A Study for Design and Development of Internal Combustion Engine Piston

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Abstract— A piston is a component of reciprocating engines, reciprocating pumps, gas compressors and pneumatic cylinders, among other similar mechanisms. It is the moving component that is contained by a cylinder and its made gas-tight by the means of using piston rings. The work of the piston is to transforms the energy of the expanding gasses into mechanical energy. The piston rides in the cylinder liner or sleeve. Pistons are commonly made of aluminium or cast iron alloys. The main objective in this paper to review on design evaluation and Optimization of Piston parameters by using finite element method is to achieve suitable design for Piston. That can be achieved by changing such design parameters in the existing design. So firstly in this proper Finite Element Model issued to develop the piston using CAD software solid works. Then static analysis is done to determine the von Misses stress, shear stress, elastic strain, total deformation in the present design by the means of the analysis software Ansys 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 analyzing the fatigue strength. Outputs of the fatigue analysis of include fatigue life, damage, stress biaxiality indication. Then results of present model in ANSYS are compared with the results of existing design.

Keywords: Piston, Solid Works, Ansys, FEA, Structural Analysis

I. INTRODUCTION

In every engine, piston plays an important role in working and producing results. Piston forms a guide and bearing for the small end of connecting rod and also transmits the force of explosion in the cylinder, to the crank shaft through connecting rod. The piston is the single, most active and very critical component of the automotive engine. The Piston is one of the most crucial, but very much behind-the-stage parts of the engine which does the critical work of passing on the energy derived from the combustion within the combustion chamber to the crankshaft. Simply said, it carries the force of explosion of the combustion process to the crankshaft. Apart from the critical job that it does above, there are certain other functions that a piston invariably does .It forms a sort of a seal between the combustion chambers formed within the cylinders and the crankcase. The pistons do not let the high pressure mixture from the combustion chambers over to the crankcase.

Its top known by many names such as crown, head or ceiling and thicker than bottom portion. Bottom portion is known as skirt. There are grooves made to accommodate the compression rings and oil rings. The groove, made for oil ring, is wider and deeper than the grooves made for compression ring. The oil ring scraps the excess oil which flows into the piston interior through the oil return holes and thus avoiding reaching the combustion chamber but helps to lubricate the gudgeon pin to some extent. In some designs the oil ring is provided below the gudgeon pin boss .The space between the grooves are called as lands. The diameter of piston always kept smaller than that of cylinder because the piston reaches a temperature higher than cylinder wall and expands during engine operation. The space between the cylinder wall and piston is known as piston clearance. The diameter of the piston at crown is slightly less than at the skirt due to variation in the operating temperatures. Again the skirt itself is also slightly tapered to allow for unequal expansion due to temperature difference as we move vertically along the skirt the working temperature is not uniform but slightly decrease. Cast Iron, Aluminum Alloy and Cast Steel etc. are the common materials used for piston of an Internal Combustion Engine. Cast Iron pistons are not suitable for high speed engines due its more weight. These pistons have greater strength and resistance to wear. The Aluminum Alloy Piston is lighter in weight and enables much lower running temperatures due to its higher thermal conductivity. The coefficient of expansion of this type of piston is about 20% less than that of pure aluminum piston but higher than that of cast iron piston and cylinder wall. To avoid seizure because of higher expansion than cylinder wall, more piston clearance required to be provided. It results in piston slap after the engine is started but still warming up and tends to separate the crown from the skirt of the piston.

A. Parts inside the Piston

1) Piston Head or Crown:

The piston head or crown may be that convex or concave depending upon the design of combustion chamber.

It with stands the pressure of gas in the cylinder.

The selection of piston crown primarily depends upon the requirement of values for the combustion chamber.

2) Piston Rings:

These are used to seal the cylinder in order to prevent heritage of the gas past the piston.

To act as passage of heat flow from piston crown to the wall of the cylinder.

To act as a lubricating oil controller on the cylinder wall so as to minimize wear.

To absorb some part of the piston due to side thrust.

The material for piston rings is usually cast iron & alloy cast iron due to their good wearing qualities & also they retain the spring characteristics ever at high temperatures.

B. Piston Rings Are Two Types:

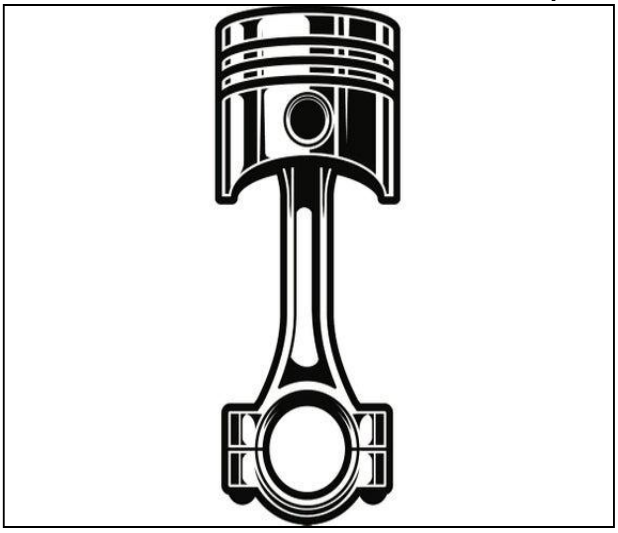
1) Compression rings

Sealing of the combustion gas.

Heat transfer from piston crown to the cylinder wall.

2) Oil control rings to prevent excessive oil from Passing through the end gap of rings and between the cylinder wall & the ring face.

Structural task (reinforcing the compound), but is also used to change physical properties such as wear resistance, friction coefficient, or thermal conductivity.



The piston is a vital component of a cylindrical engine. It Reciprocates inside the cylinder bore. The piston acts as a moveable end of The combustion chamber. The cylinder head is the stationary end of the combustion chamber. 0 piston head is the top surface (closest to the cylinder head) of the piston which is subjected to pressure fluctuation, thermal stresses and mechanical load during normal engine operation. By the forces of combustion, piston reciprocates inside the cylinder bore.

– In order to increase the efficiency of operation and better functionality, the piston material should satisfy the following requirements:

- Light weight
- Good wear resistance
- Good thermal conductivity
- High strength to weight ratio
- Free from rust
- Easy to cast
- Easy to machine
- Non magnetic
- Non toxic
- Piston should be designed and fabricated with such features to satisfy the above requirements.

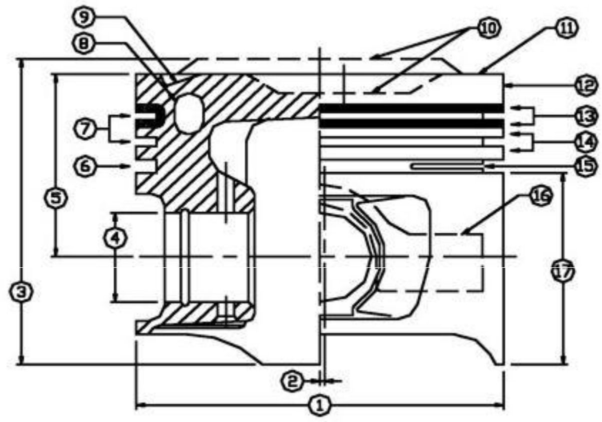
A recessed area located around the circumference of the piston is used to retain piston ring. These rings are expandable and split in type.

– They are used to provide a seal between piston and cylinder wall. Three Such rings employed in a diesel engine are-

1) Compression ring
2) Wiper or second compression ring
3) Oil ring

– The components of piston are presented in Figure

1) Piston skirt diameter
2) Eccentricity of piston axis
3) Total piston length
4) Piston pin whole
5) Compression height
6) Oil ring groove
7) Piston ring grooves
8) Oil cooling tunnel
9) Valve pocket
10) Combustion chamber
11) Piston crown
12) Crown land
13) Al-Fin reinforcement
14) 14 Ring land
15) Oil slit groove
16) Hidden steel struts
17) Skirt area



Components of a piston

Compression ring is used to prevent the leakage from combustion Chamber during combustion process. It is located closest to the piston head. The wiper ring is placed between compression ring and oil ring. It further seals the combustion chamber and keeps the cylinder wall clean by wiping out the excess oil. Combustion gases passed through the compression ring are stopped by the wiper ring. Oil ring is located near the crank case which's used to wipe excess oil from the cylinder wall during piston movement. Piston ring must be provided with a radial fit between the cylinder wall and the running surface of the piston for an efficient seal. Piston ring varies depending upon the size of the engine.

C. Finite element analysis

FEA tool is the mathematical idealization of the real system. It is a computer based method that breaks geometry into elements joined by nodes and a series of equation to each element are formed, and then solved simultaneously to evaluate the behaviour of the entire system. An analytical solution is a mathematical Expression that gives the values of desired unknown quantity at any location in a body structure and as a consequence, it is valid for an in finite number of locations in the body/structure. However, analytical solutions Can be obtained only for simple engineering problems. It is extremely di cult to obtain exact analytical mathematical solutions for many complex engineering problems. In such cases, the technique known as finite

Element method (FEM) is used. In mathematics, the finite element method (FEM) is a numerical technique for finding approximate solution to boundary value problems for partial differential equations. It uses subdivision

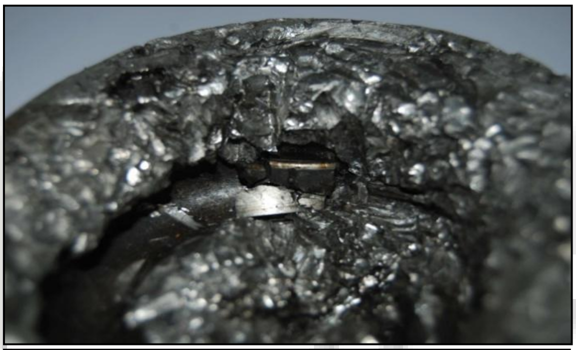
Of a whole problem domain into simpler parts, called finite elements, and variation methods from the calculus of variations to solve the problem by minimizing an associated error function. The subdivision of a whole domain Into simpler parts have several advantages

1) Accurate representation of complex geometry
2) Inclusion of dissimilar material properties
3) Easy representation of the total solution
4) Capture of local effects.

D. Meshing

In Finite Element Method, the body is divided into finite number of smaller units known as elements. This process of dividing the body is called as discretization. The elements are considered interconnected at joints which are known as nodes. In FEM the amount of data can be handled is dependent upon the number of elements into which the original body is divided. Mesh generation is the practice of generating a polygonal or polyhedral mesh that approximates a geometric do-main. The term grid generation is often used interchangeably. Three dimensional meshes created for finite element analysis need to consist of tetrahedral, pyramids, prisms or hexahedra. In this work, the mesh generation is done with the help of ANSYS workbench. The mesh size or the element size is given as 2 mm in all the analysis. The method of mesh element or the type of mesh is selected as tetrahedron because of less CPU time requirement or less computational time and accuracy of results.

1) *Piston Failures*



2) *Mechanical piston damage*

3) *Fusion of the piston head and the ring area*

4) *Fusion of the piston head and the ring area*

5) *A piston skirt seizure*

6) *A crack on the piston pin: a) cracked piston head; b) cracked piston skirt*

A hole in the piston head in a spark-ignition engine is caused by a premature ignition or a hot-bulb ignition

II. LITERATURE REVIEW

[1]Dr. L.N. Wankhade et al. [12] measured the stress and temperature distribution on the top surface of a piston. The structural model of the piston would be developed using CATIA V5 software. Then they imported the CAD model into the Hyper Mesh for geometry cleaning and meshing purpose.

[2]Amit B. Solankiet al. [13] described design analysis and optimization of hybrid Piston for 4 stroke single cylinder 10 HP (7.35 kW) diesel Engine. They used high strength cast steel for piston crown and light alloy like aluminium alloy for piston wall. Using FEM they investigated the stress distribution of piston and analyzed the actual engine condition during combustion process. To avoid the failure of the piston, the stresses due to combustion were considered.

[3]SasiKiran Prabhala et al. [14] replaced the steel components with aluminium components to reduce the weight. The strength of aluminium components was not enough compared to steel components. Therefore, they were taking the aluminium alloy because the aluminium alloy exhibits the strength like the steel.

[4]Deovrat Vibhandik et al. [15] compared the behavior of the combustion engine pistons which were made of different type of materials under thermal load. Geometrical model of the piston was developed by CAD software. The model was based on the actual engine piston of TATA MOTORS four stroke diesel engine.

[5][Vaishali R. Nimbarteet al. [16] investigated and analyzed the stress distribution of piston at actual engine condition. In their paper, pressure analysis, thermal analysis and thermo-mechanical analysis of the piston was performed. For analyzed the piston they used operating gas pressure, temperature and material properties of piston as parameter. Piston was analyzed using boundary conditions, which includes pressure on piston head during working condition and temperature distribution from piston head to skirt. K

[6]Venkateswara Raoet al. [17] designed a 5B.H.P diesel engine piston. They modeled the piston using Pro-E software. They used Cast Aluminium, Aluminium MMC and Brass as piston material. Structural analysis was done on the

piston by applying the pressure to determine the strength of the piston using 3 materials. Thermal analysis was done to find out the temperature distributions, heat transfer rate of the piston

[7]Vinod Yadavet al.[18] illustrated design procedure for a piston for 4 stroke petrol engine for Hero bike. They analyzed by the comparison with original piston dimensions which was used in bike. They considered the combined effect of mechanical and thermal load while determining various dimensions of the piston.

[8]Kethavath Vishalet al [19] worked with the design and analysis of piston. Here the piston design, analysis and the manufacturing processes were studied. Purpose of the investigation was the measurement of piston transient temperature at various points on the piston, from cold start to steady condition and comparison with the results of finite element analysis.

[9]Dilip Kumar Sonar et al [20] designed a piston using CATIA V5R20 software. Complete design was imported to ANSYS 14.5 software and analyzed. Aluminium alloy was selected for structural and thermal analysis of piston.

[10]Hitesh Pandey et al [21] studied the pressure due to expanding combustion gases in the combustion chamber space at the top of the cylinder which generate thermal stresses due to presence of heat involved on the reciprocating masses. They worked with the use of different materials for IC engine piston and a comparative study was made to achieve the best possible result.

[11]A. R. Bhagat et al. [22] described the stress distribution of piston for four stroke engine. The main objectives were to investigate and analyze the thermal stress distribution of piston at the real engine condition during combustion process. Using finite element analysis technique, they presented the mesh optimization to get the higher stress and critical region on the piston.

[12]P. Carvalheira et al. [23] compared two different materials for the engine piston. One of the materials was Aluminium Alloy A390-T5 and another was Ductile Iron 65-45-12.They compared the two materials with the help of Finite Element Analysis (FEA) and chose the best suited material for piston. To predict the thermal and mechanical stresses on the piston, a number of FEA were done and thus they optimized the piston shape.

[13]Muhammet Cerit[24]described temperature and stress distributions in a partial ceramic coated spark ignition (SI) engine piston. He investigated the effects of coating thickness and width on temperature and stress distribution and made a comparison with results from an uncoated piston. He observed the coating surface temperature increase with increasing the thickness in a decreasing rate. With 0.4 mm coating thickness surface temperature of the piston was increased up to 82 °C.

[14]M. Cerit et al. [25] investigated the effect of partially thermal barrier coating on piston temperature distribution and cold start HC emissions of a spark ignition (SI) engine numerically and experimentally. They performed thermal analysis for both standard and coated pistons by using ANSYS. They used a single cylinder, water cooled SI engine for both standard and coated cases. The result of their analysis shown that the surface temperature of the coated piston part was increased up to 100◦C, which leads to an increase in air fuel mixture temperature in the crevice and wall quenching region. Thus, cold start HC emissions considerably decrease compared to the standard engine without any degradation in engine performance. Maximum decrease in HC emissions was 43.2% compared to the standard engine.

[15]A work on optimization of a piston has been done by Ch.VenkataRajam et al in the year of 2013 they have considered a piston from a practical example which has been considered in the present work as a base model. Many works has been done on the design optimization with bare pistons as well as pistons with thermal barrier coating in recent years.

[16]Ajay Ray Singh et al. [6] described the stress distribution and thermal stresses of three different aluminium alloy pistons by using finite element method in the year of 2014.

[17]Shuoguo Zhao [7] presented a structural analysis of the piston in 2012. He analyzed the piston by Pro-E software to improve and optimize the structure of the piston.

[18]Vibhandik et. al. (2014), studied that Design analysis and optimization of piston and deformation of its thermal stresses using CAE tools, he had selected I.C. engine piston from TATA motors of diesel engine vehicle. He had performed thermal analysis on conventional diesel piston and secondly on optimized piston made of aluminum alloy and titanium alloy material. Conventional diesel piston made of structural steel. The main objective of this analysis is to reduce the stress concentration on the upper end of the piston so as to increase life of piston. After the analysis he conclude that titanium has better thermal property, it also help us to improve piston qualities but it is expensive for large scale applications, due to which it can be used in some special cases.

[19]V. V. Mukkawar et. al. (2015), describes the stress distribution of two different Al alloys by using CAE tools. The piston used for this analysis belongs to four stroke single cylinder engine of Bajaj Pulsar 220 cc motorcycle. He had concluded that deformation is low in AL-GHY 1250 piston as compare to conventional piston. Mass reduction is possible with this alloy. Factor of safety increased up to 27% at same working condition. He used Al-GHY 1250 and conventional material Al-2618 and results were compared, he found that Al-GHY 1250 is better than conventional alloy piston.

[20]The study of Lokesh Singh et. al . (2015) is related to the material for the piston is aluminum silicon composites. The high temperature at piston head, due to direct contact with gas, thermal boundary conditions is applied and for maximum pressure mechanical boundary conditions are applied. After all these analysis all values obtained by the analysis is less than permissible value so the design is safe under applied loading condition.

III. MATERIAL OF PISTON

Material selected	Structural steel
Young's Modulus MPa	2.e+005
Poisson's Ratio	0.3
Bulk Modulus MPa	1.6667e+005
Shear Modulus MPa	76923

Compressive Yield Strength MPa	250
Tensile Yield Strength MPa	250
Tensile Ultimate Strength MPa	460
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	4.34e+005 mJ kg^-1 C^-1
Resistivity	1.7e-004 ohm mm

Table 1: property of Structural Steel

A. *Hero Bike Engine Specification*

Displacement	97.2 cc
Cylinders	1
Max Power	8.2 bhp @ 8,000 rpm
Maximum Torque	8.05 Nm @ 5,000 rpm
Bore	50 mm
Stroke	49 mm
Valves Per Cylinder	2
Fuel Delivery System	Carburetor
Fuel Type	Petrol
Ignition	DC - Digital CDI
Spark Plugs	1 Per Cylinder
Cooling System	Air Cooled
Gearbox Type	Manual
No. of Gears	4
Transmission Type	Chain Drive
Clutch	Wet Multiplate

B. *CAE Tools and Software*

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 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. 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 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.

IV. Conclusion

Above all researchers in the Present Paper gives the idea about designing of the Piston. It explains about the various stresses to be considered while designing the Piston and different materials used and comparing the result of all material. Also most of the researchers used the Solid works software for the modelling and ANSYS software for analysis. These can be used for designing the any piston in Automobile Industry. Piston can be designed for weight and cost reduction also to increase the life time of Piston. Up to some level of extent the weight of the piston is lighter and having more strength as compared to the original design.

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