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Investigation on Structural Analysis of Flat Head Piston

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ABSTRACT

In the investigation on structural analysis of flat head piston deflection and stress equations plays major role in mathematical modeling. The same has been used in this analysis. In the part of the analysis the thickness of the flat head of the piston is considered as the same of that of simply supported circular plate and the loads are applied on it reacts with the supports held at the top of the gudgeon hole. The piston is same as one side closed cylinder and ended with flat circular plate. It is the most general that the deflections due to axial loads are neglected. Hence the deflection and stress equations of the simply supported circular plate are adopted. Aluminum is taken as material of the component throughout the analysis and grey cast iron is taken as material for the rings in the modeling of the piston. Flexural rigidity plays a major role in the calculation for the analysis. The results of the mathematical analysis have been compared with the same of that of simulation using ANSYS software.

Key words: Flat Head Piston, Deflection, Stress, Structural Analysis

1.INTRODUCTION

A piston is an important and main component of an Internal Combustion(IC) engine moving in between top and bottom dead centers. Every IC engine is working on the combustion of liquid or gaseous fuel like diesel, bio-diesel, petrol or compressed natural gases etc [1]. Thermal expansion of gases during and after combustion of fuel takes place and as a results the forces exerts on the piston head causes deflection and stresses induces on it due to fatigue loading in the cyclic process. This takes place due to long time running of an engine[2],[3]

In view of design and modeling of the strengthened piston these deformations and stress induced are necessary to determine and can be done by the structural analysis. The crown or flat head of the piston can be considered as circular plate. The circular plate undergoes the deformation and stress induced due to loads applied on it. In the similar way the top of the flat head undergoes deformation and stress induces the stress due to thermal loads applied on it. In the cyclic process the fatigue loading takes place due to these thermal loads for long time running of the piston. In case of the piston the thermal loads are considered as the loads applying on the circular flat head which are normal to the surface.

The supports in case of the piston are fixed at gudgeon hole as its pin lift and reacts to the thermal loads applied on the top and similar to that of circular plate. The deflection due to axial loads are however negligible. Hence the supports can be held at any point of the distance from the head of the piston.

The analytical solution for the deformation and stress induced in the flat head of the piston can be obtained in the same way that of circular plate. The same has been analyzed using ANSYS software for the comparison of the results.

2.MATERIALS

Aluminum alloys can be selected as base metal for piston since it has good thermal conductivity [4]. The performance can be improved on heat treatment process [5]. Most generally the cast iron can be used as a metal for the piston rings [6].

The temperature will rise and fall on combustion of fuel takes place on the top and cooling of engine respectively. As a result of the thermal loads acts on the piston head, the structure of the piston will undergoes to deformation and stresses will be induced[7][8] . Hence the thermal properties are also important along with the physical properties. Therefore thermal properties will also be taken into consideration while modeling and design of the piston for structural analysis. The following Table I represents the maximum values of physical and thermal properties aluminum and cast iron for piston and piston rings respectively [9]-[13].

Table 1: Properties of Piston and its Coating Materials.

Physical-Thermal Properties (in SI units)		Piston Al Alloy	Piston Rings (CI)
Physical Properties	Density (Kg/m^3)	2685	7100
	Modulus of Elasticity (GPa)	85	190
	Poisson's Ratio	0.3	0.3
	Ultimate Tensile Strength(MPa)	385	910
	Tensile Yield Strength (MPa)	320	610
Thermal Properties	Thermal Conductivity [W/m ^{O}C]	172	15
	Thermal Expansion X 10^{-6} [1/ ^{O}C]	22	11
	Specific Heat [J/Kg ^{o}C]	855	450

3.MODELING AND DESIGN OF THE PISTON

Mathematical modeling is the part of the design and it is the description of calculations using various formulae for known and unknown parameters [14],[15]. The model and design of the piston can be developed by Finite Element Method and same can be done by using ANSYS Software.

4.DIMENSIONS OF THE PISTON

The following dimensions shown in the Table II are obtained from the calculations consisting of various respective formulae [16].

Table 2: Design Specifications

S.No.	Dimensions	Size in mm
1	Length of the Piston(L)	90
2	Cylinder bore/outside diameter of the piston(D)	80
3	Thickness of piston head (t_h)	12
4	Radial thickness of the ring (t_1)	2
5	Axial thickness of the ring (t_2)	2
6	Width of the top land (b_1)	12
7	Width of other ring lands (b_2)	4

5.STRUCTURAL ANALYSIS OF THE PISTON DETERMINATION OF DEFLECTION AND STRESS

The piston will undergo the deformation and stresses induced due to heavy loads applied on its flat head during the combustion. Hence in the structural analysis it is important to calculate using analytical method.

In this analysis circular plate theory is adopted as the head of the piston can be treated as a simply supported circular plate subjected to uniform distribution loads.

The deflection is given as

The supports are taken at the top point of the gudgeon hole and reacts to thermal loads. However the distance between the point of loads applied and the supports are not taken into consideration because the deflection due to axial loads are neglected. Hence the following equations can be used.

In circular plate with simply supported edges, the deflection of the surface due to pure bending by the moments is given by

$$\omega = \frac{q(a^2 - r^2)}{64D}\left(\frac{5 + \vartheta}{1 + \vartheta}\,(a^2 - r^2)\right)$$

Where
q is Intensity of a continuously distributed load
ϑ is Poisson's ratio
a is radius of the piston circular flat head
r is distance from a centre to a particular point and

Flexural rigidity is given by

$$D = \frac{Et^{\,3}}{12(1 - \vartheta^2)}$$

Where
E is Yung's Modulus of material
t_h is thickness of piston flat head

Substituting r = 0 then the deflection of the piston head at the centre is maximum and is given as

$$\omega_{max} = \frac{(5+\vartheta)qa^4}{64(1+\vartheta)D} \qquad (1)$$

The Maximum bending moment occurs at the centre of the piston flat head and is given by

$$M_r = M_t = \frac{3+\vartheta}{16}qa^2$$

And the Maximum Stress is given by

$$(\sigma_r)_{max} = (\sigma_t)_{max} = \frac{6M_r}{\ ^2} = \frac{3(3+\vartheta)qa^2}{8\ ^2} \qquad (2)$$

The above equations are obtained from the small deflection or classical plate theory.

ASSUMPTIONS:

According to Kirchhoff's hypotheses the following assumptions are made

1. The loads or pressure applied on the piston head are straight and normal to the surface
2. The deflection due to the above loads or pressure is very small. Hence the slope in deflection is neglected.
3. σ_x *and* σ_y the normal stresses are assumed to be zero
4. The shear stress is also assumed to be zero at the middle surface of the plate.
5. The stress in z direction is transverse to the other direction is small and neglected as compared with other stress components [17],[18].

6.RESULTS AND DISCUSSIONS

The deflection and maximum stress is obtained from the flexural and dimensional parameters of simply supported head of the piston from analytical method using ANSYS software.

For the aluminum piston with
Thickness of head t_h = 12mm
Young's Modulus E = 71000MPa
Pressure Applied q = 8MPa
Radius of the head a = 40mm
Then the corresponding
Flexural rigidity D = 11235164

The following Table III shows the Comparison of the deflection and stress obtained from Analytical Method and ANSYS

Table 3: Comparison of the deflection and stress

	ANALYTICAL	**ANSYS**
Deflection ω_{max}	0.0762 mm	0.0708 mm
Maximum stress $(\sigma_r)_{max}$	97 MPa	91.77MPa

The corresponding deflection occurs at centre of the piston head is shown in the following Figure 1

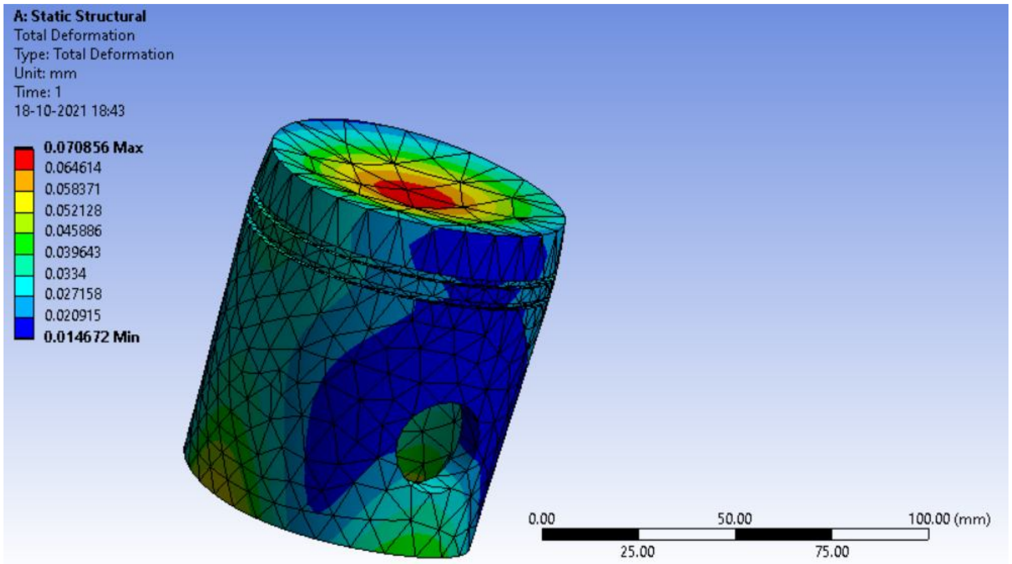

Figure 1: Deflection in Piston Head

The equivalent von-Mise stress taking place in the piston and is shown in below Figure 2

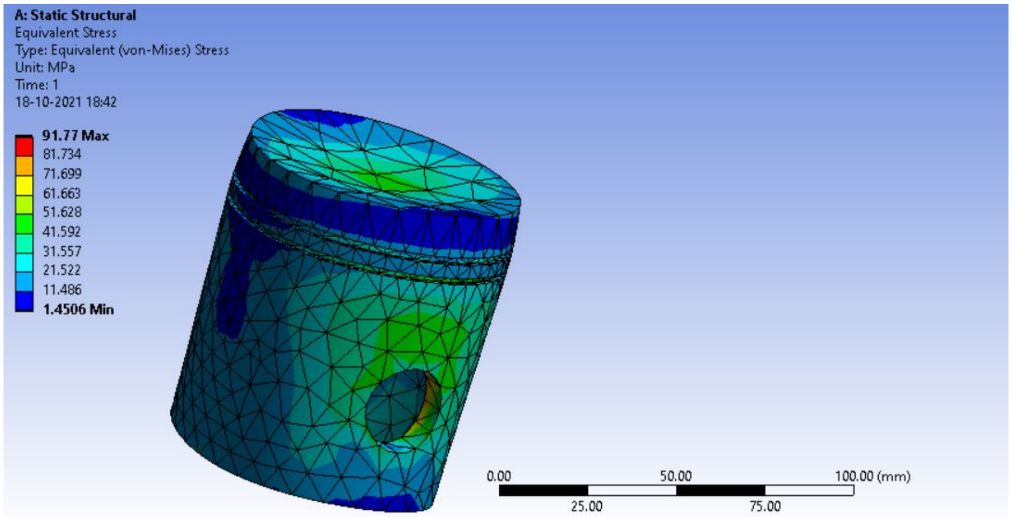

Figure 2: Equivalent von-Mises Stress

DISCUSSIONS

In this structural analysis the deflection and stress equations of simply supported circular plate were used for analytical solution. Since the head of the piston is in the circular shape. In this case it is necessary to determine the deflection occurs and stresses induced in the head of the piston. The simply supports were taken in the gudgeon hole where the gudgeon pin reacts the thermal loads applied on the top of the piston. The distance between the supports at the point and loads applied does not matter since the deflection due to the axial load is negligible. The same has been analyzed using ANSYS. The results were almost all same.

7.CONCLUSION

In the investigation on the structural analysis of the flat head piston, the top of the component is having circular shape. The mathematical modeling of the circular plate theory for deflection and stress adopted to calculate the same in case flat head piston. The same has been analyzed using ANSYS. The results of the analytical method compared with the same that of ANSYS gave for deflection and stress were 5.4% and 5.3% respectively. Hence it can be concluded that the mathematical modeling of the circular plate theory can be adopted for determining the deflection and stress.

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