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Design and Static Analysis of Piston Head Using Honeycomb Structure

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Abstract: *This project is focused on the stress distribution of the piston four stroke engines by using FEM. The main objectives are to investigate and analyze the thermal stress and maximum or minimum principal stresses, Vanishes stresses distribution on engine piston at the real engine condition during combustion process. The project describes the optimization techniques using finite element analysis technique (FEM) to predict the higher stress and critical region on that component. The stress concentration on the piston head, piston skirt and sleeve are reduced by optimization with computer aided design, CATIAV5 software the structural model of a piston will be developed. Furthermore, the FEM analysis is done using Computer Aided Simulation software.*

Keywords: FEA Analysis, Honeycomb Structure, Piston, etc.

I. INTRODUCTION

A piston is a component of engines. It is the moving component that is contained by a cylinder and is made gas tight by piston rings. In an engine, its transfer force from expanding gas in the cylinder to the crankshaft via a piston rod or connecting rod. As a main part in an engine, piston endures the cyclic gas pressure and the inertial forces at work, and this real working condition may cause the fatigue damage of piston, such as piston skirt wear, piston head or crown cracks and so on. The investigations denote 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 visually why oils with exceptionally high film strengths are very desirable. Good quality oils will offer 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. Finite element method (FEM) is commonly used for thermal Analysis. Due to the complicated working environment for the piston; on one hand, the finite element method (FEM) for the piston became more difficult, on the other hand, though there have many methods which are put forward to apply optimal design, the optimal parameters are not easy to determine. In this study, the piston is used in low idle and rated speed gas engine. In order to enhance the engine dynamic and economic, it is necessary for the piston to implement optimization. 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 Upper end of piston have evaluated, which provides a better reference for redesign of piston.

To study the various parameters of the piston mainly dealing with the finite element analysis of the vibrating piston who studied the effect of the water waves on the vibrating piston. The acoustic pressure values along the axis of the piston as a junction of distance from the piston and frequency are evaluated. The radiation impedance of the vibrating piston is also evaluated. The results of FE analysis are compared with the theoretical values. Finally, he concluded that finite element analysis can be successfully used for simulation of the vibrating piston in the water.

II. THE PROBLEM

As the pistons are crucial part of the engine, it should have characteristics which will overcome all pressure and vibrations developed inside the engine block due to air-fuel mixture blasts, as the pistons are casted and have rigid structure which emphasize the weight of the piston, which causes frictional losses and increase the fuel ratio required for the displacement of the piston.

III. CALCULATION OF PISTON

Most commonly used materials for pistons of I.C. engines are

- Cast iron.
- Cast aluminum.
- Forged aluminum.
- Cast steel.
- Forged steel.

Thickness of Piston:

$$t_h = D\sqrt{\frac{3}{16}\frac{Pmax}{\sigma b}}$$

$$\sigma_b = \sigma_t = \frac{S_{ut}}{(fs)}$$

t_h = Thickness of piston.
D = Cylinder bore.
P_{max} = maximum gas pressure or explosion pressure. (Mpa or N/mm^2)
σ_b= Permissible bending stress (N/mm^2)

1. When the data is not available, the allowable bending stress (σ_b) for gray cast iron may be taken from 35 to 40 N/mm^2
   For aluminum alloy, it may be assumed from 50 to 90 N/mm^2
2. Maximum gas pressure (P_{max}) may rise up to 8 MPa. The average value of maximum gaspressure may be taken as 4 to 5 Mpa.

We are taking cylinder bore of 4 inches. i.e., 101.6 ~~ 102

Therefore,

$$t_h = 102\sqrt{\frac{3}{16}\frac{8}{90}} = 13.18 \text{ mm}$$

Radial thickness of the Ring (t_1)

$$t_1 = D\sqrt{\frac{3Pw}{\sigma b}} = 3.45 \text{ mm}$$

P_w = Pressure of gas on cylinder wall in N/mm^2. Its value is limited from 0.025 N/mm^2 to 0.042 N/mm^2

σ_t = Allowable bending (tensile) stress in Mpa. Its value is taken from 85 Mpa to 110 Mpa.

Axial thickness of Ring (t_2) $t_2 = 0.7\ t_1$
$t_2 = 0.7 * 3.45 = 2.415$mm

Width of the top land, (i.e., the distance from the top of the piston to the first ring groove)
$b_1 = 1.2\ t_h$
$b1 = 1.2 * 13.18 = 15.816$mm

Maximum thickness of the Barrel (t_3) $t_3 = 0.03*D + b + 0.4 = 3.85$mm
$b = t_1 + 0.4 = 3.45 + 0.4 = 3.85$mm
This is we can design piston without considering the external factors affecting the dimension concern.
We are modifying the piston from rigid structure to hexagonal sub-elemental structure (composed of hexagonal internal structure)

IV. CAD MODEL

Figure 1: Standard Piston

Figure 2: Honeycomb Piston

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V. GEOMETRY OF STANDARD PISTON

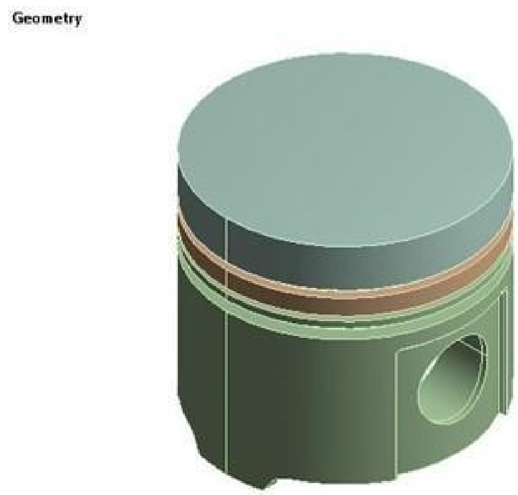

Figure 3: Geometry

5.1) Meshing

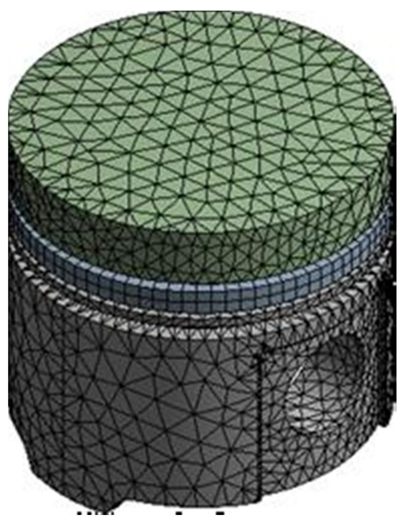

Figure 4: Meshing

Statistics	
Nodes	40496
Elements	19410

NODES AND ELEMENTS

5.2) Material Properties

5.2.1) Aluminum Alloy

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Properties of Outline Row 4: Stainless Steel

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7750	kg m^-3
4	Isotropic Secant Coefficient of Thermal Expansion		
6	Isotropic Elasticity		
7	Derive from	Young's Modulus and P...	
8	Young's Modulus	1.93E+11	Pa
9	Poisson's Ratio	0.31	
10	Bulk Modulus	1.693E+11	Pa
11	Shear Modulus	7.3664E+10	Pa
12	Tensile Yield Strength	2.07E+08	Pa
13	Compressive Yield Strength	2.07E+08	Pa
14	Tensile Ultimate Strength	5.86E+08	Pa
15	Compressive Ultimate Strength	0	Pa

5.2.2) Boundary condition: Static Structural Analysis

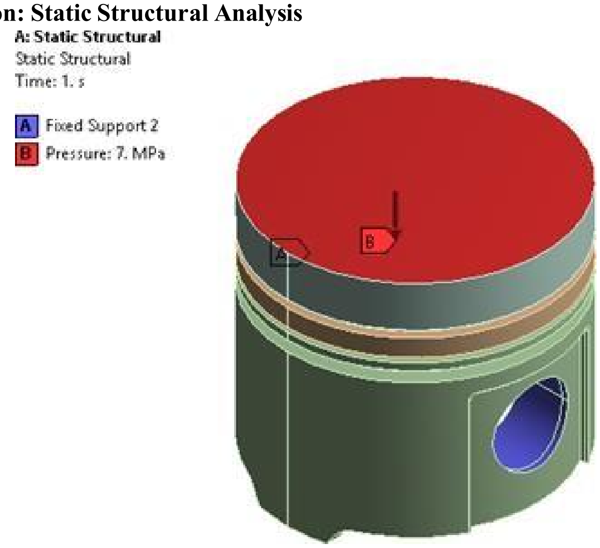

Figure 5: Boundary Condition

In 1000 to 1200 cc engines the pressure generated inside combustion chamber is about 1000 Psi which means 7 MPa of pressure is exerted on the upper surface of piston head.

5.2.3) Weight of existing Piston

Properties	
Volume	1.4305e+005 mm³
Mass	1.1087 kg

5.2.4) Results and Plots

Equivalent Strain Plot

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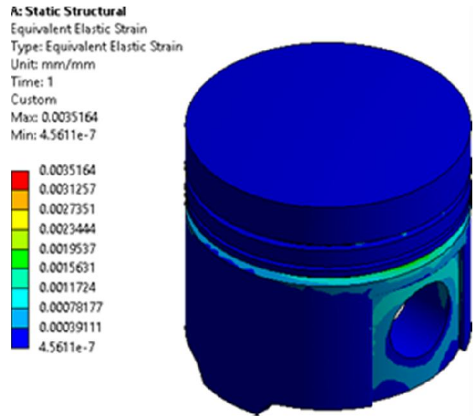

Figure 6: Equivalent strain on the piston

Total Deformation Plot

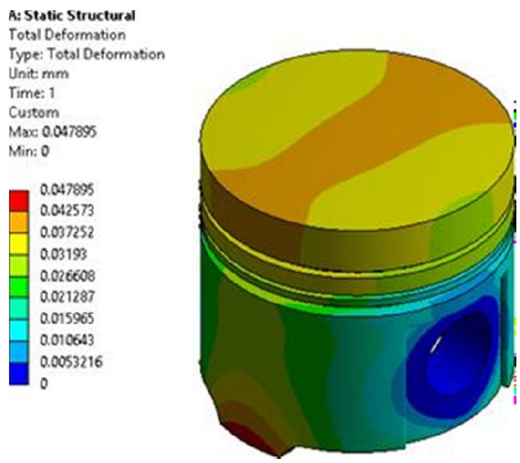

Figure 7: Total Deformation on piston

Directional Deformation Plot

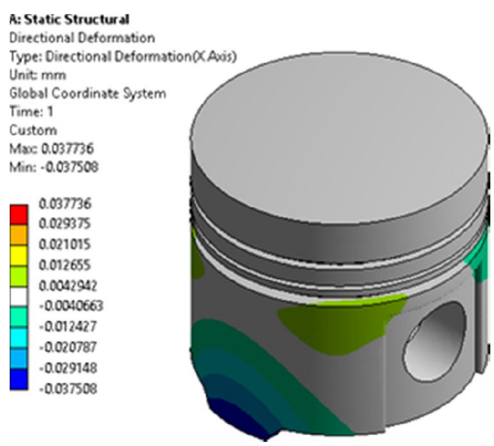

Figure 8: Directional Deformation on piston

VI. GEOMETRY OF HONEYCOMB STRUCTURED PISTON

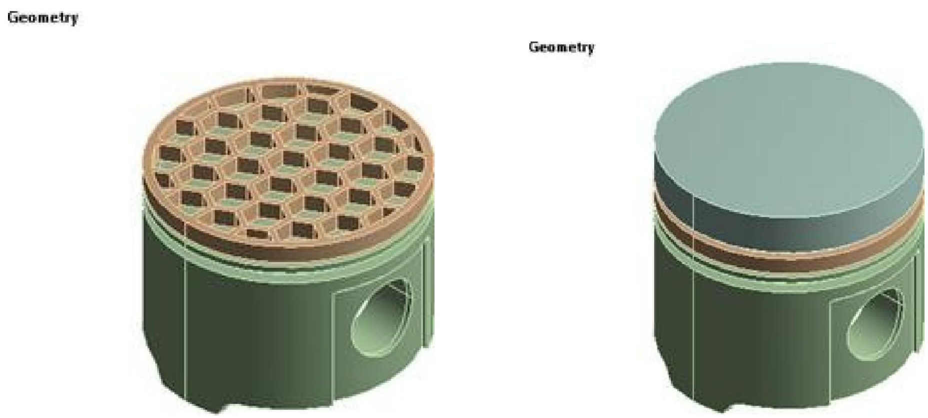

Figure 9: Geometry

6.1) Meshing

Figure 10: Meshing

Statistics	
Nodes	93940
Elements	47355

NODES AND ELEMENTS

6.2) Material Properties

6.2.1) Aluminum alloy

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	2770	kg m^-3
4	Isotropic Secant Coefficient of Thermal Expansion		
5	Coefficient of Thermal Expansion	2.3E-05	C^-1
6	Isotropic Elasticity		
7	Derive from	Young's Modulus an...	
8	Young's Modulus	7.1E+10	Pa
9	Poisson's Ratio	0.33	
10	Bulk Modulus	6.9608E+10	Pa
11	Shear Modulus	2.6692E+10	Pa

6.2.2) Boundary condition: Static Structural Analysis

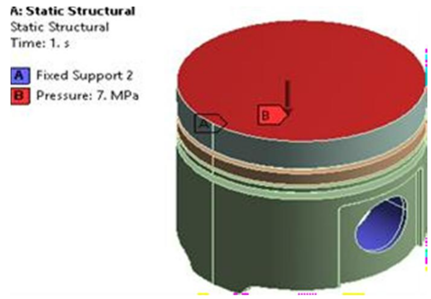

Figure11: Boundary Condition

6.2.3) Weight of existing Piston

Properties	
Volume	1.2835e+005 mm³
Mass	0.95771 kg

6.2.4) Results and Plots

Equivalent Strain Plot

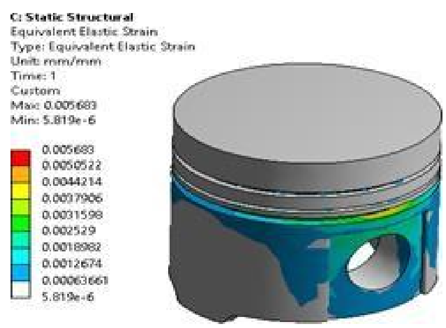

Figure 12: Equivalent strain on honeycomb structured piston

Total Deformation Plot

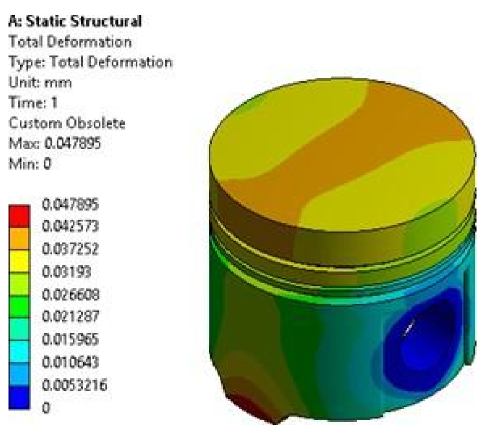

Figure 13: Total Deformation on honeycomb structured piston

Directional Deformation Plot

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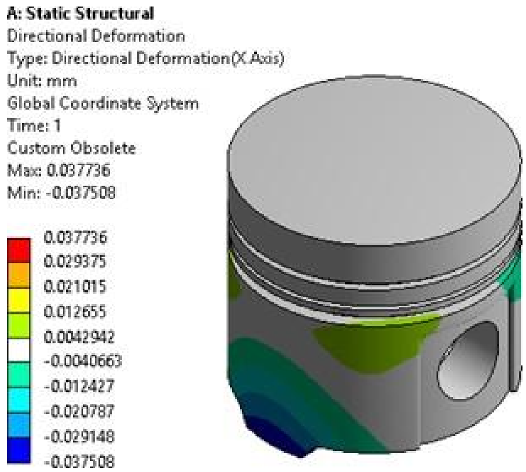

Figure 14: Directional Deformation on honeycomb structured piston

VII. EXPERIMENTAL VALIDATION

7.1) Specification of UTM

1	Max Capacity	400KN
2	Measuring range	0-400KN
3	Least Count	0.04KN
4	Clearance for Tensile Test	50-700 mm
5	Clearance for Compression Test	0- 700 mm
6	Clearance Between column	500 mm
7	Ram stroke	200 mm
8	Power supply	3 Phase, 440Volts, 50 cycle. A.C
9	Overall dimension of machine (L*W*H)	2100*800*2060
10	Weight	2300Kg

Figure 15: Specifications of UTM

- Fixture is manufactured according to component designed.
- Single force is applied as per FEA analysis and reanalysis is performed to determine strain by numerical and experimental testing.
- Strain gauge is applied as per FEA results to maximum strained region and during experimental testing force is applied as per numerical analysis to check the strain obtained by numerical and experimental results.
- During strain gage experiment two wires connected to strain gage is connected to micro controller through the data acquisition system and DAQ is connected to laptop. Strain gage value are displayed on laptop using DEWESOFT software.

VIII. MANUFACTURING PROCEDURE

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- Laser cutting of honeycomb structured plate is being done.
- The laser cut plate is of Aluminum alloy and the remaining body is of different material.
- Due to different material Brazing of laser cut plate is being done.
- Fixture for experimental testing is manufactured by M.S. material.

1. **1.** Weight optimization of piston is done by inserting an honeycomb structured plate.
2. **2.** After optimization process an experimental analysis is done on the piston to find out strain value.
3. **3.** Setup for UTM testing is done and piston is installed on the fixture.
4. **4.** UTM testing is done on the piston.
5. **5.** After experimental testing strain gauge is installed on the piston where strain is maximum.

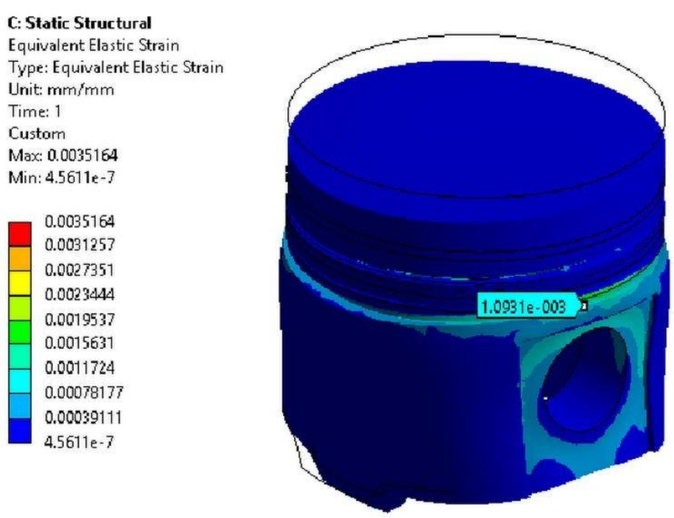

Figure 16: Equivalent Elastic Strain

Maximum strain value is 1 mm

8.1) Strain Gauge Test Values

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Figure 17: Strain Gauge Test Value

The strain gauge value for PISTON is 1082micron.

IX. CONCLUSION

As we have replaced the whole disc with honeycomb structured plate and plotted the strain values. We have observed no extreme change in strain values and also the weight of the piston is reduced 0.96 kg from 1.1 kg.
So, we have successfully reduced the weight of piston by 13%.

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