

Design and Structural Analysis of IC Engine Piston Using FEA Method

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Abstract— Piston is the part of engine which converts heat and pressure energy liberated by fuel combustion into mechanical works. Engine piston is the most complex component among the automobiles. This paper illustrate design procedure for a piston for 4 stroke petrol engine for hero splendor –pro bike and its analysis by its comparison with original piston dimensions used in bike. The design procedure involves determination of various piston dimensions using analytical method under maximum power condition. In this paper the combined effect of mechanical and load is taken into consideration while determining various dimensions. The basic data of the engine are taken from a located engine type of hero splendor –pro bike. the 3D model of this piston modeled using CATIAV5R20 and analysis done using ANSYS 14

Keywords—piston, engine, hero splendor pro, CATIAV5 R20, ANSYS14

INTRODUCTION

Piston is one of the mechanical component, piston invented in a German scientist Nicholas August Otto in year 1866



Fig 1: Father of piston

Piston is considered to be one of the most important parts in a reciprocating Engine, reciprocating pumps, gas compressors and pneumatic cylinders, among other similar mechanisms in which it helps to convert the chemical energy obtained by the combustion of fuel into useful (work) mechanical power. The purpose of the piston is to provide a means of conveying the expansion of gases to the crankshaft via connecting rod. The piston acts as a movable end of the combustion chamber. Piston is essentially a cylindrical plug that moves up & down in the cylinder. It is equipped with piston rings to provide a good seal between the cylinder wall,

Functions of Piston

1. To reciprocate in the cylinder as a gas tight plug causing suction, Compression, expansion, and exhaust strokes.

2. To receive the thrust generated by the explosion of the gas in the cylinder And transmit it to the connecting rod .
3. To form a guide and bearing to the small end of the connecting rod and to take the side thrust due to obliquity of the rod.

Piston Assemble Model

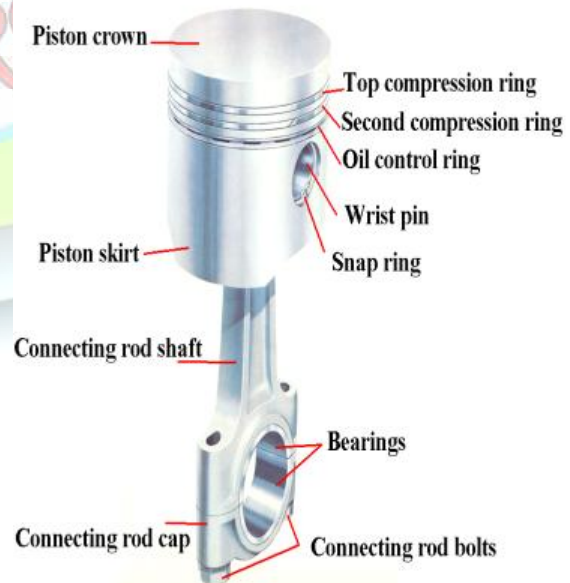


Fig 2 : piston assembly

Factors Considered For Proper Functioning Of Piston

1. The piston should have enormous strength and heat resistance properties to withstand gas pressure

and inertia forces. They should have minimum weight to minimize the inertia forces.

2. The material of the piston should have good and quick dissipation of heat from the crown to the rings and bearing area to the cylinder walls. It should form an effective gas and oil seal.

3. Material of the piston must possess good wearing qualities, so that the piston is able to maintain sufficient surface-hardness unto the operating temperatures.

4. Piston should have rigid construction to withstand thermal, mechanical distortion and sufficient area to prevent undue wear. It has even expansion under thermal loads so should be free as possible from discontinuities

Major force acting over piston

1. Due to explosion of fuel gases
2. Due to compression of fuel gases
3. Side wall friction and forces
4. Thermal load

Engine Type	Air-cooled, 4-stroke single cylinder OHC
Displacement	97.2 cc
Max. Power	5.66 KW, @5000 rpm
Max. Torque	7.130 N-m @ 2500 rpm
Compression Ratio	9.9 : 1
Starting	Kick Start / Self Start
Ignition	DC - Digital CDI
Bore	50 mm
Stroke	49 mm

5. Inertia force due to high frequency of reciprocation of piston
6. Friction and forces at crank pin hole

PISTON DESIGN

Nomenclature of Piston

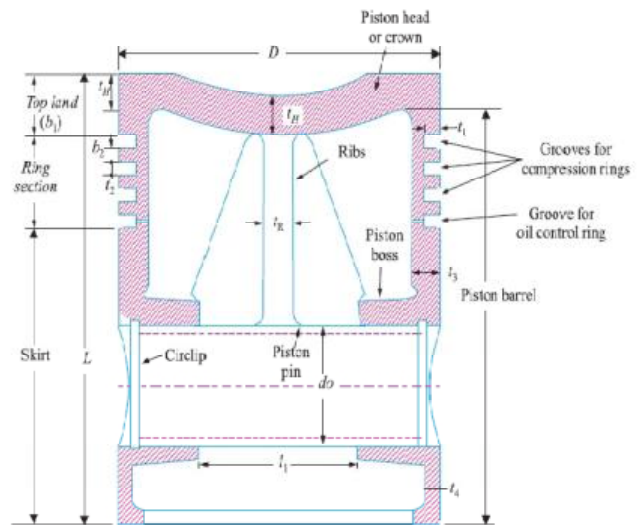


Fig 3 : Nomenclature of Piston
Design Considerations Of A Piston

In designing a piston for I.C. engine, the following points should be taken into consideration

1. It should have enormous strength to withstand the high gas pressure and inertia forces.
2. It should have minimum mass to minimize the inertia forces.
3. It should form an effective gas and oil sealing of the cylinder.
4. It should provide sufficient bearing area to prevent undue wear.
5. It should disperse the heat of combustion quickly to the cylinder walls.
6. It should have high speed reciprocation without noise.
7. It should be of sufficient rigid construction to withstand thermal and mechanical distortion.
8. It should have sufficient support for the piston pin.

Piston Function Design Requirement

1. Easily move to the reciprocating motion inside of cylinder
2. Reducing friction between the connecting rod and piston pin
3. There is no strain occurring the piston pin
4. Piston move even at minimum pressure

Piston Structural Design Requirement

1. Piston designed in cylindrical shape because easily Move to the up & down direction
2. Piston should be a compact size
3. Piston head geometry (curve, flat) should be in correct shape so that in gives maximum efficiency

Characteristics Of Piston

1. Hammering effect of a combustion gas



- pressure.
2. High temperature of the gases.
3. Light in weight.
4. Silent in a operation.
5. Mechanically strong

By knowing the basic engine specifications like bhp, bore , stroke, compression ratio ,maximum power and maximum torque

We Find the Various Dimensions Of The Piston Which Are Sated Below:-

- Thickness of the piston head
- Radial thickness of the ring
- Axial thickness of the ring
- Height of the first land
- Thickness of the piston barrel
- Radial thickness of ring groove
- Length of piston skirt
- Length of piston
- Diameter of piston pin hole
- Thickness of piston at open end

III.THEORETICAL CALCULATION FOR PISTON

1) Torque

$$P = \frac{2\pi NT}{60}$$

We know that $p=5.6 \text{ kw}$
 $5.6 \times 10^3 = 2 \times 3.14 \times 7500 \times T / 60$
 $T=7.130 \text{ N-m}$

2) Diameter of piston

$$\pi r^2 h = cc$$

Cylinder area = displacement

We know that displacement so to find diameter of piston

$$3.14 \times r^2 \times 0.049 = 97 \times 10^{-6} \text{ m}^3$$

r = radius

Diameter $D = 2 \times r$

$$\mathbf{D = 2 \times 0.025 \text{ m} = 0.05 \text{ m} = 50 \text{ mm}}$$

3) Cylinder inside pressure

Pressure = force/area (F/A)

Force = power/velocity (P/V)

We know that power

$$\text{Velocity} = 2LN/60 = 2 \times 0.049 \times 5000/60 = \mathbf{8.16 \text{ M/S}}$$

$$\text{Force} = 5.6 \times 10^3 / 8.16 = \mathbf{686.274 \text{ N}}$$

$$\mathbf{P = \text{Force}/\text{Area}}$$

$$\text{Area} = \pi r^2 = 3.14 \times (0.025)^2 = 1.934 \times 10^{-3} \text{ M}^2$$

$$P = 686.27 / 1.934 \times 10^{-3} = 0.34953 \text{ Mpa}$$

(minimum)

Maximum pressure = 15 Mpa

$$P_{\text{max}} = 15 \times 0.34953 = 5.24 \text{ Mpa}$$

$$\mathbf{\text{Max pressure} = 5.24 \text{ Mpa}}$$

The Procedure For Piston Designs Consists Of The Following Steps:

1) Thickness of piston head

The Piston Thickness Of Piston Head Calculated Using Following Grashoffs Formula

$$t_H = D \sqrt{\frac{3}{16} \cdot \frac{P}{\sigma_t}} \text{ (in mm)}$$

Where

P = maximum pressure in N/mm^2

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

σ_t = permissible tensile stress for the material of the piston.

$$t_H = \mathbf{4.01 \text{ mm}}$$

2) Radial thickness of ring (t_1)

$$t_1 = D \sqrt{\frac{3 \cdot P_w}{\sigma_t}} \text{ (in mm)}$$

Where,

D = cylinder bore in mm

P_w = pressure of fuel on cylinder wall in N/mm^2 . Its value is limited from 0.042 N/mm^2 to 0.0667 N/mm^2

For present material, σ_t is 152.2 Mpa

$$t_1 = \mathbf{1.812 \text{ mm}}$$

3) Axial thickness of ring (t_2)

The thickness of the rings may be taken as

$$t_2 = 0.7 t_1 \text{ to } t_1$$

$$t_2 = 0.92 \times 1.812$$

$$t_2 = \mathbf{1.66 \text{ mm}}$$

4) Top land thickness (b_1)

The width of the top land varies from

$$b_1 = t_H \text{ to } 1.2 \times t_H$$

$$b_1 = 1.2 \times 4.01$$

$$\mathbf{b_1 = 4.81 \text{ mm}}$$



5) Thickness of other land (b_2)

$$b_2 = 0.75 \times t_2 \text{ to } t_2$$

$$b_2 = 0.75 \times 1.66$$

$$b_2 = 1.242 \text{ mm}$$

6) Maximum thickness of barrel (t_3)

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

$$b = t_1 + 0.4$$

$$b = 1.812 + 0.4$$

$$b = 2.212 \text{ mm}$$

$$t_3 = 0.03 \times D + 2.212 + 4.5 \text{ mm}$$

$$t_3 = 8.212 \text{ mm}$$

7) open end of the barrel thickness (T_{open})

At the open end the thickness is taken as

$$T_{\text{open}} = (0.20 \text{ to } 0.30 T_p)$$

$$T_{\text{open}} = 0.25 \times 8.212 = 2.053$$

$$T_{\text{open}} = 2.053 \text{ mm}$$

8) Gap between the rings (T_L)

$$T_L = 0.055 \times D$$

$$T_L = 2.75 \text{ mm}$$

$$\text{Second ring} = 0.04 \times D = 0.04 \times 50 = 2.00 \text{ mm}$$

9) Depth of ring groove (D_r)

$$D_r = t_1 + 0.4$$

$$D_r = 1.812 + 0.4$$

$$D_r = 2.212 \text{ mm}$$

10) Length of piston

$$L_p = L_{ps} + 3 \times t_l + 3 \times D_r$$

Here L_{ps} is taken nearly as 0.5 of the piston diameter
(0.5D)

$$L_{ps} = 0.5D = 0.5 \times 50 = 25$$

$$L_{ps} = 25$$

$$L_p = 25 + 3 \times 1.812 + 3 \times 2.212$$

$$L_p = 37.072 \text{ mm}$$

11) Piston pin diameter

$$P_{do} = 0.3D \text{ to } 0.45D,$$

$$P_{do} = 0.32 \times 50$$

$$P_{do} = 16 \text{ mm}$$

$$P_{di} = 12 \text{ mm}$$

Table: 2 Parameters dimension

PARAMETERS	CALCULATED VALUES (mm)	ACTUAL VALUES (mm)
Piston length	37.072	37
Piston diameter	50	49.5
Piston hole external diameter	16	14
Piston hole internal diameter	12	9
Piston axial thickness	1.63	0.8
Piston radial thickness	1.812	2
Depth of ring groove	2.212	2.01
Gap between the rings	2.75	2.6
Top land thickness	4.01	5.6
Piston top end thickness	4.81	6.6
Piston open end thickness	2.053	1.7

IV MATERIALS FOR PISTON

The most commonly used materials for pistons of I.C. engines are cast iron, cast aluminum, forged aluminum, cast steel and forged steel. The cast iron pistons are used for moderately rated engines with piston speeds below 6 m/s and aluminum alloy pistons are used for highly rated engines running at higher piston speeds. It may be noted

1) Since the coefficient of thermal expansion for aluminum is about 2.5 times that of cast iron, therefore, a greater clearance must be provided between the piston and the cylinder wall in order to prevent seizing of the piston when engine runs continuously under heavy loads. But if excessive

clearance is allowed, then the piston will develop 'piston slap' while it is cold and this tendency increases with wear. The less clearance between the piston and the cylinder wall will lead to seizing of piston.

2) Since the aluminum alloys used for pistons have high **heat conductivity (nearly four times that of cast iron), therefore, these pistons ensure high rate of heat transfer and thus keeps down the maximum temperature difference between the center and edges of the piston head or crown.

3). Since the aluminum alloys are about three times lighter than cast iron, therefore, its mechanical strength is good at low temperatures, but they lose their strength (about 50%) at temperatures above 325°C. Sometimes, the pistons of aluminum alloys are coated with aluminum oxide by an electrical method.

Table: 3 Material Properties

V FAILURE MODES OF PISTON

There are two types of piston failure

- 1) **Rough out failure**
- 2) **Wrong out failure**

Rough out failure

- ✓ Damage from Running Unmixed Fuel
- ✓ Damage from Over-Speeding the Engine
- ✓ Damage from Detonation
- ✓ Damage from Heat Seizure

Wrong out failure

- ✓ Damage from Debris Getting Through the Air Filter
- ✓ Damage from Bearing Failure

VI MODELING OF PISTON IN CATIA

The 2D sketch of the piston in CATIA sketch window as shown in the Fig below



Fig 4: Line Sketch of the Piston

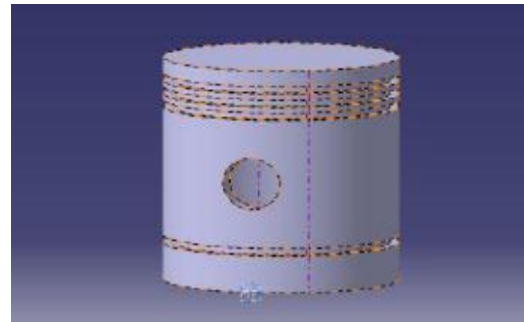


Fig 5: 3D Sketch of the Piston

VII STRUCTURAL ANALYSIS

Structural analysis is the determination of the effects

MATERIAL	ALUMINIUM ALLOY
Young's Modulus	71GPa
Poisson ratio	0.33
Coefficient of conduction	174.15 W/mK
Tensile strength	485MPa
Yield strength	435MPa
Density	2.77E-6 kg/mm

of loads on physical structures and their components. Structures subject to this type of analysis include all that must withstand loads, such as buildings, bridges, vehicles, machinery, furniture, attire, soil strata, prostheses and biological tissue. Structural analysis incorporates the fields of applied mechanics, materials science and applied mathematics to compute a structure's deformations, internal forces, stresses, support reactions, accelerations, and stability. The results of the analysis are used to verify a structure's fitness for use, often saving physical tests. Structural analysis is thus a key part of the engineering design of structures.

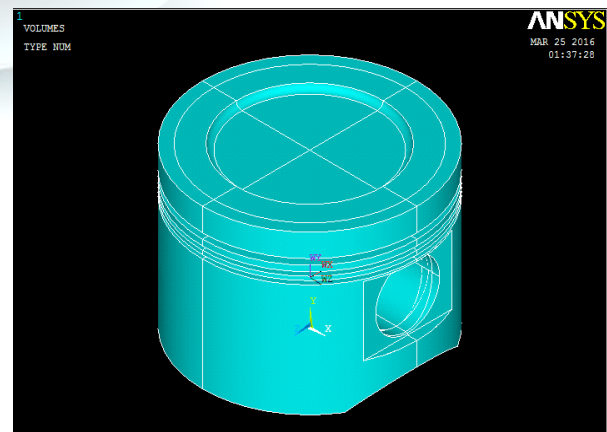


Fig 6: Imported ANSYS Model

In order to avoid complexity the model was divided in to four equal parts & one part is taken for analysis

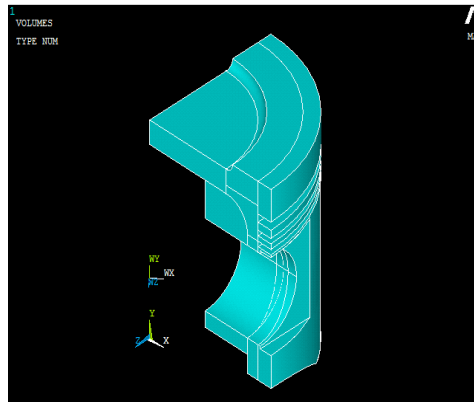


Fig 7: Meshing model

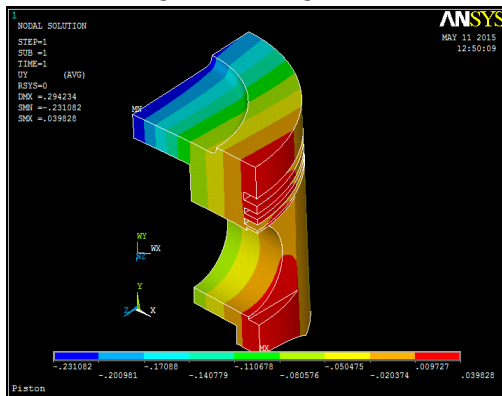


Fig 8: DOF SOLUTION FOR Y DIRECTION

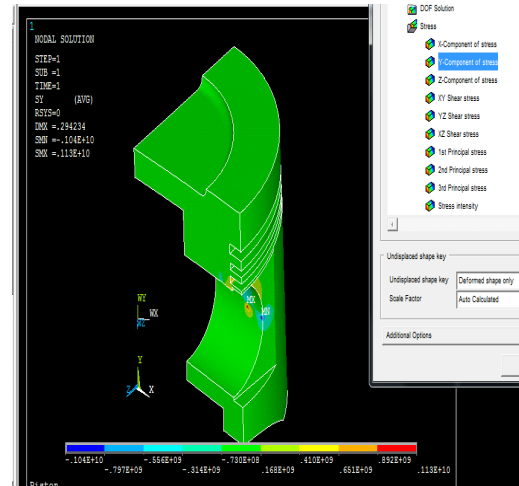


Fig 9: STRESS ANALYSIS IN Y DIRECTION

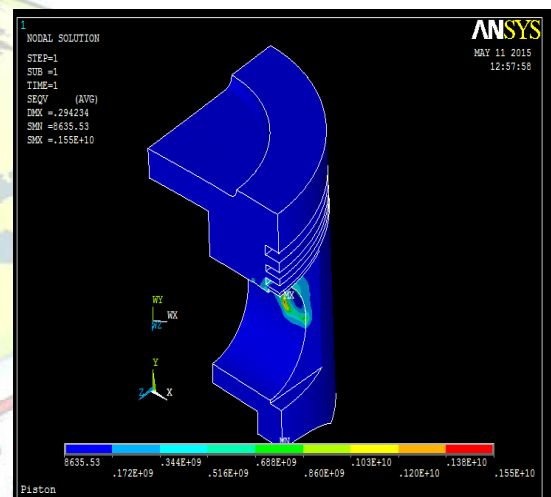


Fig 10 : VONMISES STRESS

FACTOR OF SAFETY

$$\text{Ultimate stress} = 0.155e^{10}$$

$$\text{Normal stress} = 152.2e^6$$

$$\text{Factor of safety} = \frac{\text{Ultimate stress}}{\text{Normal stress}}$$

$$= \frac{0.155e^{10}}{152.2e^6} = 10.157$$

$$\text{Factor of safety} = 10.157$$

VIII RESULT AND DISCUSSION

The result given above are first calculated by using the formulas presented in paper and then compared with the dimensions of the actual pistons currently being used in the hero splendor bikes then the piston is to be designed CATIA& analyzing used ANSYS software



IX. CONCLUSION

The fundamental concepts and design methods concerned with single cylinders petrol engine have been studied in this paper the results found by the use of this analytical method are nearly equal to the actual dimensions used now a days. Hence it provides a fast procedure to design a piston which can be further improved by the use of various software and methods. The most important part is that very less time is required to design the piston and only a few basic specification of the engine From von misses stress analysis the ultimate stress obtained using analytical method yields the value is $155e^7 \text{ N/m}^2$ The stress assumed for the design calculation is $152e^6 \text{ N/m}^2$ therefore the design is safe as for the assumed stress value Also the parameter of piston are safe as for the assumed condition the factor of safety 10.157

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