper end of the piston head. Due to deformation, stress concentration is caused on the upper end of the piston and ,The stress distribution on the piston mainly depends on the deformation of piston. Therefore piston crown should have enough stiffness to reduce the deformation.[1]The preliminary analyses presented in the paper was to compare the behavior of the combustion engine piston made of different type of materials under thermal load[2] Finite element analysis is used to analyze stresses in a piston of an internal combustion engine. The stresses due to combustion gas load only are considered so as to reduce the weight and hence to increase the power output of engine.

Conclusion-

In present work detailed design and analysis of existing gudgeon pin is done to find stress concentration of the pin.The stress concentration is then minimize by making suitable changes in gudgeon pin with reference to the various material specifications.Present work consist of design of gudgeon and then the finite element method is establish using ANSYS software to analyse the stresses.

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