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Thermal and Structural Analysis of CI Engine Piston for Different Open Type Combustion Chambers with Composite Materials Using CATIA & ANSYS Tools

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Abstract:

In this project, the work is process to find the stress and temperature distribution on the crown of the piston. In I.C. Engine, piston crucial part therefore for safe running of vehicle piston should be in proper working condition.The failure of Pistons due to structural and thermal stresses. piston Analysis is done with boundary conditions, which contains pressure on top of piston head during working condition and uneven distributed temperature from piston head to skirt. The analysis find that due to temperature whether the top of the piston damaged or broken during the working conditions, because broken or damaged parts are so expensive to replace and generally are not easily available.

The main objective of this preliminary analysis presented in this thesis was to compare the behaviour of the various open combustion chambers of piston made of various type of materials under thermal load. There are 4 types of open combustion chambers 1.Shallow depth chamber 2.Hemispherical chambers 3.Cylindrical chambers 4.Toroidal chambers. A thermo structural analysis of these different combustion chambers of engine piston was completed by using various composite materials. The piston was analysed by a temperature distribution inside it and appropriate average thermal boundary conditions such as temperatures and heat fluxes were set at different surfaces of the FE model.

The FE analyses were carried out by using CATIA and ANSYS software. In the same manner the analysis is being processed for various pistons which are discussed earlier with applying various materials like ALUMINIUM ALLOYS-286 and INCONEL alloy 625 with application of same thermal load and pressure for all four pistons. From the analysis it is found that the Factor Safety plays a best role, which gives more life time for all conditions and more suitable for present generation for 100% combustion of fuel in combustion chamber to increase the efficiency. Hemispherical combustion chamber proves to be the best, as it has highest factor of safety compared to other three types.

Keywords:

Combustion chamber, engine piston, coefficient of linear thermal expansion, thermal analysis, FE analysis.

1. INTRODUCTION:

Pistons are one of the most crucial components among all automobile and other industry field components. The piston can be called the heart of a engine. There are lot of research works processed, for pistons development like new materials, new geometries and other manufacturing techniques, and this evolution has undergone with a continuous improvement. There are a more number of damaged pistons. Pistons Damaged due to wear, temperature, and fatigue related.

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The main need of piston design is to measure the distribution of temperature on the surface of piston which tells us to optimize the thermal aspects for design of piston at lower cost.

1.1 CLASSIFICATION OF COMBUSTION CHAMBERS OF C.I ENGINES:

The major function of C.I engine combustion chamber is to provide proper mixing of air and fuel in less time. In order to get this, an organized movement of air called swirl is provided to generate very high relative velocity between the air the fuel droplets.

C.I engine combustion chambers are classified into 2 types: Direct Injection Type, Indirect Injection Type

1.2 TYPES OF PISTONS:

There are no. of designs of open combustion chamber some of which are shown below. These chambers generally consist of gap between a flat cylinder head and a cavity in the piston crown with different shapes. The fuel is directly injected into space. For this chamber the injection nozzles used are generally of multi-hole type running at a relatively high pressure (about 200 bar).

Shallow Depth Chamber:

In this chamber the cavity depth provided in the piston is quite small. This chamber is generally adopted for heavy engines running at less speeds. Here the diameter of cavity is very large, so the squish is negligible.

Hemispherical Chamber:

This chamber also gives little squish. However, the ratio of depth to diameter for a cylindrical chamber can be changed to provide any required squish to give better significance.

Cylindrical Chamber:

This design was done in present diesel engines. It is a modification of the l chamber in the form of a truncated cone with base angle of 30°.The produced swirl masking the valve for nearly 1800 of circumference. Squish can also be varied by varying the depth.

Toroidal Chamber:

The reason behind this shape is to give a required squish along with the air movement, which is similar to that of the familiar smoke ring, within the toroidal chamber. Due to requirewd squish the mask needed on inlet valve is small and there is better using of oxygen. The cone angle of spray for this type of chamber is 150° to 160°.

2. LITERATURE REVIEW:

3. Piotr Szurgott et al (2003) performed the Thermo mechanical FE analysis of the engine piston made of composite material with low histeresis[1] The material such as steel is excellent to heat resistance and corrosion resistance The cast iron is a highly brittle material with good machining ability also the cast iron weight is higher which increases the overall weight of the engine unnecessarily.So the study was carried out by author on the composite materials to find out the behavior of different piston material with the use of FEA, So the need has been raised to find out the best suitable material for the piston which can handle higher temperature and structural stresses which could not affect the working of piston.

Praful R. Sakharkar(2003) performed Thermal analysis of ic engine piston using FEA [2] The main objective of this proposed model is to increase the quality of piston to withstand high thermal and structural stresses and at the same time reduce stress concentration the top end of the piston [3]. The FEA is carried out for standard CI engine piston and the result of analysis are compared for maximum stress. Different types of alloys of aluminium are tested for maximum stiffness at operating thermo structural stress using FEA. Ghodake A. P et al (2014) performed Piston Design and Analysis by CAE Tools [3] It is observed that although fatigue is not only the responsible for biggest damage of pistons, but due to the induced stresses major portion of the piston failure [3].

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Also from analysis various results are obtained like The maximum depormatioin occurred about 0.29669mm due to the application of 180bar gas pressure on crown of piston , 231.25N/mm2 of maximum principal stress is observed., - 250.5 N/mm2 of minimum principal stress is observed. Also von mises stress of 200.97N/mm2 are observed.

3.GEOMETRY:

The model of piston is prepared by modeling software's CATIA V5.for the analysis we are use the analysis software ANSYS 14.5. For analysis, the following 3 types of boundary conditions are applied. Heat transfer co-efficient on the top surface. Inertia Forces for hemispherical piston & Pin Force.

3.1 Finite Element Model:

The element selected for meshing the piston model's solid187 tetrahedral element. The meshing size Elements are 23000 and no. Of nodes are 39334. The meshing element is shown below.

Table 1: COPARISION STATEMENT OF DIFFERENT PISTON MATERIALS:

PROPERTIES	CAST IRON	ALLOY STEEL	ALUMINIUM ALLOY-286	INCONEL ALLOY - 625
CTE, linear	15µm/m-°C	17.2µm/m-°C	16.5µm/m-°C	12.8 µm/m-°C
Tensile strength	310Mpa.	655MPa	620 MPa	880 Mpa
Yield strength	200Mpa.	415MPa	275 MPa	460 Mpa
Poisson's ratio [µ]	0.25	0.3	0.33	0.302
Young's Modulus [E]	125 GPa	207GPa	126 Gpa	140 Gpa

3.2.PROBLEM DEFINITION:

The mean temperature of gases will generally be in the order of 600°C-800°C .

Hence the stress analysis performed assuming the mean temperature of gases as 700℃ .

4. THEORETICAL CALCULATIONS

Boundary Conditions

In this coupled analysis, the following three types of boundary conditions are applied:

Heat Transfer Co-Efficient on the Top Surface

$$T_m = \frac{T_a + T_s}{2}$$

Where, T_m =Mean temperature

T_a = Ambient Temperature

T_s = Surface Temperature

$$\text{Reynolds No. Re} = \frac{\rho v d}{\mu}$$

Where, $\rho = \text{density in } Kg/m^3$

$\mu = \text{Absolute viscosity in } Nsec/m^2$

$$\text{Velocity of piston } v = 2 * L * N$$

Where,L=Stroke length

N=Speed in rpm

Nusselt No.=0.023 $Re_D^{0.8} Pr^n$ (Dittus-Boelter eq.)

n= 0.4 for heating of fluids

n= 0.3 for cooling of fluids

Where Pr=Prandtl No.

$$Nu = \frac{hd}{k}$$

Where, h=heat transfer coefficient in W/m^2K

d=diameter of the hemispherical bowl in m=0.03m

κ=Thermal conductivity in W/mK

Calculations

Assuming Ambient Temperature T_a=30°C = 303K

Surface Temperature T_s=700°C =973K

$T_m = \frac{30+700}{2}$=365°C=638K

From heat transfer data book,

κ=0.04549 W/mK

$\rho = 0.6628\ Kg/m^3$

Prandtl No.Pr=0.657

$\mu = 26.9145 * 10^{-6}\ Ns/m^3$

L=0.1 m

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N=1500rpm (Assume)
v=2*0.1*1500
=300 $^{m}/_{min}$
=5 $^{m}/_{sec}$
Re.No=$\frac{0.6628*5*0.03}{26.9145*10^{-6}}$
=3693.91

$$Nu = 0.023 * (3693.91)^{0.8} * (0.657)^{0.3}$$
=14.487

$$h = \frac{14.487 * 0.04549}{0.03}$$
=21.9671 $^{W}/_{m^2K}$

Calculations of Inertia Forces for hemispherical piston

Volume of the piston V=337474.56 mm^3

Density $\rho = 8400\ ^{kg}/_{m^3}$

Total surface area T_S=$4902.81 \times 10^{-6} m^2$

m=$\rho * V$
=8400*337474.56
=2.64Kg

Angular Velocity $\omega = \frac{2*\pi*N}{60}$
=$\frac{2*\pi*1500}{60}$ $^{rad}/_{sec}$
=157.07

Length of the piston L=110 mm
Diameter of the piston D=81.76 mm
Radius of the piston R=40.88 mm

$$F_I = mr\omega^2(\cos\theta + \frac{\cos 2\theta}{n})$$

n=$^{l}/_{r} = \frac{3000}{50} = 60$

Where l=length of the connecting rod=3000mm(Assumed)
r=radius of the crank=50mm

$$F_I = 2.64 * 50 * 10^{-3} * (157.07)^2 * (\cos 60 + \frac{COS\ 120}{60})$$

=3737 N

Pin Force

$\cos\beta = \sqrt{1 - \frac{y^2}{l^2}}$ y= $r * \sin\theta$

Force due to piston pin $F_C = \frac{F}{\cos\beta}$

Net force $F = F_L + mg - F_I$

$F\frac{\pi}{4}82^2 \times 10^{-6} \times 10 \times 10^5 + 2.64 \times 9.81 - 3747$

F=2500N

$F_c = \frac{F}{\cos 1.33} = \frac{2500}{\cos 1.33} = 2500.67N$

P=$\frac{F_c}{A} = \frac{2500.67}{4902.81\times10^{-6}}$=$51 \times 10^4\ ^{N}/_{m^2}$

Threfore the pressure applied on the pin hole of the piston is $51 \times 10^4\ ^{N}/_{m^2}$

But for the analysis we fixes the pin hole instead of applying pressure because without constrained the body analysis will not carry the load effort which is on the top of piston. The weight of the piston W=mg which acts at the center of gravity which is vertically downward direction.

5. EVALUATION AND RESULTS:

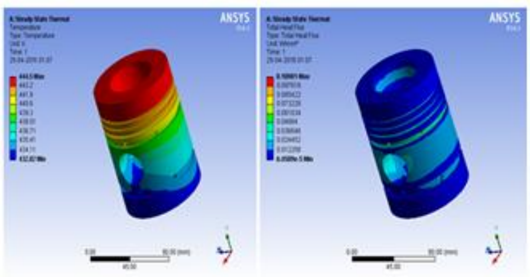
By applying boundary conditions like temperature at the top surface and convectional properties of insulation materials on the boundaries like water and air.

(a) Water convection (b) air convection

Applying Convective Heat Transfer Mode to Piston

(a) Applying Pressure (b) Fixing Geometry

By giving all the boundary conditions for pistons we will get required results for different open combustion chambers. For idea here we provide the results of hemispherical combustion chamber



(a) Total Temparature (b) Total Heat Flux

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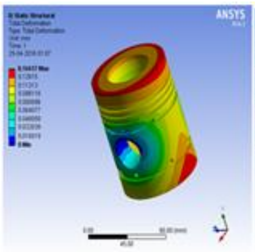
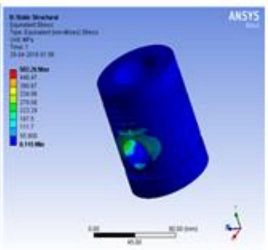
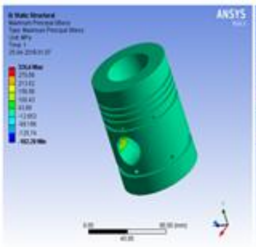
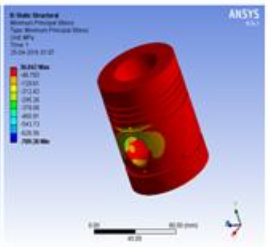



(c) Total Deformation (d) Equivalent stresses

e)Maximum principal stresses f)Minimum principal stresses

5.1 Mechanical Analysis:

Applying pressure on the top surface the application pressure is like (UDL) Uniform Distributed Load by fixing the geometries at bore end holes.

Table 2: Analysis is carried out for various pistons. (Temperature and heat flux)

S.No	Type of Piston	Temperature (K)		Total Heat Flux (W/mm^2)	
		Min.	Max.	Min.	Max.
1.	Cylindrical	444.6	456.22	6.8587 e^{-5}	0.074306
2.	Hemispherical	432.82	444.5	6.4509 e^{-5}	0.10981
3.	Shallow	446.22	452.17	7.2393 e^{-5}	0.077781
4.	Toroidal	449.22	462.27	0.00023831	0.083331

5.2 Comparison of Results :

Thermal Analysis:

We are applying the temperature on crown face part of the piston is 700 °C with convective heat transfer co-efficient $21.96 W/m^2K$ along with it on the top surface of the piston.

Structural Analysis:

We are applying the maximum pressure whose magnitude is 10bar on the upper surface which acts normal to the surface and it is fixed at the pin hole on top because when the piston moves from TDC to BDC the pin force act vertically upwards for that the upper surface is fixed and the analysis is carried out for various pistons. From this results we concluded that temperature distribution is maximum for toroidal piston by comparing it with other pistons. It takes more temperature because of its effective squishing in toroidal combustion chamber. For that reason design of toroidal piston is in such a way that it has to with stand the thermal resistivity and effective air and oil convective cooling takes place.

Table 3: Analysis is carried out for various pistons. (Stresses and Deformaion)

S. No	Type of Piston	Min. Principal Stress (M Pa)		Max. Principal Stress (M Pa)		Equivalent Stress (M Pa)		Total Deformation (mm)	
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1.	Cylindrical	-735.53	44.215	-158.55	309.47	0.29476	518.53	0	0.15789
2.	Hemispherical	-709.38	36.042	-182.28	326.6	0.115	502.26	0	0.14417
3.	Toroidal	-792.74	49.974	-176.52	339.95	0.2089	549.55	0	0.1627
4.	Shallow	-805.19	49.44	-170.33	398.95	0.3446	569.78	0	0.15828

6. CONCLUSION:

From the result shown above that although fatigue is not the responsible for biggest damage of pistons, but the induced stresses are the main factor for failure of piston. Also from analysis various results are obtained like maximum pressure, maximum deformation and maximum principle stresses are observed. In the same way the analysis is being carried out for various pistons which are discussed earlier with applying various materials like cast aluminum alloy and Inconel with application of same thermal load and pressure for all four pistons. And finally the Factor Safety plays a major role which tells us which is being gives more life time for all given conditions and best suited for present generation for 100% complete combustion of fuel in combustion chamber to increase the efficiency. Hemispherical combustion chamber proves to be the best, as it has highest factor of safety and minimum deformation because of its low temperature distribution compared to other three types and from the comparision statement INCONEL have lesser CTE and maximum tensile and yield strengths, so from this properties cast Inconel alloy is best suited for the manufacture of piston.

7. FUTURE SCOPE:

Piston Design models are simulated on iteration based and it requires more number of iterations to check if design is safe or not and to validate the models with the allowable. Instead of using NX/Catia software process, DOE – Design of Experiments concept can be used to optimize the design within short time and to get better optimized parameters. DOE should be carried in Ansys workbench. In Ansys workbench modelling can be done from Catia or Design Modeller using parametric model options.

References:

[1] Piotr Szurgott et al (2003) performed the Thermo mechanical FE analysis of the engine piston made of composite material with low histeresis, Vol. 2(4), pp .01-04, 2012.

[2] Praful R. Sakharkar(2003) performed Thermal analysis of ic engine piston using FEA, International Journal of Modern Engineering Research (IJMER), Vol.2, Issue.4, pp.2919-2921, 2012.

[3] Ghodake A. P et al (2014) performed Piston Design and Analysis by CAE Tools ,SAE Paper, vol. 820086, 1982.

[4] Kamo R., Assanis D.N., Bryzik W.: Thin thermal barrier coatings for engines. SAE Transactions 1989, No 980143.

[5] W. D. Drotning, "Thermal Expansion Glasses in the Solid and Liquid Phases," International Journal of Thermophysics, Vol. 6, No. 6, 1985, pp. 705-714.

[6] X. Wan, and D. Lin. Engine Design. TianJin University Press,China, 1989.

[7] Y. Zheng. "The finite element design for non-cylinder hole of piston", Design and Manufacture of Diesel Engine, vol. 87, pp. 44-49, 1999.

[8] P.Gustof, A.Hornik, "International Journal of Achievements in Materials and Manufacturing Engineering" ,Vol. 35 Issue 2 August 2009.

[9] HEAT TRANSFER AND DESIGN DATA BOOKS

[10] For material Properties we refer this website: http://www.azom.com/