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Optimization of Piston Design Using Taguchi Method

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A B S T R A C T

The design of piston has significant effect on thermal and structural characteristics of engine piston. The current research investigates the effect of thermal load on radial and tangential stresses generated in IC engine piston using techniques of Finite Element Analysis. The design of piston is then optimized using Taguchi response surface method. The ring land zone is selected for design optimization. The optimization technique used in the analysis is central composite design scheme. The design points are generated from design of experiments using central composite design scheme. The dimensions of piston corresponding to maximum radial and tangential stresses are determined. The minimum radial stress obtained from optimization is 75.06MPa and maximum tangential stress obtained from optimization is 38.06MPa. The dimensions of piston for maximum and minimum tangential stress are also determined.

Keywords: IC Engine piston, Finite Element Analysis, Optimization

1. Introduction:

During the early days of automobile manufacturing, IC engine pistons were made from cast iron. Due to increased inertia effect caused by high weight the cast iron was substituted with low weight Aluminium alloy with silicon which had reduced expansion and higher strength as compared to cast iron. On the basis of concentration of silicon, the alloy can be regarded as eutectic (12% silicon) or hypereutectic (22% silicon). Further increase in silicon would make the piston brittle and unsuitable for structural or thermal application. As IC engines are subjected to high temperatures, the piston materials should able to withstand it without causing any failures. The vulnerable areas of piston are top ring groove and bowl rim and have to be protected from premature failure.

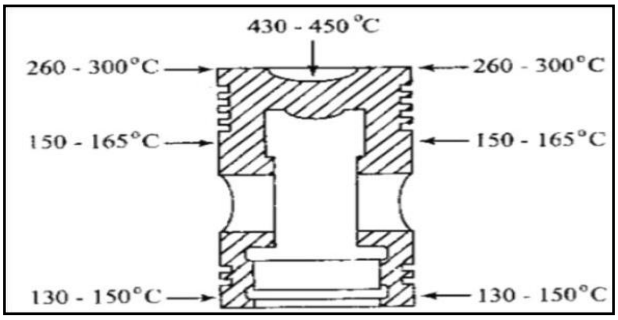

Figure 1: Temperature ranges

In IC engines, about 6 to 8 percent of fuel energy is transferred to piston and in uncooled piston 60 percent of heat is passed through piston ring area .Additional heat is passed through the skirt into the coolant jacket and from the underside of the piston via oil splash/mist to the crankcase oil *[1][2]*. For an oil cooled piston, a major amount of heat is carried by oil thus reducing the relative amount that passes through the ring region. Different temperature zones of piston is shown in figure 1 above.

2. Literature Review

Gaddeanilkumaret. al. [6] Piston plays a main role in energy conversation. Failure of piston due to various thermal and mechanical stresses. The working condition of the piston is so worst in comparison of other parts of the internal combustion engine. The main objective of this work is to investigate and analyze the stress distribution of piston. Design and analysis of an IC engine piston using three different materials that are used in this project. Ajeet Kumar Raiet. al. [7]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. Results are shown and a comparison is made to find the most suited design.

Aditya Kumar Guptaet. al. [8]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. Then the analysis becomes completed on the different parameters (temperature, stress, deformation) and easily analysis the result. In this work the piston become optimized after the reducing the material of the piston. The mass and volume of the piston become reduced.

Dilip Kumar Sonar et al. [9] there are lots of research works proposing, for engine pistons, new geometries, materials and manufacturing techniques, and this evolution has undergone with a continuous improvement over the last decades and required thorough examination of the smallest details. Notwithstanding all these studies, there are a huge number of damaged pistons. Damage mechanisms have different origins and are mainly wear, temperature, and fatigue related. Among the fatigue damages, thermal fatigue and mechanical fatigue, either at room or at high temperature, play a prominent role

3. Proposed Work

The current research investigates the effect of thermal load on radial and tangential stresses generated in IC engine piston using techniques of Finite Element Analysis. The design of piston is then optimized using Taguchi response surface method. The ring land zone is selected for design optimization. The optimization technique used in the analysis is central composite design scheme.

4. Methodology

The FEA process involves CAD modeling of piston in ANSYS design modeler. The model is developed as shown in figure 2 below. The model developed in ANSYS design modeler is imported for meshing.

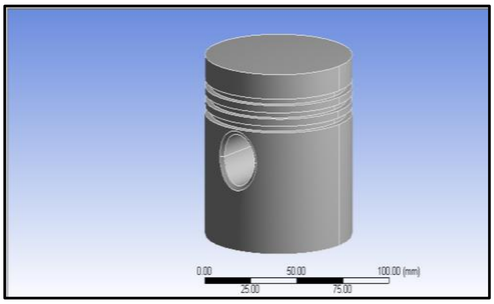

Figure 2: CAD model of I.C. Engine piston

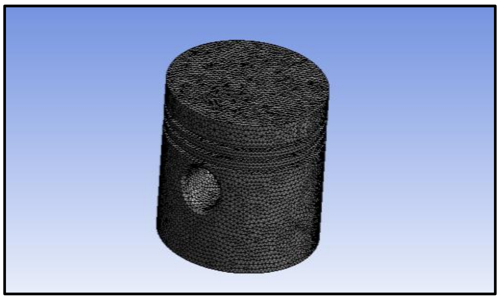

Figure 4: Meshed model of helical coil suspension

The CAD model is meshed using tetrahedral elements and fine sizing with curvature effects on. The number of elements generated is 146685 and number of nodes generated is 223600 as shown in figure 4 above. The element shape of tetrahedral element is shown in figure 3 below. It consists of 4 nodes connected to each other by tetrahedral shape. CAD model of suspension after being meshed is applied with appropriate loads and boundary conditions. The bottom face of suspension is kept fixed and top face is applied with force of 1356.4N in downward direction.

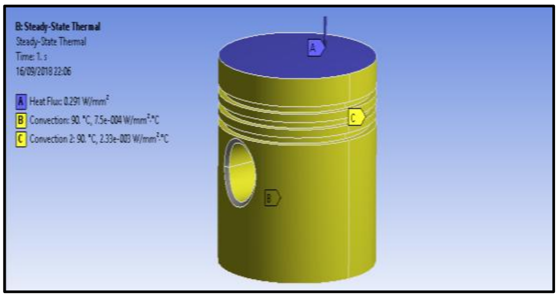

Figure 5:Thermal Loads and Boundary conditions

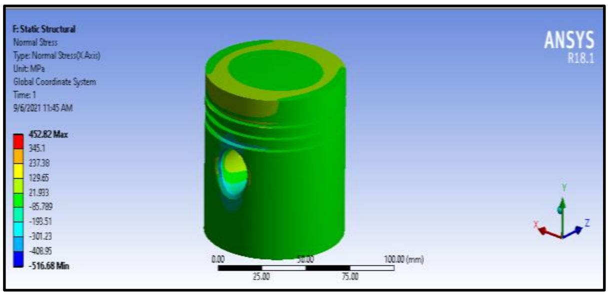

Figure 6: Radial stress distribution on piston (combined loading) using MMC

The heat flux of .29 W/mm2 and convection coefficient of .00075 W/mm2 K is applied. The ambient temperature is 90oC is defined for the analysis. The element stiffness matrix is formulated and assembled to form global stiffness matrix. The results of FEA analysis are generated and the design of piston is then optimized using central composite design of Taguchi response surface method.

5. Results and Discussion

The results of FE simulation are generated. The radial stress and tangential stress generated on piston is generated as shown in figure 6 and figure 7 below.

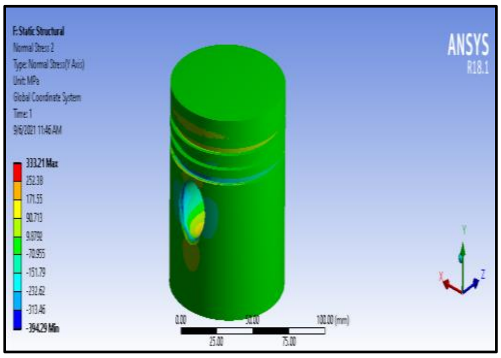

Figure 7: Tangential stress distribution on piston

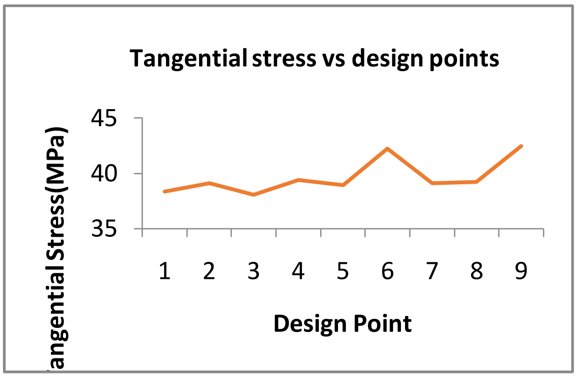

Figure8: Tangential stress vs design point (combined loading) using MMC

The design variables "RL1" and "RL2" are selected for analysis. From optimal space filling design optimization, 9 different design variables are generated as shown in table 1 below.

Table 1: Design point generated and tangential stress

Design Point	RL1 (mm)	RL2 (mm)	tangential stress (MPa)
1	2.808888889	2.786666667	38.37746129
2	2.817777778	2.795555556	39.126027
3	2.791111111	2.808888889	38.064567
4	2.804444444	2.804444444	39.38210622
5	2.786666667	2.782222222	38.90718547
6	2.795555556	2.791111111	42.25720283
7	2.8	2.817777778	39.08462905
8	2.813333333	2.813333333	39.21840924
9	2.782222222	2.8	42.47176467

The variation of tangential stress with respect to design point is shown in figure 8 above. The tangential stress is maximum for design point number 9 and is minimum for design point number 3.

Table 2: Design point generated and radial stress

Design Point	RL1 (mm)	RL2 (mm)	radial stress (MPa)
1	2.808888889	2.786666667	75.12269771
2	2.817777778	2.795555556	75.086451
3	2.791111111	2.808888889	75.12130743
4	2.804444444	2.804444444	75.10195314
5	2.786666667	2.782222222	75.16033
6	2.795555556	2.791111111	75.06471111
7	2.8	2.817777778	75.095933
8	2.813333333	2.813333333	75.10603029
9	2.782222222	2.8	75.11176114

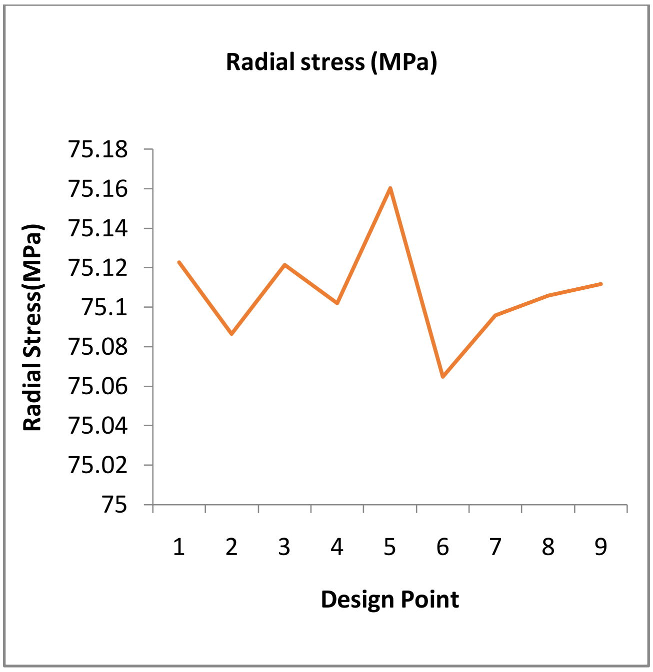

Figure 9: Radial stress vs design point

The variation of radial stress with respect to design point is shown in figure 9 above. The radial stress is maximum for design point number 5 and is minimum for design point number 6.

6. Conclusion

The FE simulation is conducted on engine piston to determine radial stress and tangential stress. The design points are generated from design of experiments using central composite design scheme. The dimensions of piston corresponding to maximum radial and tangential stresses are determined. The minimum radial stress obtained from optimization is 75.06MPa and maximum tangential stress obtained from optimization is 38.06MPa. The dimensions of piston for maximum and minimum tangential stress are also determined.

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