DESIGN, ANALYSIS AND OPTIMIZATION IN I C ENGINE OF O.D. PISTON BY USING ANSYS

Karani Singh[1], Ramnarayan Sahu[2], Yogesh Mishra[3]

[1]Research Scholar Master of Technology (MD&R) Department of Mechanical Engineering, NIIST, Bhopal

[2] Assistant Professor Department of Mechanical Engineering, NIIST, Bhopal

[3]Professor and Head Department of Mechanical Engineering, NIIST, Bhopal

Abstract

A piston is a component of reciprocating engines, reciprocating pumps, gas compressors and pneumatic cylinders, among other similar mechanisms. It is the moving component that is contained by a cylinder and is made gastight by piston rings. In an engine, its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod and/or connecting rod. In a pump, the function is reversed and force is transferred from the crankshaft to the piston for the purpose of compressing or ejecting the fluid in the cylinder. In the current study attempt has been made to analyses the actual working condition of the internal combustion engine piston using finite element method. Static stress analysis and thermal analysis were performed on piston using two Al alloy materials. Performance of piston made of conventional piston material i.e. cast iron is replaced by light weight material such as Al alloy 2618 and AA2124/SiC/25p composite and all two materials are optimized for weight reduction. The above analysis is carried out with the help of using SOLIDWORKS and ANSYS. In order to achieve reduction in weight material of cast iron piston is replaced with lighter Al alloy 2618 and AA2124/SiC/25p Composite respectively. Piston is optimized for these two materials for getting maximum reduction in weight without compromising with safety factor.

Keywords: *Piston, Solid work, ANSYS, IC Engine, Optimization, Analyses.*

Introduction

Automobile components are in great demand these days because of increased use of automobiles. The increased demand of components is due to improved performance and reduced cost. The production of low weight component will be one of the major activities of the R&D Labs. R&D and testing engineers should develop critical components in shortest possible time to minimize launch time for new products. The necessitate understanding of new technologies and quick absorption in the development of new products.

A piston is a component of reciprocating engines, reciprocating pumps, gas compressors and pneumatic cylinders, among other similar mechanisms. It is the moving component that is contained by a cylinder and is made gastight by piston rings. In an engine, its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod and/or connecting rod. In a pump, the function is reversed and force is transferred from the crankshaft to the piston for the purpose of compressing or ejecting the fluid in the cylinder. In some engines, the piston also acts as a valve by covering and uncovering ports in the cylinder wall [1]. The piston used in internal combustion engine is usually of trunk type. Such pistons are open at one end. Trunk piston consists of [2]:

1. Head or crown to carry the cylinder pressure
2. Skirt to act as a bearing for connecting rod side thrust
3. A piston pin to connect it to the connecting rod
4. Piston ring to seal the cylinder

Piston is a cylindrical component fitted into the cylinder forming the moving boundary of the combustion system. It fits perfectly into cylinder providing gas tight space with the piston rings and the lubricant. It forms the first link in transmitting the gas forces to the output shaft. A slipper piston is a piston for a petrol engine that has been reduced in size and weight as much as possible. In the extreme case, they are reduced to the piston crown, support for the piston rings, and just enough of the piston skirt remaining to leave two lands so as to stop the piston rocking in the bore. The sides of the piston skirt around the gudgeon pin are reduced away from the cylinder wall. As shown in figure 1.

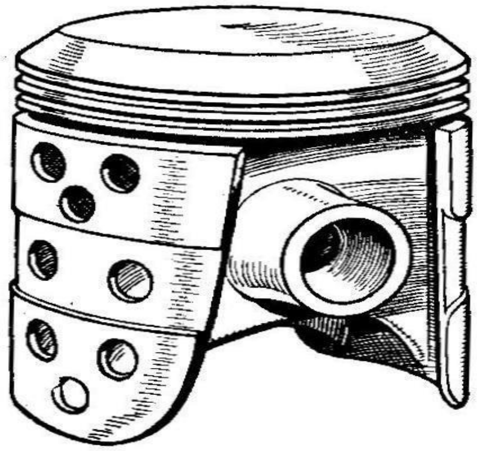

Fig. 1. Slipper Piston

This method was developed at the time of 1960, especially to analyse the structural, dynamics problems. It is based on the weigh residual method. This method is a beneficial over the difference method as it can handle complex geometries and use arbitraries on irregular shapes [5]. The finite element method (FEM) (its practical application often known as Finite Element Analysis (FEA) is a numerical technique for finding approximate solutions to partial differential equations (PDE) and their systems, as well as (less often) integral equations. In simple terms, FEM has an in built algorithm which divides very large problems (in terms of complexity) into small elements which can be solved in relation to each other.

Literature Review

Reddy et al. 2013 [9] Performed on analysis and optimization of piston using FEM. In this study, firstly, static analyses are investigated on a conventional (uncoated) diesel piston, made of aluminium silicon alloy for design 1 and design 2 parameters. Secondly, static analyses are performed on piston, coated with Zirconium material by means of using a commercial code, namely ANSYS. The main objective is to investigate and analyze the deformation and stress distribution of piston at the real engine condition during combustion process. This describes the mesh optimization by using finite element analysis technique to predict the higher stress and critical region on the component.

Jaber et al. 2014 [10] had work on design and analysis of I.C. engine piston and piston-ring using CATIA and ANSYS software. In this present work a piston and piston ring are designed for a single cylinder four stroke petrol engine using CATIA V5R20 software. Complete design is imported to ANSYS 14.5 software then analysis is performed. Three different materials have been selected for structural and thermal analysis of piston. For piston ring two different materials are selected and structural and thermal analysis is performed using ANSYS 14.5 software. Piston made of three different materials Al alloy 4032, AISI 4340 Alloy steel and Titanium Ti-6Al-4V (Grade 5) are analyzed. Their structural analysis shows that the maximum stress intensity is on the bottom surface of the piston crown in all the materials, but stress intensity is close to the yield strength of Al alloy piston. Maximum temperature is found at the centre of the top surface of the piston crown. This is equal for all materials. Depending on the thermal conductivity of the materials, heat transfer rate is found maximum in Al alloy piston and minimum in Ti alloy piston. For the given loading conditions, Al alloy piston is found most suitable.

Gupta et al. 2014 [11] was investigated on design analysis and optimization of internal combustion engine piston using CAE tool ANSYS. In this study work there are two steps of analysis of the piston they are designing and Analysis. Firstly design the model of the piston in giving design specification on the modelling software like INVENTOR. Then giving it the constraints, which are act on the working condition of the piston after import the model of the piston into the analysis software ANSYS in IGES format.

Bhagat et al.2012 [12] had done design, analysis and optimization of piston which is stronger, lighter with minimum cost and with less time. Since the design weight of the piston influence the engine performance. The FEA is carried out for standard piston model used in diesel engine and the result of analysis indicate that the maximum stress has changed from 228 MPa to 89MPa and biggest deformation has been reduced from 0.419 mm to 0.434 mm.

Singh et al. 2015 [13] was performed on finite element analysis of piston in ANSYS. In present, work a three-dimensional solid model of piston including piston pin is designed with the help of CATIA and SOLIDWORKS software. The thermal stresses, mechanical stresses and couples' thermo-mechanical stresses distribution and deformations are calculated. After that fatigue analysis was performed to investigate factor of safety and life of the piston assembly using ANSYS workbench software. Aluminium-silicon composite is used as piston material. The stress analysis results also help to improve component design at the early stage and also help in reducing time required to manufacture the piston component and its cost. It was found that the maximum stress is 207 MPa which is less than the maximum tensile stress (650 MPa) and yield strength (480 MPa) of the material. The maximum thermal stress is found to be 96.014 MPa at a maximum temperature of360℃. The minimum factor of safety is 1.379 which is greater than unity so our design of piston is safe under the applied loading conditions.

Bhattacharya et al. 2014 [14] was performed on analysis of piston of two stroke engine using ANSYS. In the present study, piston of a two-stroke spark ignition internal combustion engine having maximum power of 6.5 kW at 5500 rpm has been designed and analysed. The piston made up of Aluminium 4032 alloy is designed by conventional approach and then both thermal and transient structural analysis have been carried out. The piston has been modelled in CATIA and analysed using ANSYS Workbench. In order to improve the design of piston, two alternative designs have been considered by providing openings at the skirt region of the piston.

Naresh et al. 2015 [15] was observed on Design and Thermal Analysis of I.C Engine Piston using ANSYS. Here the piston is designed, analysed and the manufacturing process has been studied. Piston temperature has considerable influence on efficiency, emission, performance of the engine. Purpose of the investigation is measurement of piston transient temperature at several points on the piston, from cold start to steady condition and comparison with the results of finite element analysis. In this project the piston is modelled and assembled with the help of CATIA software and component is meshed and analysis is done in ANSYS software and the thermal and static behaviour is studied and the results are tabulated.

Pandey et al. 2014 [4] was investigated on thermal stress analysis of a speculative IC engine piston using CAE tools. The present work deals with the use of different materials for IC engine piston and a comparative study is made to achieve the best possible result. Piston parameters are taken using the conventional formulas and are constant throughout the analysis. Aluminium alloy should be used as a piston material as it has minimum thermal stress and mechanical distortion in same working condition as that of cast iron and structural steel as piston material. Aluminium alloys have high heat conductivity thus; high rate of heat transfer is possible between the centre and edge of the piston head.

Buyukkaya et al. 2007 [16] had work on Thermal analysis of a ceramic coating diesel engine piston using 3-D finite element method. In this study, firstly, thermal analyses are investigated on a conventional (uncoated) diesel piston, made of aluminium silicon alloy and steel. Secondly, thermal analyses are performed on pistons, coated with MgO–ZrO_2 material by means of using a commercial code, namely ANSYS. Finally, the results of four different pistons are compared with each other. The effects of coatings on the thermal behaviours of the pistons are investigated. It has been shown that the maximum surface temperature of the coated piston with material which has low thermal conductivity is improved approximately 48% for the AlSi alloy and 35% for the steel.

Cerit M. 2011 [17] had worked on Thermo mechanical analysis of a partially ceramic coated piston used in an SI engine. The purpose of this paper is to determine the temperature and the stress distributions in a partial ceramic coated spark ignition (SI) engine piston. Effects of coating thickness and width on temperature and stress distributions were investigated including comparisons with results from an uncoated piston. It is observed that the coating surface temperature increase with increasing the thickness in a decreasing rate. Surface temperature of the piston with 0.4 mm coating thickness was increased up to 82 °C.

Nimbarte et al. 2015 [18] had worked on stress analysis on piston using pressure load and thermal load. The main objective of this research work is to investigate and analyze the stress distribution of piston at actual engine condition. In this paper pressure analysis, thermal analysis and thermo-mechanical analysis is done. The CAD model is created using PRO-E software. CAD model is then imported into ANSYS software for geometry and meshing purpose. The FEA (Finite Element Analysis) performed by using ANSYS12. Analysis was done for cast iron piston material. Structural analysis of piston was carried out in which equivalent stress was found 78.588 MPa.

Research Gaps

With the advancement in material science, very light weight materials with good thermal and mechanical properties can be used for safe design of the I.C. Engine. From the above literature it can be clearly seen that using lightweight aluminum alloy gives reduction in both equivalent stress and deformation. This will reduce the fuel consumption and protect the environment. Aluminum alloys are lighter in weight thus provides good mechanical strength at low temperatures compare to the structural steel and cast iron.

Objectives

The piston is one of the most critical components of an engine. Therefore, it must be designed to withstand from damage that is caused due to extreme heat and pressure of combustion process. The value of stress that causes the damages can be determined by using Finite Element Analysis (FEA). Thus, it can reduce the cost and time due to manufacturing the components and at the same time it can increase the quality of product. The objective of this study is:

- To calculate the equivalent (Von-Mises) stress.
- To calculate the total deformation by considering the gas load.
- To optimize the piston model for mass reduction.
- To calculate the total heat flux.

Methodology

In the current study attempt has been made to analyses the actual working condition of the internal combustion engine piston using finite element method. Static stress analysis and thermal analysis were performed on piston using two Al alloy materials. Performance of piston made of conventional piston material i.e. cast iron is replaced by light weight material such as Al alloy 2618 and AA2124/SiC/25p composite and all two materials are optimized for weight reduction. The above analysis is carried out with the help of using SOLIDWORKS and ANSYS 14.5 software. The solid model of piston is drawn with the help of SOLIDWORKS software. Then the solid model of piston in IGES format is imported in ANSYS 14.5 workbench. In ANSYS 14.5, static structure analysis is carried out in which total deformation and equivalent (Von-Mises) stresses are calculated and then steady-state thermal analysis is also performed in which temperature distribution and total heat flux are calculated for two materials i.e. Al alloy 2618 and AA2124/SiC/25p composite.

SELECTION OF MATERIAL FOR PISTON

Al alloy 2618 and AA2124/SiC/25p composite (Aluminium alloy 2124 based metal matrix composite reinforced with 25 % fine (2 - 3 µm) SiC particles) in place of existing Cast iron.

Table 1 Chemical composition of material

Material	% by weight (Al 2618 grade aluminium alloy) [4]	% by weight (AA2124/SiC/25p Composite) [19]
Aluminium	93.7	93.8
Silicon	0.18	0.17
Copper	2.3	3.86
Magnesium	1.6	1.52
Manganese		0.65
Nickel	1.0	
Iron	1.1	
Titanium	0.07	

Table 2 Material Property of piston

Mechanical properties	Cast iron [18]	Al 2618 grade aluminium alloy [4]	AA2124/SiC/25p Composite [19]
Young's Modulus (E)	100 GPa	73.7 GPa	115 GPa
Poisson's ratio (μ)	0.27	0.33	0.30
Tensile Yield strength		370 MPa	480 MPa
Tensile ultimate strength	140 MPa	440 MPa	650 MPa
Thermal conductivity	46.6 W/m℃	146 W/m K	150 W/m K
Density	7200 kg/m^3	2768 kg/m^3	2880 kg/m^3
Coefficient of thermal expansion	19.4 $\times 10^{-6}/°C$	25.9 $\times 10^{-6}/°C$	22.9 $\times 10^{-6}/°$

PISTON DESIGN

The dimensions are calculated in terms of SI Units. Length of piston, diameter of piston, Thicknesses of piston, and width of top land and other land etc., parameters are taken into considerations. A dimension of 4-stroke diesel engine piston used is given in the table 3

Table 3 Design specification of piston

S. No.	Design Parameter	Size in mm
1	Length of piston (L)	130
2	Cylinder bore/ diameter of piston (D)	100
3	Radial thickness of ring (t_1)	3.50
4	Axial thickness of ring (t_2)	3
5	Maximum thickness of barrel (t_3)	11.40
6	Thickness of piston head	16
7	Width of top land (b_1)	18
8	Width of other land (b_1)	2.50
9	Piston pin hole diameter	30

Results

Results are obtained for static structural analysis and thermal analysis by using ANSYS 14.5 software. In static structural analysis we found total deformation and equivalent (Von-Mises) stress for two Al alloy materials i.e. Al alloy 2618 and AA2124/SiC/25p Composite. In thermal analysis we found temperature distribution and total heat flux for two Al alloy materials i.e. Al alloy 2618 and AA2124/SiC/25p Composite. Results are shown in following fig. given below.

STATIC ANALYSIS RESULTS

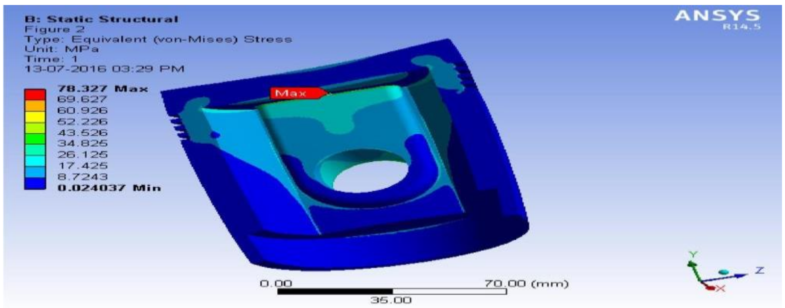

Fig. 2 Equivalent (Von-Mises) stress of the piston (for Cast Iron)

The result of maximum Von-Mises stress for cast iron of Nimbarte et al. which is 78.588 MPa and we have analyse the same material, geometrical conditions and working conditions then found 78.327 MPa and error is less than 1%. Mass of piston is found 3.604 kg for cast iron piston material.

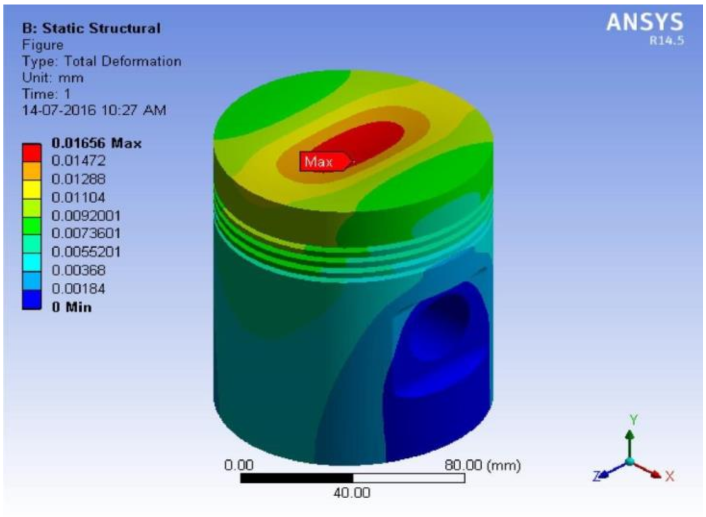

Fig. 3 Total Deformation of the piston (for Al Alloy 2618)

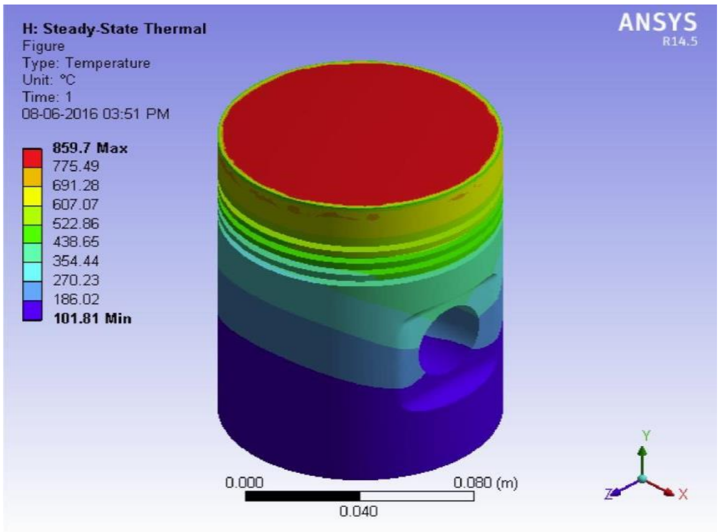

Fig. 4 Temperature distribution of the piston (for AA2124/SiC/25p Composite)

It is shown in the Fig. 4 that the temperature distributions along the surface of pistons are equal for all materials. As it is expected maximum temperature is observed on the piston crown and minimum temperature on the piston skirt.

OPTIMIZATION RESULT

There are following tables in which given value of various parameters for changed geometry and different material of the piston.

when the axial thickness of piston ring changes from 3.5 to 3 mm, width of the top land changes from 18 to 17 mm and parabolic cut on bottom of the piston skirt = 14 mm. Therefore, optimization results are given in table.

Table Optimization result

Parameter	Al alloy 2618	AA2124/SiC/25p Composite
Mass reduction of piston	0.215 kg	0.223 kg
Total deformation	0.018165 mm	0.011872 mm
Equivalent (Von-Mises) stress	56.112 MPa	52.185 MPa
Safety factor (Min.)	1.5362	1.6518

Conclusions

In order to achieve reduction in weight material of cast iron piston is replaced with lighter Al alloy 2618 and AA2124/SiC/25p Composite respectively. Piston is optimized for these two materials for getting maximum reduction in weight without compromising with safety factor. Following conclusions are drawn from our study are described below:

- After replacing the existing martial cast iron by Al alloy 2618 and AA2124/SiC/25p Composite without optimization 62 % and 60 % reduction in weight is obtained respectively.
- After optimization reduction in weight is obtained which is 16 % for Al alloy 2618 and 16 % for AA2124/SiC/25p Composite as compared to before optimization.
- After optimization biggest equivalent stress is reduced from 77.287 to 50.981 MPa and total deformation slightly increase from 0.010827 to 0.011873 mm for AA2124/SiC/25p composite material.
- After optimization biggest equivalent stress is reduced from 75.928 to 54.094 MPa and total deformation slightly increase from 0.016560 to 0.018165 mm for Al alloy 2618 material.

Future Scope

- Study should be performed for other lighter material like magnesium alloy with refectory alloy by using ANSYS software.
- Reduction of parameters like equivalent stress, total deformation etc. with coating on the piston head of materials like ceramics, aluminium oxide etc.
- Other part of engine should also be optimized for lighter weight material by using ANSYS software.

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