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Design and Analysis of Piston by FEA

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ABSTRACT

Piston design has been done using design data hand book and the two wheeler motorcycle specifications, then analysis has been done based on the material properties and the boundary conditions. With the Ansys software, a three-dimensional definite-element analysis has been carried out to the engine piston. Considering the thermal boundary condition, the stress and the deformation distribution conditions of the piston under the coupling effect of the thermal load and explosion pressure have been calculated, thus providing reference for design improvement. Results show that, the main cause of the piston failure, the piston deformation and the great stress is the temperature. So it is feasible to further decrease the piston stress with structure design.In structural analysis pressure of 0.4MPa was applied on the piston top by Clamping Gudgeon pin Hole,20MPa Von Mises stress was obtained and 0.033mm deformation was obtained which are within the allowable limit. In thermal analysis 300^0c temperature was applied by Clamping Gudgeon pin Hole, 110MPa Von Mises stress was obtained and 0.34mm deformation was obtained which are within the allowable limit.In coupled thermal and structural analysis, both pressure and temperatures of 0.4MPa and 300^0c were applied on piston, by Clamping Gudgeon pin Hole 120MPa Von Mises stress was obtained and 0.32mm deformation was obtained which are within the allowable limit.
The material which is used for design and analysis is NASA 398, is a hypereutectic alloy (16% w. Si), which has similar specifications for usage to conventional A390.0, Mahle 126, Zolloy Z16 and AE 425. It is a heat treatable Al-Si alloy consisting of small polygonal primary silicon particles evenly distributed in an aluminum matrix for high strength and high wear resistance applications at elevated temperatures. NASA alloys can also be made in eutectic and hypoeutectic forms (<13% wt. Si). NASA alloys can be produced economically from conventional permanent mold or sand casting, and they are best used for applications from 500 ° F (260 ° C) to about 750 ° F (400 ° C).

Keywords— Piston, design, Stress analysis, FEA.

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I. INTRODUCTION

The Piston is a ‘heart’ of an automobile engine. It’s one of the key components of the engine and it’s working the hard condition. The function of the piston is bearing the gas pressure and making the crankshaft rotation through the piston pin. Piston works in high temperature, high pressure, high speed and poor lubrication conditions. Piston contact with high temperature gas directly, the instantaneous temperature can be up to 2500K. Because of the high temperature and the poor cooling condition, the temperature of the top of the piston can reach 600~700K when the piston working in the engine. And the temperature distribution is uneven. The top of the piston bears the gas pressure, in particular the work pressure. The investigations indicate that greatest stress appears on the upper end of the piston and stress concentration is one of the mainly reason for fatigue failure.

Increased need for high power density, low emissions and high fuel efficiency impose restrictions on engine component design. Hence design and analysis of engine components has become more complex. One of these components is the engine piston. The piston of a diesel engine is usually subjected to periodically changing thermal and mechanical loads. The stress fields induced onto the piston due to coupled thermal-mechanical loads are difficult to analytically determine, however using finite element analysis methods it possible to study and analyze the strength of pistons and other complex components and structures. The main requirements of the piston are that it should contain all the fluids above and below the piston assembly during the cycle and that it should transfer the work done during combustion process to crankshaft via the connecting rod with minimal mechanical and thermodynamic losses . To meet these two major requirements, the piston should have sufficient thermal conductivity, Low thermal expansion, and high temperature strength, high strength to weight ratio and High resistance to surface abrasion. The above requirements demand for high thermal and mechanical strength designs for engine piston.

II. LITRETURE REVIEW

P. O'Hara[1] analyzed heat transfer problems exhibiting sharp thermal gradients using the classical and generalized finite element methods.**V. Ucar, A. Ozel**[2] investigates a transient thermal and structure finite element solution has been employed to analyze the level of the thermal stresses developed in plasma coating systems subjected to thermal loading. **J Chareonsuk, P Vessakoso**[3] proposed a high-order control volume finite element method (CVFEM) to explore thermal stress analysis for functionally graded materials (FGMs) at steady state with the unstructured mesh capability for arbitrary-shaped domain. **Douglas M. Assanis**[4] present a methodology for a coupled thermodynamic and heat transfer analysis of diesel engine combustion chambers. **U.A. Benz,J.J. Rencis**[5] a dual reciprocity boundary element formulation using quadratic elements was presented for coupling two-dimensional and axisymmetric zones for transient heat transfer applications. **Bao-Lin Wang,Yiu-Wing Ma**[6]i establishes a solution method for the one-dimensional transient temperature and thermal stress fields in non-homogeneous materials. **E C Trujillo**[7] proposes a methodology for the estimation of the mean temperature of the cylinder inner surface in an air-cooled internal combustion engine.Sook-Ying Ho, Allan Paull describes a relatively simple and quick method for implementing aerodynamic heating models into a finite element code for non-linear transient thermal-structural and thermal-structural-vibrational analyses of a Mach 10 generic HyShot scramjet engine.

D Vibhandik, **etal**,[8] stated that in I.C. Engine, piston was most complex and important part therefore for smooth running of vehicle piston should be in proper working condition. Pistons fail mainly due to mechanical stresses and thermal stresses. Analysis of piston was done with boundary conditions, which includes pressure on piston head during working condition and uneven temperature distribution from piston head to skirt. The analysis predicts that due to temperature whether the top surface of the piston may be damaged or broken during the operating conditions, because damaged or broken parts are so expensive and difficult to replace and generally are not easily available.

The main purpose of the preliminary analyses presented in the book was to compare the behaviour of the combustion engine piston made of different type of materials under thermal load. FEA analysis is carried out using ANSYS software. Development of the FEA model was also presented. Geometrical CAD model of the piston is developed based on the actual engine piston of TATA MOTORS four stroke diesel engine. The piston is loaded by a temperature field inside it. Appropriate averaged thermal boundary conditions such as temperatures and heat fluxes were set on different surfaces of the FEA model. In this study, firstly, thermal analyses are investigated on a conventional diesel piston, made of structural steel for design.

III. MATERIAL PROPERTIES

TABLE 1
Material Properties

Temperature		Thermal Expansion (10^{-6}K)	Thermal Diffusivity (cm^2/sec)	Specific Heat (J/kg. K)	Thermal Conductivity (W/m.K)	Density (g/cm^3)
^{0}F	^{0}c					
72	25	18.50	0.525	820	120.0	2.76
212	100	18.65	0.519	820	125.4	…
392	200	19.17	0.506	915	128.0	…
572	300	19.72	0.489	952	129.0	…
662	350	19.93	0.480	990	131.4	…

Design of the Piston

Design of the piston is done based on the specifications of two wheeler vehicle and by using V.B.Bhandari design data handbook. Part modeling of the piston was done in Pro/Engineer CAD software.The piston model is shown below.

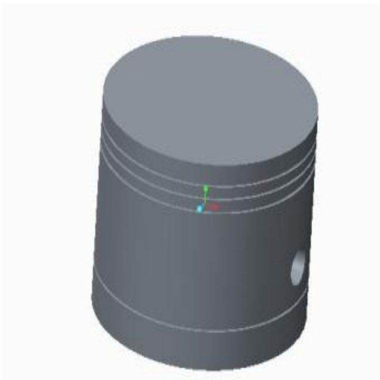

Fig.1.Piston Part Model

Meshed Model

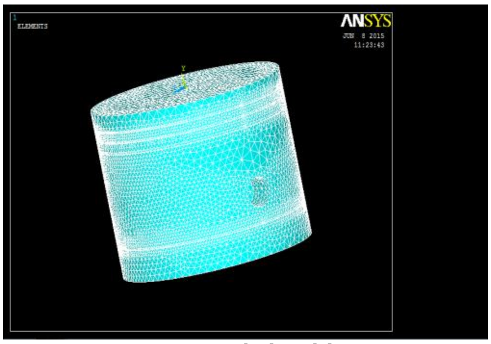

Fig.2.Meshed model

IV. FINITE ELEMENT ANALYSYS

Structural Analysis

Element used : Solid 185

Material : Aluminum Alloy NASA 398

Pressure on top surface : 0.4MPa

Clamped on Gudgeon pin Hole

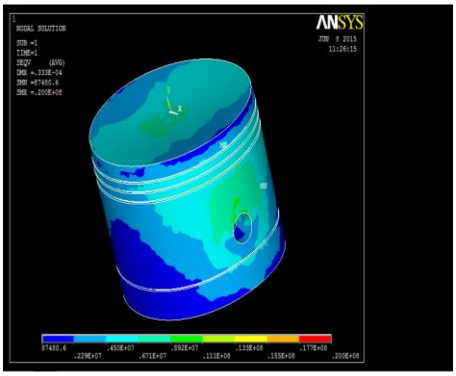

Fig.3.Structural Analysis Stresses

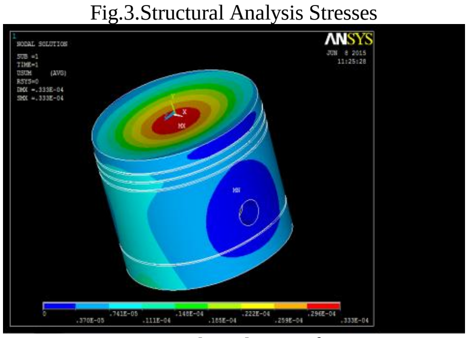

Fig.4.Structural Analysis Deformation

In structural analysis pressure of 0.4MPa was applied on the piston top by Clamping Gudgeon pin Hole,20MPa Von Mises stress was obtained and 0.033mm deformation was obtained which are within the allowable limit.

Stress graph along diameter of top surface for structural load.

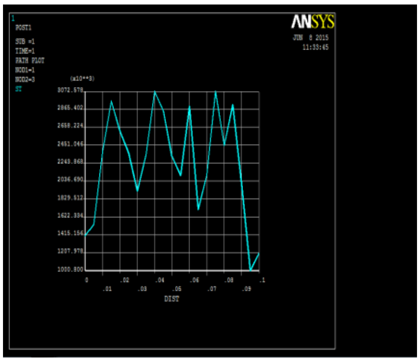

Fig.5.Stress Graph

Thermal Analysis

Element used : Solid 227

Material : Aluminum Alloy NASA 398

Temp. on top surface : 300^0C

Clamped on Gudgeon pin Hole

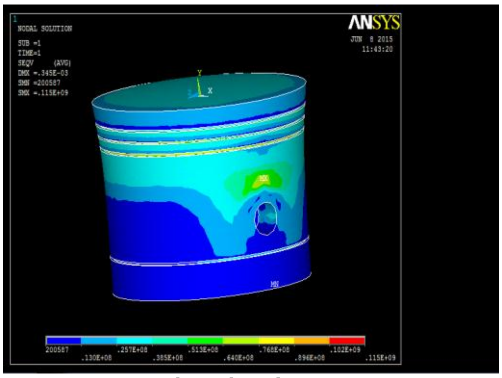

Fig.6.Thermal Analysis Stresses

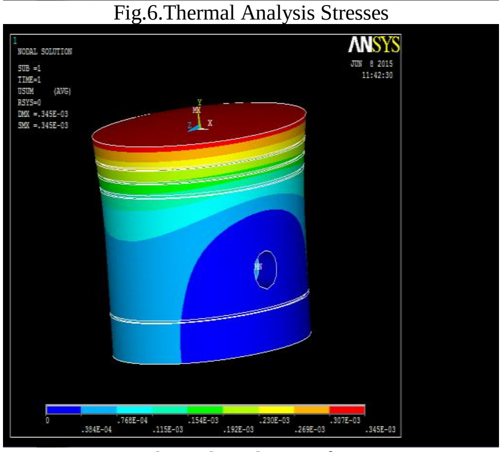

Fig.7.Thermal Analysis Deformation

In thermal analysis 300^0c temperature was applied by Clamping Gudgeon pin Hole, 110MPa Von Mises stress was obtained and 0.34mm deformation was obtained which are within the allowable limit

Stress graph along diameter of top surface for thermal load.

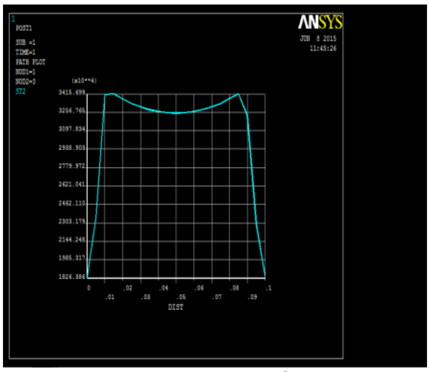

Fig.8.Stress Graph

Coupled Structural and Thermal Analysis

Element used : Solid 227

Material : Aluminium Alloy NASA 398

Temp. on top surface : 300^0C, pressure 0.MPa

Clamped on Gudgeon pin Hole

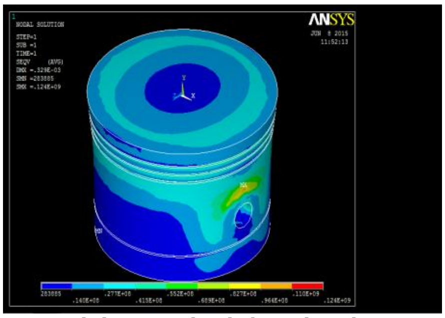

Fig.9. Coupled Structural and Thermal Analysis Stresses

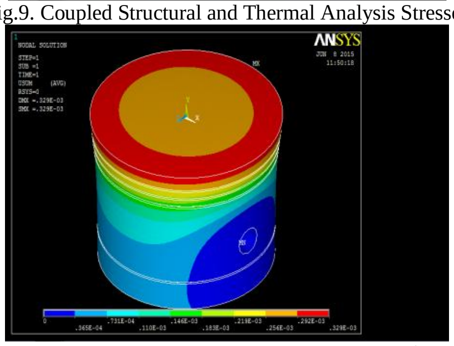

Fig.10. Coupled Structural and Thermal Analysis Deformation

In coupled thermal and structural analysis, both pressure and temperatures of 0.4MPa and 300^0c were applied on piston, by Clamping Gudgeon pin Hole 120MPa Von Mises stress was obtained and 0.32mm deformation was obtained which are within the allowable limit.

Stress graph along diameter of top surface for coupled load

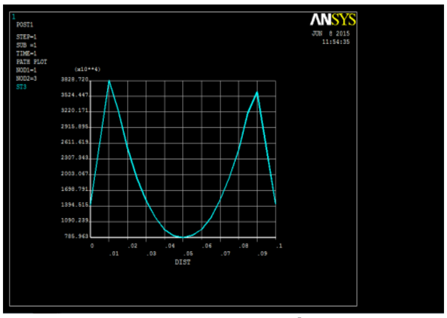

Fig.11.Stress Graph

V. CONCLUSION

In structural analysis pressure of 0.4MPa was applied on the piston top by Clamping Gudgeon pin Hole,20MPa Von Mises stress was obtained and 0.033mm deformation was obtained which are within the allowable limit. In thermal analysis 300^0c temperature was applied by Clamping Gudgeon pin Hole, 110MPa Von Mises stress was obtained and 0.34mm deformation was obtained which are within the allowable limit. In coupled thermal and structural analysis, both pressure and temperatures of 0.4MPa and 300^0c were applied on piston, by Clamping Gudgeon pin Hole 120MPa Von Mises stress was obtained and 0.32mm deformation was obtained which are within the allowable limit.

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