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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 automotives. 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,herosplendor pro,
CATIAV5R20,ANSYS14

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INTRODUCTION

Piston is one of n 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

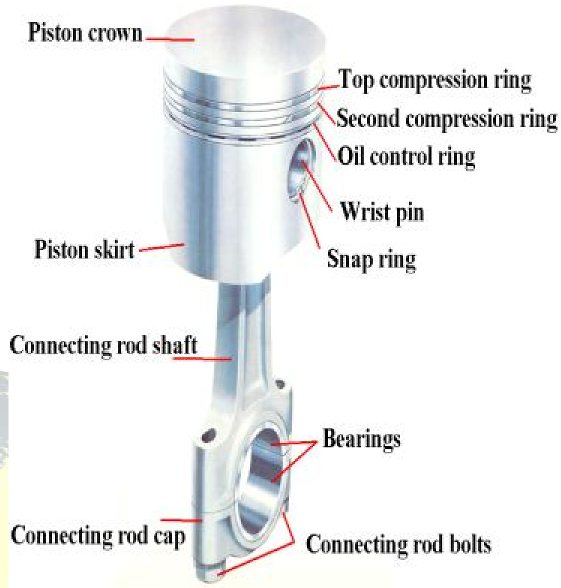

Fig 2 : piston assembly

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

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PISTON DESIGN

Nomenclature of Piston

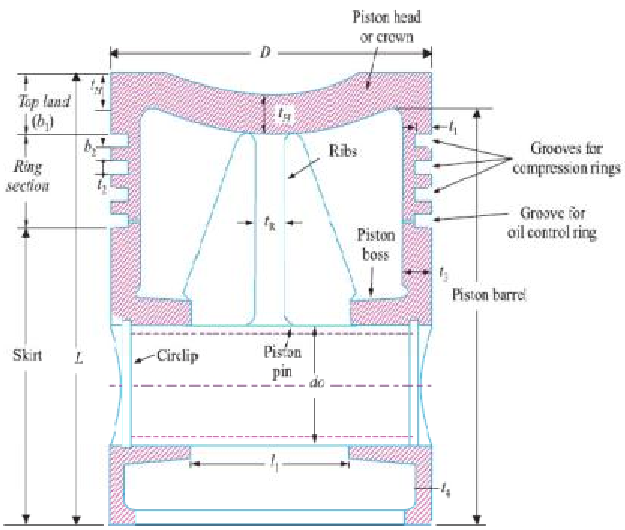

Fig 3 : Nomenclature of Piston

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.

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**

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

Table1:Technical Specifications **(splendor-pro)**

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

a) Thickness of the piston head
b) Radial thickness of the ring
c) Axial thickness of the ring
d) Height of the first land
e) Thickness of the piston barrel
f) Radial thickness of ring grove
g) Length of piston skirt
h) Length of piston
i) Diameter of piston pin hole
j) Thickness of piston at open end

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III.THEORETICAL CALCULATION FOR PISTON

1) Torque

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

We know that p=5.6 kw

$5.6\times e^3 = 2\times 3.14\times 7500\times T / 60$

T=7.130 N-m

2) Diameter of piston

$\pi r^2 h = cc$

Cylinder area = displacement

We know that displacement so to find diameter of piston

$3.14\times r^2\times 0.049 = 97\times E^{-5}\ m^3$

r = radius

Diameter D = 2×r

D = 2*0.025 m =0.05m=50mm

3) Cylinder inside pressure

Pressure = force/area (F/A)

Force =power/velocity (P/V)

We know that power

Velocity =2LN/60=2×0.049*5000/60= **8.16M/S**

Force $=5.6e^3/8.16$ = **686.274N**

P = Force/Area

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

$P = 686.27/1.934E^{-3} = 0.34953$ Mpa

(minimum)

Maximum pressure =15 Mpa

P max =15× 0.34953 =5.24 Mpa

Max pressure = 5.24 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

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

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.

t_H **= 4.01mm**

2) Radial thickness of ring (t_1)

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

Where,

D = cylinder bore in mm

Pw= pressure of fuel on cylinder wall in N/mm². Its value is limited from 0.042N/mm². to 0.0667 N/mm² For present material, σt is 152.2Mpa

t_1 =1.812mm

3) Axial thickness of ring (t_2)

The thickness of the rings may be taken as

t_2 = 0.7t1 to t1

t_2 = 0.92×1.812

t_2 =1.66mm

4) Top land thickness (b_1)

The width of the top land varies from

$b_1 = t_H$ to $1.2\times t_H$

$b_1 = 1.2\times 4.01$

b_1 =4.81mm

5) Thickness of other land (b_2)

$b_2 = 0.75\times t_2$ **to** t_2

$b_2 = 0.75\times 1.66$

b_2 = 1.242mm

6) Maximum thickness of barrel (t3)

$t_3 = 0.03\times D + b + 4.5$mm

b = t1+0.4

b = 1.812+0.4

b = 2.212mm

$t_3 = 0.03\times D + 2.212 + 4.5$mm

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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

t_3 = 8.212mm

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

At the open end the thickness is taken as

T_{open} = (0.20 to0.30Tp)

T_{open} = 0.25 × 8.212 =2.053

T_{open} = 2.053mm

8) Gap between the rings (T_L)

T_L= 0.055 × D

***T_L* =2.75 mm**

Second ring = 0.04 ×D =0.04×50 = **2.00mm**

9) Depth of ring groove (D_r)

D_r = t1 + 0.4

D_r = 1.812 +0.4

D_r = 2.212 mm

10) Length of piston

$L_p = L_{ps} + 3\times t_1 + 3\times D_r$

Here Lps is taken nearly as 0.5 of the piston diameter
(0.5D)

L_{Ps} =0.5D =0.5 × 50 = 25

L_{Ps} = 25

L_P = 25 + 3× 1.812 + 3 ×2.212

L_P = 37.072mm

11) Piston pin diameter

P_{do} = 0.3D to 0.45D,

P_{do} = 0.32 × 50

P_{do} = 16mm

P_{di} = 12mm

Table: 2 Parameters dimension

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.

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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

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

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

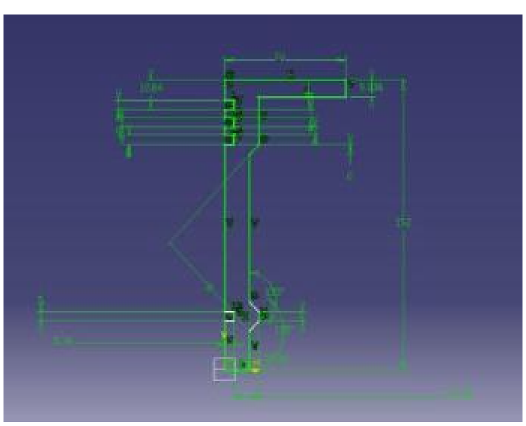

Fig 4 : Line Sketch of the Piston

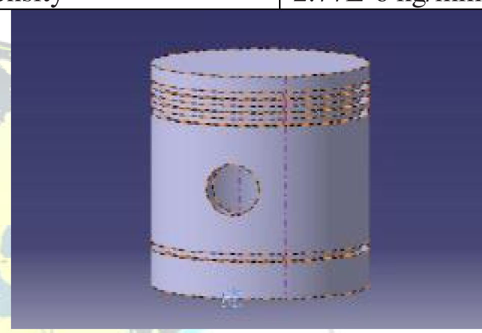

Fig 5 : 3D Sketch of the Piston

VII STRUCTURAL ANALYSIS

Structural analysis is the determination of the effects 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.

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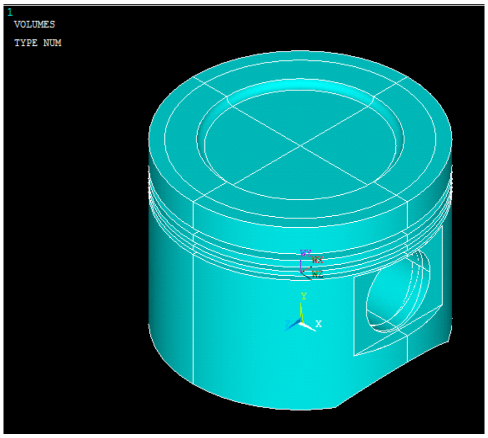

Fig 6: Imported ANSYS Model

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

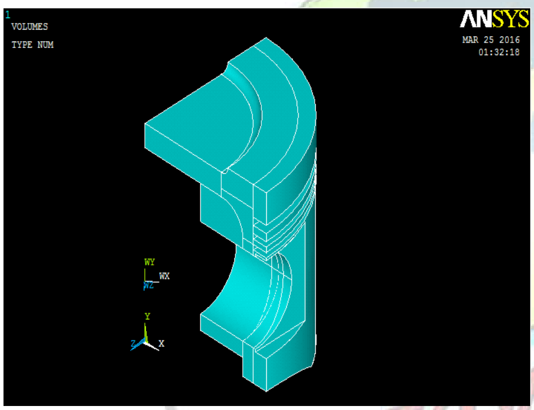

Fig 7: Meshing model

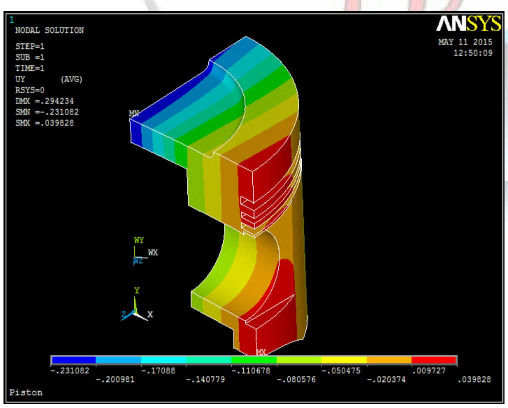

Fig 8: DOF SOLUTION FOR Y DIRECTION

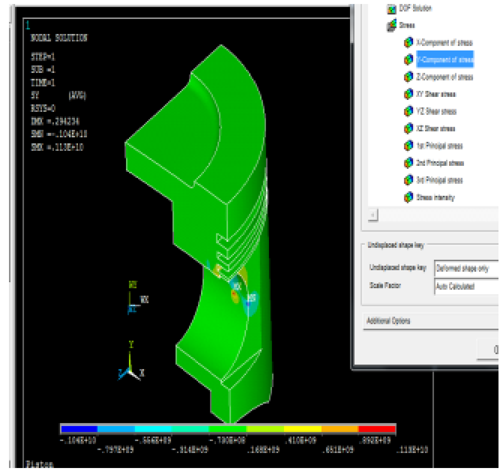

Fig 9: STRESS ANALYSIS IN Y DIRECTION

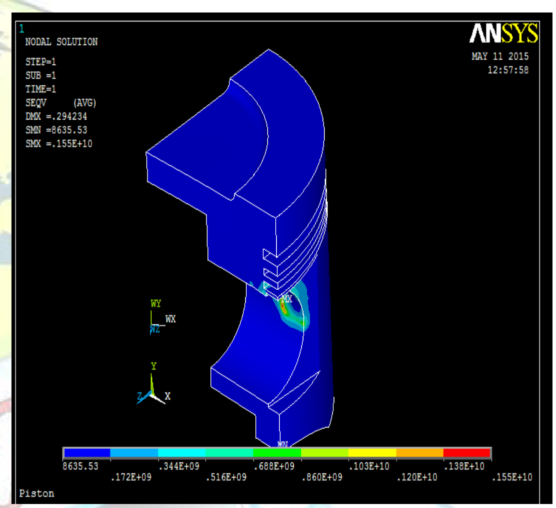

Fig 10 : **VONMISSES STRESS**

FACTOR OF SAFETY

Ultimate stress $= 0.155e^{10}$

Normal stress $= 152.2e^{6}$

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

$$= \frac{0.155e10}{152.2e6} = 10.157$$

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 $155e^7$ N/m^2 The stress assumed for the design calculation is $152e^6$ 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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