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Design Analysis and Optimization of (Direct Injection) Diesel Engine

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Abstract – **This paper focuses on the design, Analysis and optimization of piston which is stronger, lighter with minimum cost and with less time. Since the design and weight of the piston influence the engine performance. Study Design: Analysis of the stress distribution in the various parts of the piston to know the stresses due to the gas pressure and thermal variations using with Ansys. The Piston of an engine is designed, analyzed and optimized by using graphics software. The CATIA V5R16, CAD software for performing the design phase and ANSYS 14.0 for analysis and optimization phases are used. Results indicate that the volume of the piston is reduced by 24%, the thickness of barrel is reduced by 31%, width of other ring lands of the piston is reduced by 25%, Von misses stress is increased by 16% and Deflection is increased after optimization. But all the parameters are well with in design consideration.**

Keywords– **Piston Crown, CAD, FEA.**

I. INTRODUCTION

Automobile components are in great demand these days because of increased use of automobiles. The increased demand is due to improved performance and reduced cost of these components.

R&D and testing engineers should develop critical components in shortest possible time to minimize launch time for new products. This necessitates understanding of new technologies and quick absorption in the development of new products. A piston is a component of reciprocating IC-engines. It is the moving component that is contained by a cylinder and is made gas-tight by piston rings. In an engine, its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod and/or connecting rod. As an important part in an engine, piston endures the cyclic gas pressure and the inertial forces at work, and this working condition may cause the fatigue damage of piston, such as piston side wear, piston head/crown cracks and so on. The investigations indicate that the greatest stress appears on the upper end of the piston and stress concentration is one of the mainly reason for fatigue failure. On the other hand piston over heating seizure can only occur when something burns or scrapes away the oil film that exists between the piston and the cylinder wall. Understanding this, it's not hard to see why oils with exceptionally high film strengths are very desirable. Good quality oils can provide a film that stands up to the most intense heat and the pressure loads of a modern high output engine. Thermal analysis is a branch of materials science where the properties of materials are studied as they change with temperature. FEM method is commonly used for thermal Analysis .Kamet. al. considered a problem of optimum coating thickness. Compared to thick coatings, thin coatings offer the advantage of longer durability and the moderate increase in surface temperature. Thermally sprayed TBCs are usually two-layer, the layer adjoining the substrate provides adequate adherence of the coating, protects base metal from corrosion and facilitates stress relaxation, the outermost layer is sprayed with ceramic material coat and a 0.25 mm thick layer of partially stabilized zirconia.

II. PROPOSED PISTON DESIGN

The piston is designed according to the procedure and specification which are given in machine design and data hand books. The dimensions are calculated in terms of SI Units. The pressure applied on piston head, temperatures of various areas of the piston, heat flow, stresses, strains, length, diameter of piston and hole, thicknesses, etc., parameters are taken into consideration.

1. Design Considerations for a Piston

In designing a piston for an engine, the following points should be taken into consideration:

- It should have enormous strength to withstand the high pressure.
- It should have minimum weight to withstand the inertia forces.
- It should form effective oil sealing in the cylinder.
- It should provide sufficient bearing area to prevent undue wear.
- It should have high speed reciprocation without noise.
- It should be of sufficient rigid construction to withstand thermal and mechanical distortions.
- It should have sufficient support for the piston pin.

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2. Procedure for Piston Design

The procedure for piston designs consists of the following steps:

- Thickness of piston head (tH)
- Heat flows through the piston head (H)
- Radial thickness of the ring (t1)
- Axial thickness of the ring (t2)
- Width of the top land (b1)
- Width of other ring lands (b2)

The above steps are explained as below:

3. Thickness of Piston Head (th)

The piston thickness of piston head calculated using the following Grashoff's formula,

$tH = \sqrt{(3pD2)/(16\sigma t)}$ in mm

Where

P= maximum pressure in N/mm²

D= cylinder bore/outside diameter of the piston in mm.

σt=permissible tensile stress for the material of the piston. Here the material is a particular grade of AL-Si alloy whose permissible stress is 50 Mpa-90Mpa.

Before calculating thickness of piston head, the diameter of the piston has to be specified.

The piston size that has been considered here has a L*D specified as 152*140.

4. Heat Flow through the Piston Head (H)

The heat flow through the piston head is calculated using the formula

H = 12.56*tH* K * (Tc-Te) Kj/sec

Where

K=thermal conductivity of material which is 174.15W/mk

Tc = temperature at center of piston head in °C.

Te = temperature at edges of piston head in °C.

Radial Thickness of Ring (t1)

$t1 = D\sqrt{3pw}/\sqrt{t}$

Where D = cylinder bore in mm

Pw= pressure of fuel on cylinder wall in N/mm². Its value is limited from 0.025N/mm² to 0.042N/mm². For present material, □t is 90Mpa

5. Axial Thickness of Ring (t2)

The thickness of the rings may be taken as

t2 = 0.7t1 to t1

Let assume t2 =5mm

Minimum axial thickness (t2)

= D/(10*nr)

Where nr = number of rings

6. Width of the top land (b1)

The width of the top land varies from

b1 = tHto 1.2 tH

7. Width of other lands (b2)

Width of other ring lands varies from

b2 = 0.75t2 to t2

8. Maximum Thickness of Barrel (t3)

t3 = 0.03*D + b + 4.5 mm

Where

b = Radial depth of piston ring groove

Thus, the dimensions for the piston are calculated and these are used for modeling the piston in CATIA V5R19. In the above procedure the ribs in the piston are not taken into consideration, so as make the piston model simple in its design. In modeling a piston considering all factors will become tedious process.

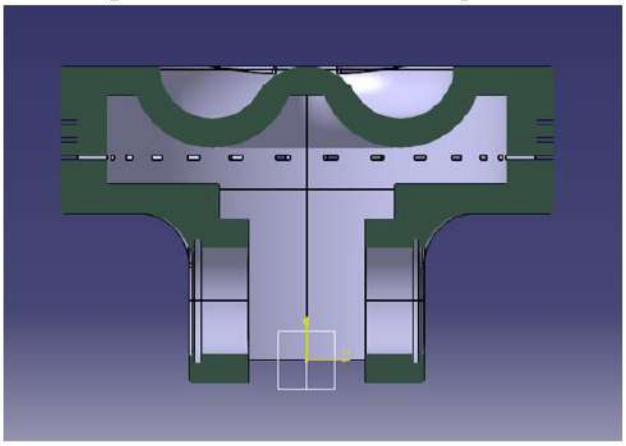


Fig.1. Sketch of the Piston before optimization.

It was then imported to ANSYS 16.0. For the analysis and optimization specifications of the Piston before optimization are shown in Table 1.

Table -I: Design Specification before optimization.

S.No.	Dimensions	Size in mm
1	Length of the Piston(L)	152
2	Cylinder bore/outside diameter of the piston(D)	140
3	Thickness of piston head (t_H)	9.036
4	Radial thickness of the ring (t_1)	5.24
5	Axial thickness of the ring (t_2)	5
6	Width of the top land (b_1)	10
7	Width of other ring lands (b_2)	4

III. THE CAD AND FEA OF PISTON

The design of the piston starts with the definition of the piston geometry using 3D CAD software. This 3D CAD geometric model is then imported to FEA software and analysed under the predicted service conditions before anything is made. That speeds up the design and testing process, reduces the lead time to create new pistons designs, and produces a better product. The idea behind finite analysis is to divide a model piston into a fixed finite number of elements. Computer software generates and predicts the overall stiffness of the entire piston. Analyzing the data it is possible predict how the piston will behave in a real engine and allows the engineer to see where the stresses and temperatures will be the greatest and how the piston will behave [4]. Analysis of the piston is done to optimize the stresses and minimize the weight using ANSYS. The mathematical model of optimization is established firstly, and the FEA is carried out by using the ANSYS software. Based on the analysis of optimal result, the stress concentrates on the piston has become evaluate, which provides a better reference for redesign of piston.

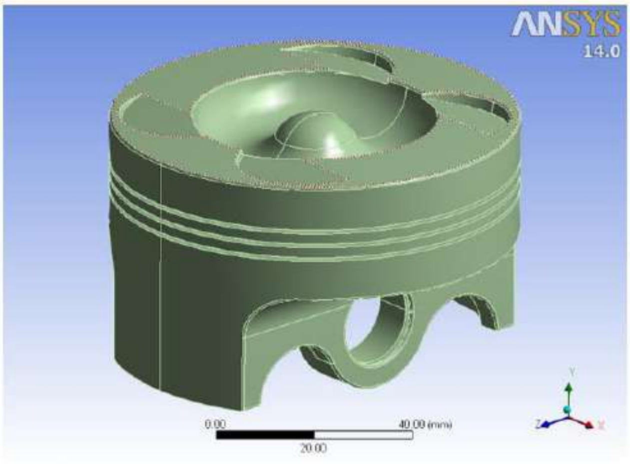


Fig.2. Piston before optimize in ANSYS.

1. Meshing of piston before optimization
Element used is 20 node Tetrahedron named soilid90 [5]. The element size is taken as 5,
then total number elements were 57630 and nodes were 91176 found in meshed model.

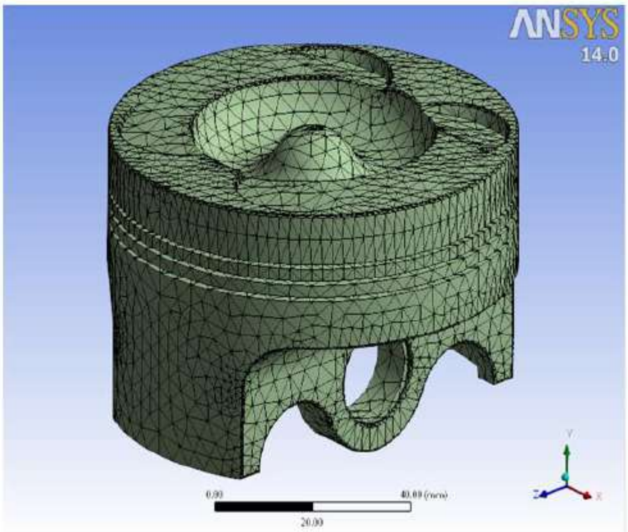


Fig.3. Shows meshed model of the piston.

IV. OPTIMIZATION

After generating an accurate finite element model a strategy for the optimization workflow was defined. Target of the optimization was to reach a mass reduction of the piston.
Objective Function: Minimize mass
Subject to constraints:

- Maximum Vonmises stress<Allowable or design stress
- Factor of safety>1.2
- Manufacturing constraints
- After carrying out static structural analysis the stresses in each loading conditions were studied and then area where excess material can be removed were decided so that maximum vonmises stress does not exceed allowable and factor of safety is kept above 1.5 .

Following reasons where scope for material removal

- Radial Thickness of the ring
- Axial Thickness of the ring
- Maximum Thickness of the Barrel
- Width of the Top Land
- Width of other ring lands

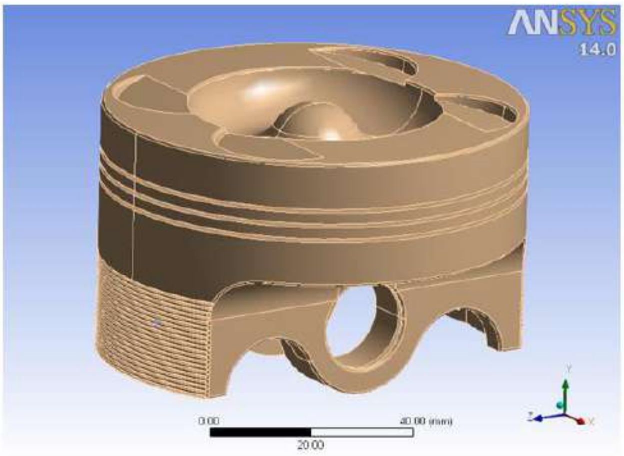


Fig.4. Piston after optimization in ANSYS.

1. Meshing of piston after optimization
The meshing of the piston after optimization is done with the same element structure and size taken before optimization. The total number elements were 78221 and nodes were 47286 found in meshed model.

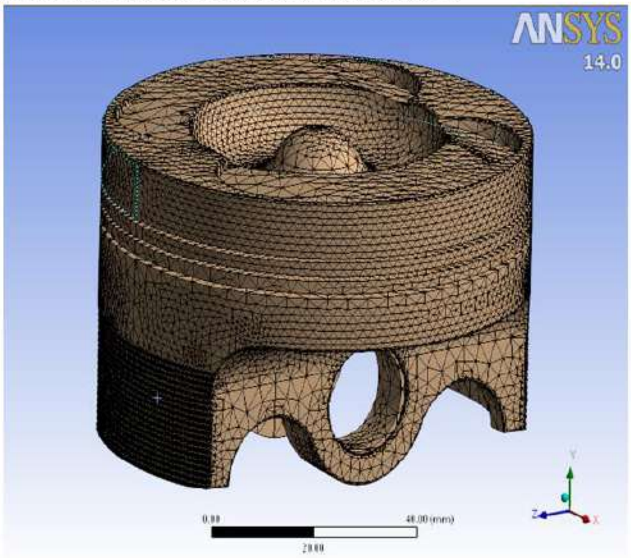


Fig.5. shows meshed model of the piston after optimization.

2. Boundary Conditions for Structural Analysis of Piston

Combustion of gases in the combustion chamber exerts pressure on the head of the piston during power stroke. The pressure force will be taken as boundary condition in structural analysis using ANSYS mechanical APDL. Fixed support has given at surface of pin hole. Because the piston will move from TDC to BDC with the help of fixed support at pin hole. So whatever the load is applying on piston due to gas explosion that force causes to failure of piston pin (inducing bending stresses). Pressure acting on piston = 3.3 N/mm2 as shown in Fig.

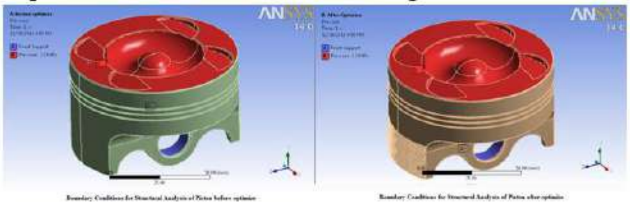
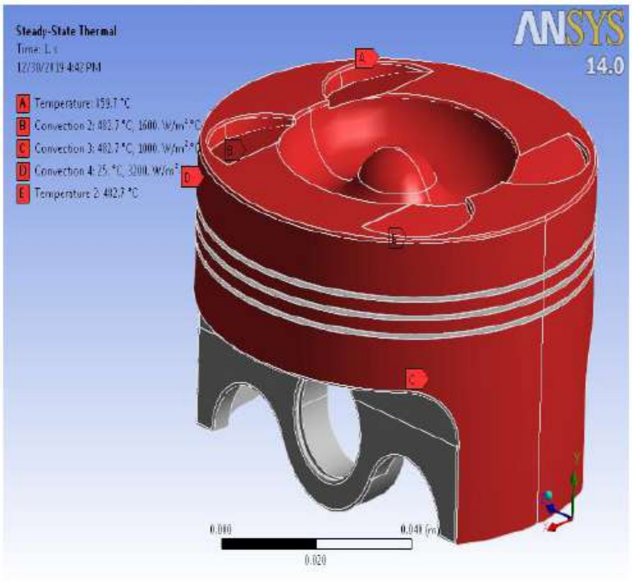


Fig.6. Structural Boundary Condition before and after optimize in ANSYS.

3. Boundary Condition for Thermal Analysis of Piston

The thermal boundary conditions consist of applying a convection heat transfer coefficient
and the bulk temperature, and they are applied to the piston crown, land sides, piston skirt.
Maximum on piston head temperature = 859.7 0C, Bulk temperature = 250C, Heat transfer coefficient on piston surface =3200 W/m2K, Maximum temperature at edges piston = 482.7 0C, Heat transfer coefficient on edge piston = 2400 W/m2K, Heat transfer coefficient on lands rings =1600 W/m2K, Heat transfer coefficient on piston skirt = 1000 W/m2K.



4. Thermal Boundary Condition before optimize in ANSYS

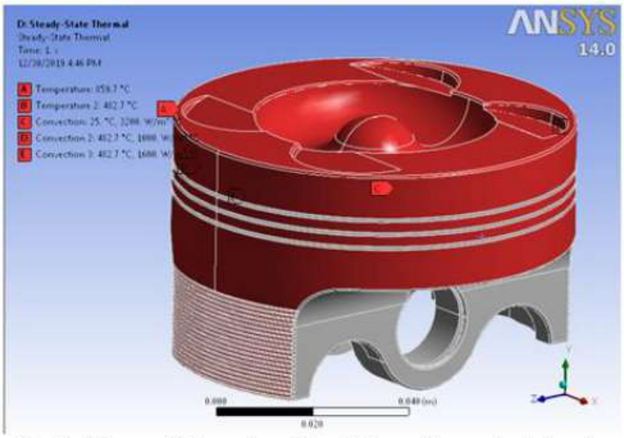


Fig.7. Thermal Boundary Condition after optimizing in ANSYS.

V. CONCLUSION

The deflection due to pressure applied after optimization is more than before optimization and this value is taken into consideration for design purpose. The stress distribution on the piston mainly depends on the deformation of piston. Therefore, in order to reduce the stress concentration, the piston crown should have enough stiffness to reduce the deformation. All the phases in this project given can be extended to the piston design with reduction of material at bottom. The material is removed to reduce the weight of the piston so as to improve the efficiency. It is essential to obtain the optimized results for new piston with reduced material.

In brief:

1. 1 The optimal mathematical model which includes formation of piston crown and quality of piston ad piston skirt.
2. The FEA is carried out for standard piston model used in diesel engine ceramic coating on crown and the result of analysis indicate that the maximum stress has changed from 1.786e8 to 1.802e8 Pa.

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