

STUDY ON DESIGN AND STATIC ANALYSIS OF PISTON HEAD

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Abstract

I.C engine piston is one of the most important and complex component in the engine. It is also sometimes referred as the heart of engine. It is widely used mainly in automotive and mechanical fields hence, a detailed study on its static behavior is important. This paper emphasizes on the static analysis of the piston head of a 4-stroke I.C engine. In the present work piston head is designed using CATIAV5R20 and this model is analyzed in ANSYS 14.5 and a study on its static behavior is performed. Aluminum alloy has been selected as piston material for structural analysis. The theoretical stress values obtained is compared with the stress values obtained after the analysis in ANSYS 14.5.

Keywords: Piston Head, I.C Engine, CATIA V5R20, ANSYS 14.5, Static Analysis.

1. INTRODUCTION

Piston is one of the most important components of engine. It is a part in motion which is present in cylinder. In the engine the expansion of gas occurs in cylinder up to crankshaft through connecting rod. The piston lasts this gas pressure and inertial forces at work and this may lead to crack formation and piston wear. The study reports show that stress concentration is highest at upper portion and this is one of the main reasons for crack formation and wear. This paper describes stress distribution on piston head of an IC engine by using finite element method. It is achieved by CAD and CAE softwares. Our main purpose is to study the static behavior of piston head and analyze the stress distribution. By using CATIAV5R20 model of the piston head is developed. Stress analysis is carried out by using ANSYS 14.5. The results obtained from ANSYS 14.5 are compared with the calculated theoretical stress values.

A lot of research has been undertaken in optimizing the piston head. Ashwani Kumar et al [1] the main objective of this research work is to investigate and analyze the stress distribution of piston at actual engine condition. Analysis of the stress distribution was carried out on different parts of the piston for determining the stresses due to the gas pressure. S N Kurbet et al [2] studies related to the working of the engine parts, the piston is considered as main source of the vibration and noise the emphasis is on the piston vibration and to find out the various methods to predict mechanical noise produced by the primary and secondary motion of the engine part.

2. MATERIAL PROPERTIES

Aluminium alloy is selected for the design and analysis of the piston head. Properties of the aluminium alloy are mentioned below.

Density – 2770 (Kg/m³)

Poisson Ratio – 0.33

Young Modulus – 7.1x10¹⁰ (Pa)

Tensile Ultimate Strength – 3.1x10⁸ (Pa)

Tensile Yield Strength – 2.8x10⁸ (Pa)

Compressive Yield strength – 2.8 x10⁸ (Pa) [3]

3. CALCULATIONS

Bore diameter = 100 mm (D), Stroke length = 120 mm (L), Gas pressure = 5 MPa, BMEP = 0.5 MPa, Fuel consumed = 0.15 (Kg) / Brake Power (W), Speed = 2200 rpm (N) [4]

Step 1:

Brake power (BP) .in KW

$$BP = PLAN / (1000 \times 60) \text{ KW}$$

Where, P = BEMP = 0.5 MPa

L = Stroke length m

A = Cross Section area m²

N = Speed rpm

$$BP = 0.5 \times 120 \times 100^2 \times 2200 \times \pi / (1000 \times 4 \times 60)$$

$$= 17.275 \text{ KW}$$

Step 2:

Thickness of the piston head by considering the heat dissipation

$$t_1 = D^2 q / [1600 \times K \times (T_c - T_e)] \text{ mm}$$

Where, t₁ = thickness of piston head mm

q = Heat flow J/s-m²

k = Heat conductivity W- mm/(m²-°C)

T_c-T_e = difference between the Temperature at centre and edges = 222 K

$$q = K_1 \times C \times W \times BP / (A) \text{ J/s-m}^2$$

Where, K₁ = Constant which represents the amount of heat soaked by piston.

$C =$ Calorific value of the fuel $= 42000 \text{ KJ/Kg}$

$W =$ fuel consumed $= 0.15 \text{ Kg-hr/KW}$

$$A = \pi d^2 / (4) = \pi \times (0.1)^2 / (4) = 7.85 \times 10^{-3} \text{ m}^2$$

$$q = 0.05 \times (42000 \times 1000) \times (0.15/3600) \times 17.278 / (7.854 \times 10^{-3}) = 192491 \text{ J/s-m}^2$$

$$t_1 = 100^2 \times 192491 / (1600 \times 460 \times 222) = 11.78 \text{ mm}$$

Step 3:

The thickness of the piston head using Grashof's formula

$$t_1 = 0.43 D \sqrt{P/\sigma_t} \text{ mm}$$

$P =$ Gas pressure in MPa

$\sigma_t =$ Allowable tensile stress MPa

$$= 280/2.25$$

$$= 124.4 \text{ MPa}$$

$D = 100 \text{ mm}$

$$= 0.43 \times 100 \sqrt{5/124}$$

$$= 8.7 \text{ mm} = 9 \text{ mm}$$

Adopt the greater value of the t_1 i.e. $t_1 = 11.78 \text{ mm}$

Step 4:

Piston ring properties

The radial thickness of the ring t_r

$$t_r = D \sqrt{3P_r / \sigma_t} \text{ mm}$$

Where, P_r is pressure exerted by fuel on cylinder wall in N/mm^2 . Its value varies from 0.025 to 0.042 N/mm^2

$$= 100 \times \sqrt{3 \times 0.042 / 124}$$

$$= 3.187 \text{ mm}$$

The distance from top to first groove t_g

$$t_g = 1t_1 \text{ to } 1.2 t_1$$

$$= 1.2 \times 11.78$$

$$= 14 \text{ mm}$$

Number of rings i

$$i = 100 / (10 \times h)$$

$$= 100 / (10 \times 2.22) = 4 \text{ rings}$$

The maximum thickness of piston barrel t_3

$$t_3 = 0.03D + b + 4.5 \text{ mm}$$

Where, b is the depth of the ring grooves in mm

$$b = t_r + 0.4 \text{ mm}$$

$$= 3.187 + 0.4$$

$$= 3.587 \text{ mm}$$

$$t_3 = 0.03 \times 100 + 3.587 + 4.5$$

$$= 11.08 \text{ mm}$$

Thickness of the wall towards the open end of the piston t_4

$$t_4 = 0.25 t_3 \text{ to } 0.35 t_3$$

$$= 0.25 \times 11.08$$

$$= 3.32 \text{ mm}$$

Diameter of the piston pin

$$d = \pi \times D^2 \times P_{\max} / (4 \times l_1 \times P_b)$$

Where $l_1 = 1.5d$

P_b is bearing pressure in MPa which is 15.7 for aluminium alloys.

$$= \pi \times 100^2 \times 5 / [4 \times (1.5d) \times 15.7]$$

$$d = 40.83 \text{ mm}$$

Step 5:

Theoretical Stress Calculation

$$\sigma_b = M_b / W_b \text{ MPa}$$

Where M_b is the bending moment and W_b is the moment of resistance to the bending

$$M_b = 1/3 \times P_{\max} \times r_1^3 \text{ MNm}$$

$P_{\max} =$ Maximum gas pressure in MPa . This value varies between 2-5 MPa in case of aluminium alloys. [3]

$r_1 =$ crown inner radius m

$$W_b = 1/3 \times G \times r_1^2 \text{ m}^3$$

$G =$ Thickness of piston crown m

$$r_1 = [D/2 - (s + t_r + dt)] \text{ m}$$

$dt =$ Radial clearance between piston rings and channel m

$s =$ Thickness of the sealing part m

$$= [0.1/2 - (0.005 + 0.0008 + 0.0031)] = 0.0413 \text{ m}$$

$$M_b = 1/3 \times 5 \times 0.0413^3$$

$$= 1.174 \times 10^{-4} \text{ MNm}$$

$$G = (0.08 \text{ to } 0.1) D \text{ m}$$

$$= 0.091 \times 100$$

$$= 9.1 \text{ mm}$$

$$W_b = 1/3 \times 0.0413 \times 0.0091^2$$

$$= 1.14 \times 10^{-6} \text{ m}^3$$

$$\sigma_b = 1.17 \times 10^{-4} / 1.14 \times 10^{-6}$$

$$= 103 \text{ MPa}$$

The theoretical stress value obtained is less than the allowable stress ($103 < 124 \text{ MPa}$). Hence the design is safe.

4. MODELLING IN CATIA V5R20

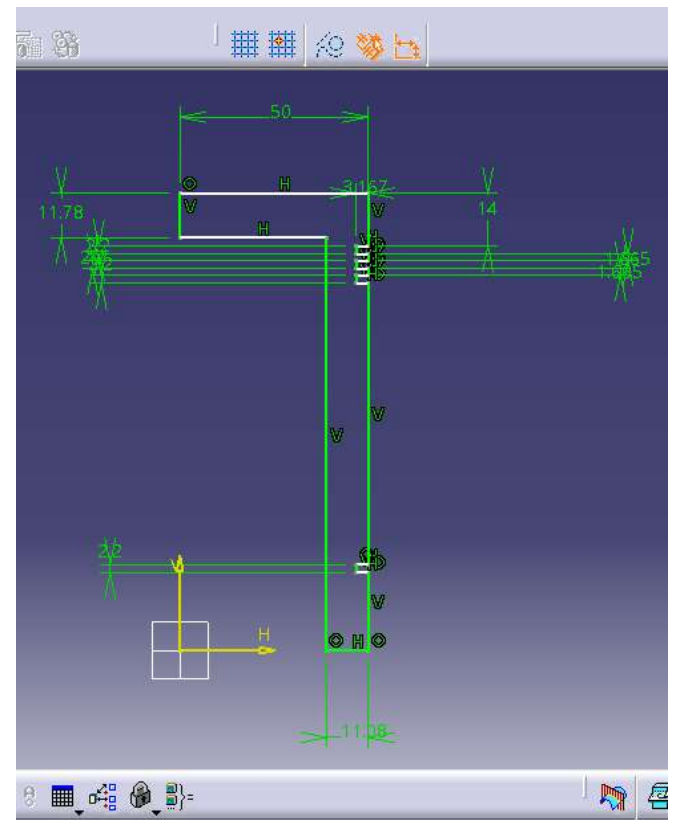


Fig. 1 Sketching in CATIA V5R20

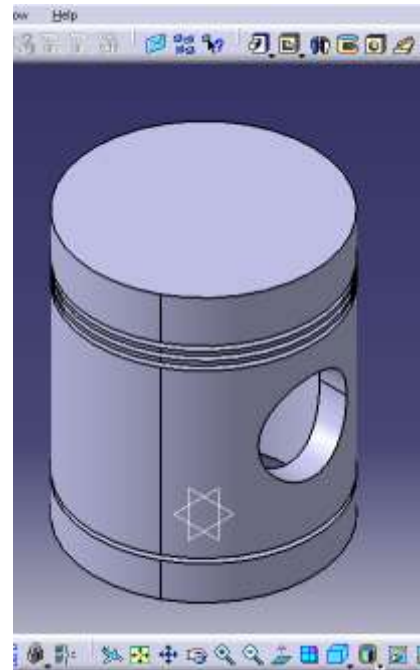
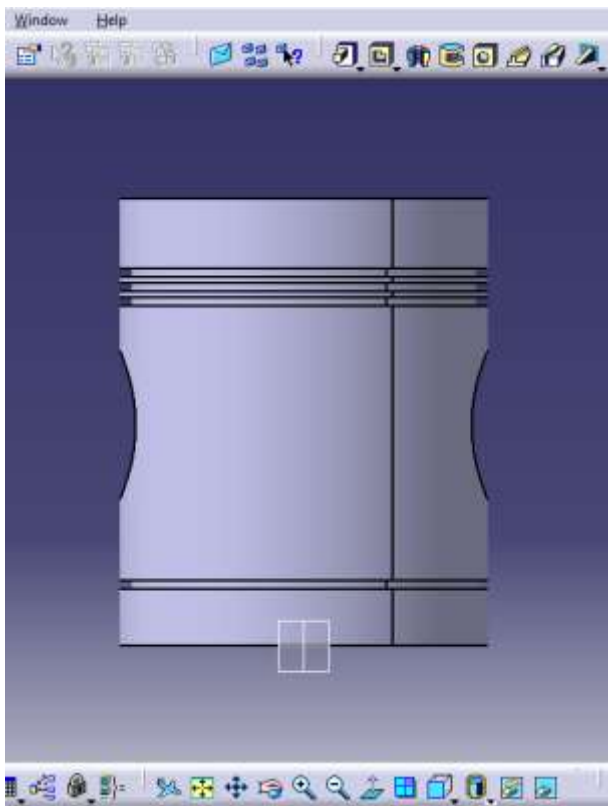
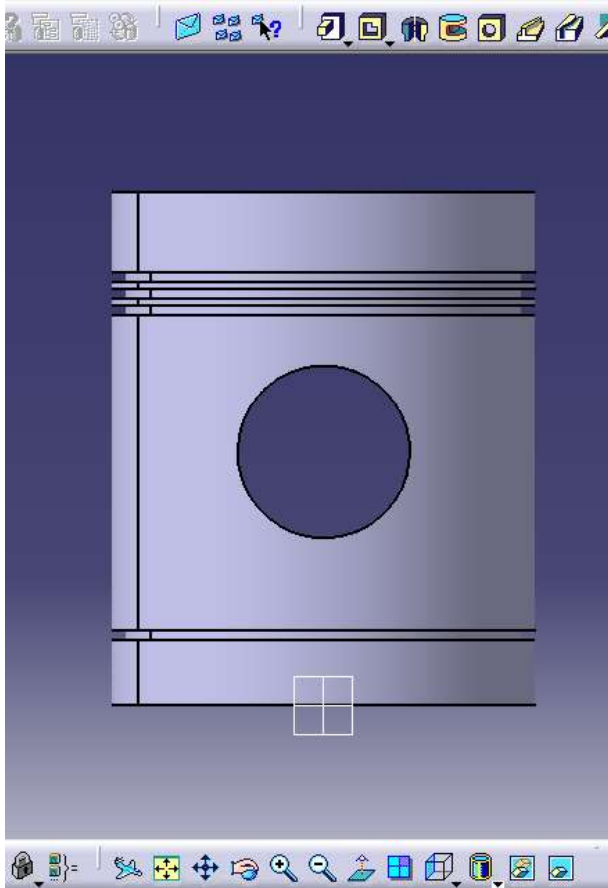


Fig.2 Piston head modeled in CATIA V5R20 based on above calculations

5. ANALYSIS IN ANSYS 14.5

After designing the model in CATIA V5R20 the model is converted to STP file and imported to ANSYS 14.5. Then analysis is carried out accordingly in following steps.

5.1 Defining the Material

Aluminum alloy is chosen and applied to the imported model. All the material properties of aluminum alloy are predefined by the software.

5.2 Meshing the Model

In order to analyze the model by FEM meshing of the model must be done. The element size and shape of the mesh are defined. Here we have considered the element size as 15 and shape of the mesh as triangular.

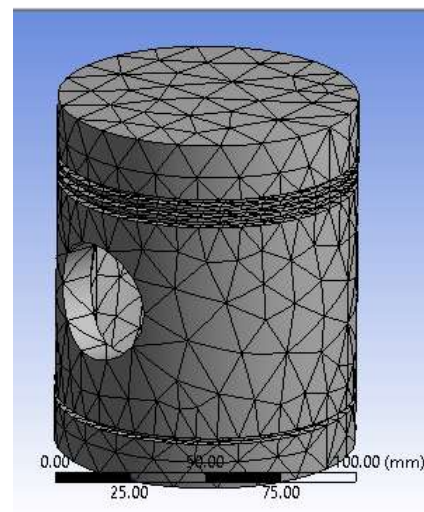


Fig.3 Meshing of the model in ANSYS 14.5

5.3 Structural Analysis

5.3.1 Restraining the Model at Piston Pin Holes

Piston pin holes are considered as fixed support. Hence frictionless support is applied and it is restrained at its holes.

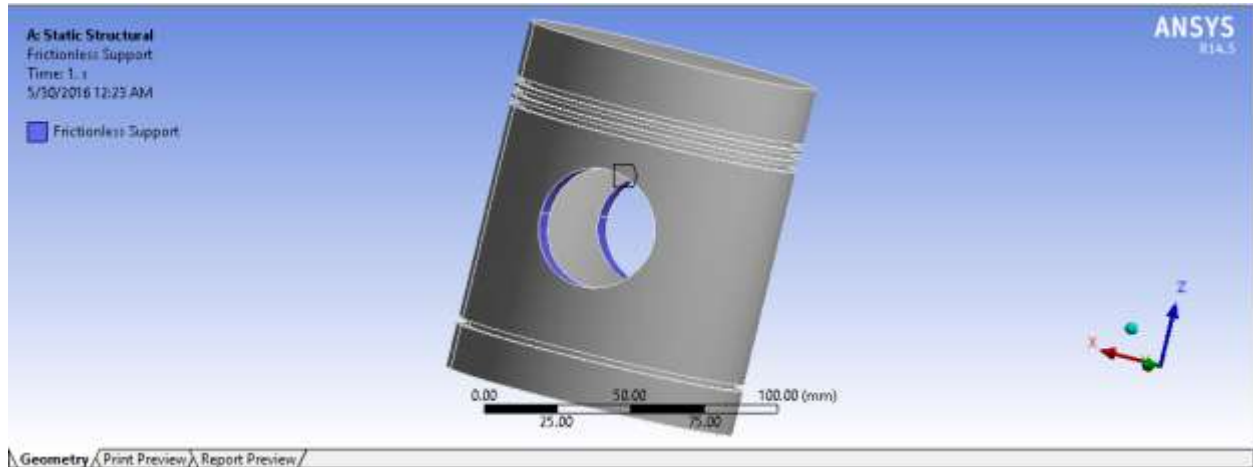


Fig.4 Restraining the model at piston pin holes

5.3.2 Applying Pressure on Top Surface

For static structural analysis the pressure of magnitude 5 MPa is applied on the top surface of the piston head. The gas combustion pressure for aluminum alloy is 5 MPa.

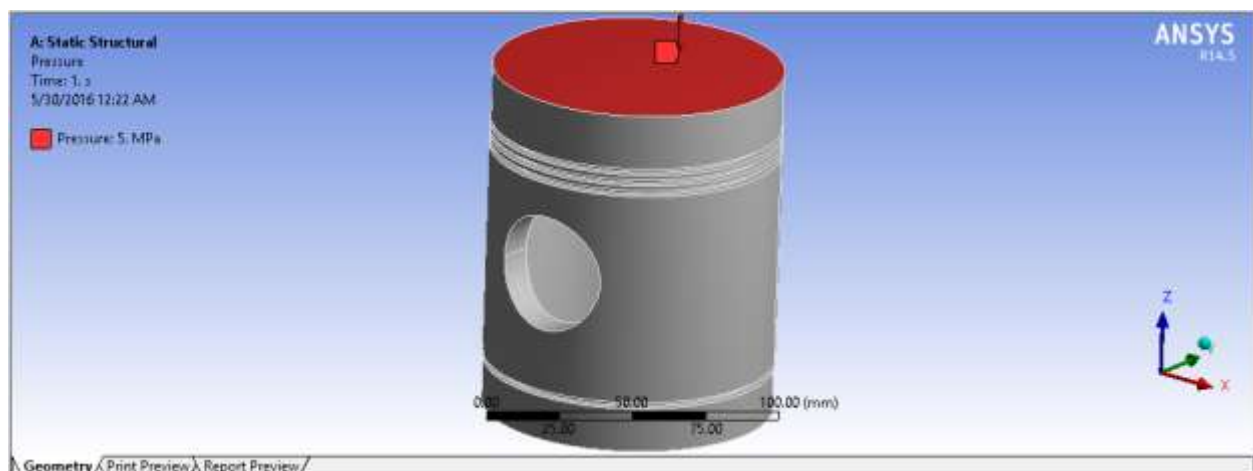


Fig.5 applying the pressure on top surface of piston head

6. RESULTS

The model is solved after applying the pressure and results are obtained for Von-Mises stress and structural deformation which are shown below. The value of structural deformation obtained is 0.7314 mm and stress value obtained is 103.32 MPa.

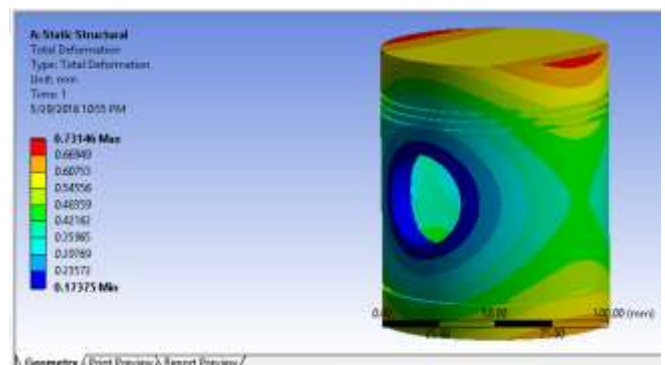


Fig.6 Results obtained for Structural deformation of piston head

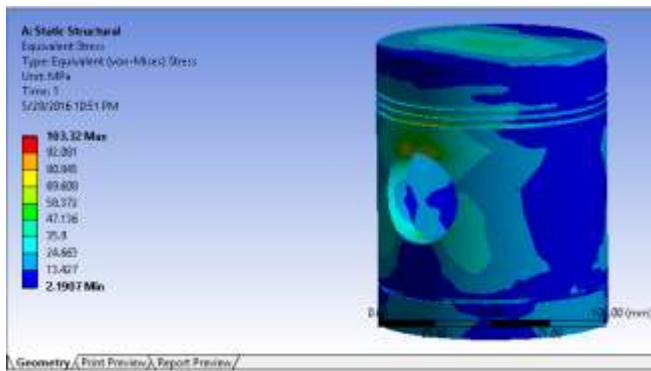


Fig.7 Results obtained for stress in piston head



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7. CONCLUSION

The following conclusions can be drawn after the analysis

- The theoretical stress value obtained is very close to the stress values obtained after analysis of the model in ANSYS 14.5.
- The structural deformation is least at the piston pin holes and maximum at the top surface.
- The stress concentration is highest at piston pin holes.

8. RECOMMENDATIONS

- The analysis can be further carried out for thermal analysis from which we can compute the thermal stress induced in various portions of piston head.
- Dynamic and vibrational analysis also can be carried out to study dynamic behavior.
- CFD analysis can be performed in order to compute the fluid forces, heat flow and impact of fluid pressure on piston.

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BIOGRAPHIES



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