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DESIGN OPTIMIZATION OF IC ENGINE PISTON USING ANSYS

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Abstract:Piston is the crucial component of IC engine which generates thrust from fuel combustion and transmits it to connecting rod. The current research investigates the Taguchi response surface method on optimization of piston design.The response surface optimization is done using optimal space filling design scheme. The design variables selected for optimization are RL1 (ring land) and RL2 and output parameters evaluated are tangential stress and radial stress.The FEA analysis is conducted on piston using ANSYS software and stresses are determined for generic design. The responses of optimization variables on output parameters are generated and sensitivities of each optimization variables are determined.

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Key Words: FEA, Piston, Response Surface Method

1. INTRODUCTION

The combustion of fuel causes expansion of gas and generates thermal energy. Piston is required to convey expansion of gas to crankshaft via connection rod. The geometry of piston is like a cylindrical plug making up and down motion inside cylinder. Piston finds its application in pneumatic cylinders and pumps and IC engines.

Figure 1: IC engine piston

It generates reciprocatory motion inside IC engine cylinder under different combustion strokes. The fuel combustion generates thrust which is exerted on piston. The piston transmits this thrust to connecting rod [10].

2. LITERATURE REVIEW

Kaushik et al [1] conducted FEA analysis on Molybdenum, Aluminium and Silicon carbide alloy to determine structural behavior. The simulation results have shown that Al-Si-C12 alloy has minimum deformation when subjected to structural and thermal loads. Therefore, the author suggest the application of this material for piston.

L. Wang et al [2] has investigated the application of TBC (thermal barrier coating) on piston to act as thermal insulation. The results have shown that TBC coating thickness should be between 300 to 400 μm for achieving best results.

D. Freiburg, d. Biermann et al [3] discussed about application of thermal coatings and plasma sprayed coating for automotive engine blocks. These coatings are to be used as cylinder liners and is viable option for achieving thermal resistance.

Mr. Atul a. Sagade et al [4] experimentally investigated the application of silver liner coating on vehicle engine. The coating created a thermal barrier and enhanced heat retention which improved thermal efficiency of IC engine by significant percentage.

Andrew Roberts et al [5] has investigated the reason for high pollution caused by IC engine during its cold start. During cold start, the thermal efficiency of quite low and due to thermal property of lubricant which affects its viscosity and delays engine start due to improper lubrication. The improper lubrication causes increase in pollution levels.

T. Karthikeyasharma et al [6] investigated the effect of mixing inert gas like argon in EGR system of vehicle and studied its effect on emission characteristics and engine performance. The findings have shown that volumetric efficiency and brake power increased with reduction in NO_x emissions.

J. Barriga et al [7] investigated selective absorber coating on engine cylinder liners. The heat retention improved combustion rate and reduced pollution levels and is highly beneficial for automobile application.

V. D. Zhuravlev et al [8] has investigated combustion process using urea as organic fuel. The effect of urea percentage on crystalline structure and morphology is studied using spectroscopy techniques and usage of urea is justified.

Helmisyahahmadjalaludin et al (2013) [9] investigated the thermal stress induced due to combustion in direct injection system (CNGDI) engine by CNG. The major limitation is the problem developed in piston crown which resulted in excessive thermal stresses.

3. OBJECTIVE

The current research is aimed at design and analysis of IC engine piston using ANSYS FEA software. The structural analysis is conducted on generic design to determine radial and tangential stresses. The DOE (design of experiments) is then performed to generated design points and corresponding stresses. The material used for piston is MMC (Metal Matrix Composite). The response surface optimization is done using optimal space filling design scheme.

4. METHODOLOGY

The design of piston is taken from literature [7] as shown in figure 2 below.

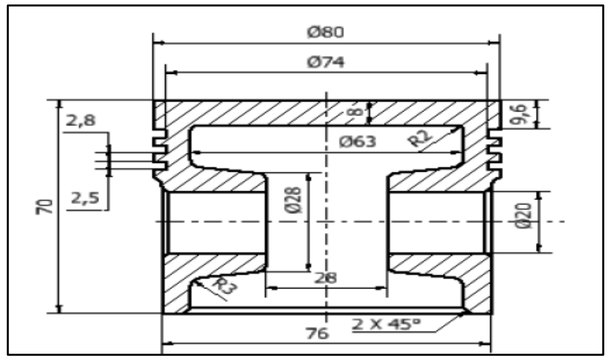

Figure 2: Schematic of piston [7]

In first stage the CAD model is developed using ANSYS software. ANSYS design modeler is specific tool used for designing and editing operation. The model is meshed using tetra elements of appropriate size and shape. After meshing appropriate loads and boundary conditions are assigned.

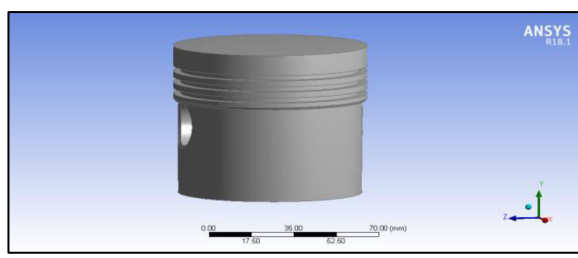

Figure 3: Imported CAD model of piston in ANSYS software

The CAD model of piston is imported in ANSYS design modeller as shown in figure 3 above. The model is checked for geometric errors, hard edges and other defects and corrected.

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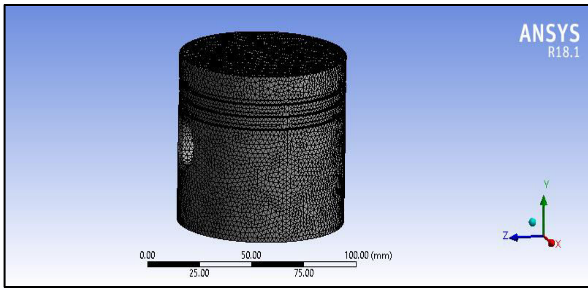

Fig 4: Meshing of suspension using ANSYS design modeler

The CAD model is meshed using tetrahedral elements and fine sizing with curvature effects on. The tetrahedral elements are suitable for complex geometries having higher curvature angles [11]. The number of elements generated is 146685 and number of nodes generated is 223600 as shown in figure 4 above.

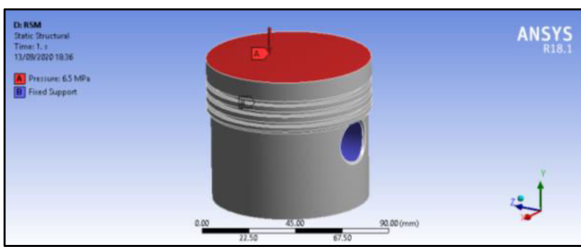

Fig 5: Applied structural loads and boundary conditions

For structural loads the piston top surface is applied with 6.5MPa pressure and cylindrical hole is applied with fixed support as shown in figure 5 above. In next stage software carries out matrix formulations, multiplications and inversions. Initially element stiffness matrix is formulated, the element stiffness matrix are assembled to form global stiffness matrix. When solver is set to run, the software calculates results at nodes and results are interpolated for entire element edge length.

5. RESULTS AND DISCUSSION

The FEA analysis is conducted on piston to determine radial and tangential stresses as discussed below.

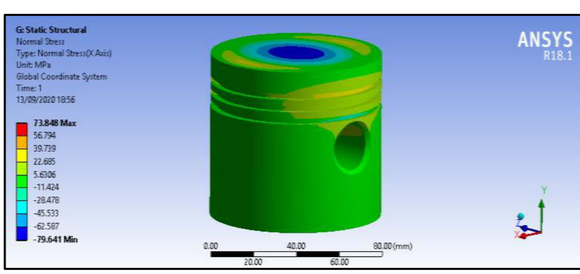

Figure 6: Radial stress distribution on piston using Eutectic alloy

The radial stress plot generated (figure 6) for eutectic alloy shows higher value of radial stress on piston crown region with magnitude of 79.64MPa shown by dark blue color which reduces towards piston skirt region and piston groves. The stress near piston groves is 39.739MPa.

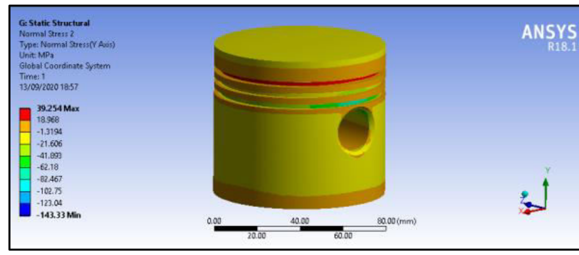

Figure 7: Tangential stress distribution on piston using Eutectic alloy

The tangential stress plot generated in figure 7 for eutectic alloy shows higher value of tangential stress on 1st piston groove region with magnitude of 39.254MPa shown by red color which reduces towards piston skirt region. The stress near piston skirt is 21.6MPa.

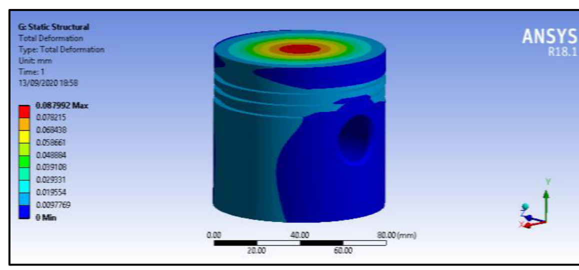

Figure 8: Deformation plot on piston using Eutectic alloy

From deformation plot shown above in figure 8, the maximum deformation is observed near piston crown region shown by dark red color of magnitude .0879mm and minimum deformation is observed on piston skirt region and piston boss shown by dark blue color. The design points are generated from Taguchi design of experiments are shown in table 1 below.

Table 1: Design points generated from DOE

Table of Outline A2: Design Points of Design of Experiments

	A	B	C	D	E
1	Name	P1 - RL1 (mm)	P2 - RL2 (mm)	P3 - tangential stress (MPa)	P4 - radial stress (MPa)
2	1	2.8089	2.7867	38.377	75.123
3	2	2.8178	2.7956	39.126	75.086
4	3	2.7911	2.8089	38.065	75.121
5	4	2.8044	2.8044	39.382	75.102
6	5	2.7867	2.7822	38.907	75.16
7	6	2.7956	2.7911	42.257	75.065
8	7	2.8	2.8178	39.085	75.096
9	8	2.8133	2.8133	39.218	75.106
10	9	2.7822	2.8	42.472	75.112

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Different design points are generated and corresponding radial and tangential stresses are determined at each design points

Table 2: Safety Factor Comparison from structural analysis

Table of Schematic I3: Response Surface: Tolerances

	A	B	C	D
1	Name	Calculated Minimum	Calculated Maximum	Maximum Predicted Error
2	P3 - tangential stress (MPa)	37.091	42.472	4.6279
3	P4 - radial stress (MPa)	75.065	75.162	0.041393

The maximum tangential stress is observed to be 42.472MPa and minimum tangential stress is observed to be 37.091MPa. The maximum radial stress is observed to be 75.162MPa and minimum radial stress is observed to be 75.065MPa.

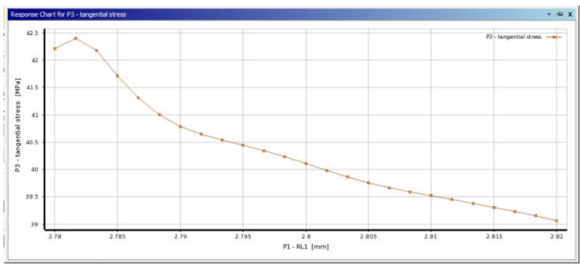

Figure 9: Tangential stress vs ring land 1 (RL1)

The maximum tangential stress for is observed to be at RL1 value of 2.782mm and then decreases thereafter and minimum radial stress is observed at 2.82mm RL1 value.

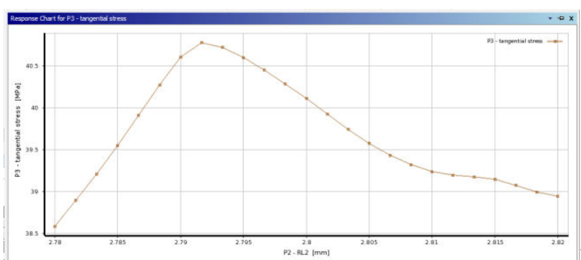

Figure 10: Tangential stress vs ring land 2 (RL2)

The minimum tangential stress is observed to be at RL2 value of 2.78mm and maximum tangential stress is observed at RL2 value of 2.795mm. The curve shows linear increase upto 2.792 and then decreases thereafter to reach minimum value.

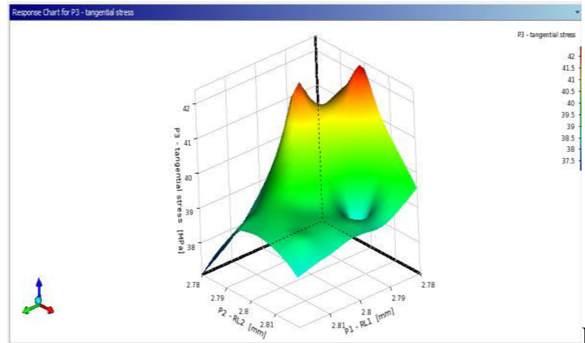

Figure 11: Response surface plot of tangential stress in vertical direction

The response surface plot of RL1 and RL2 variable versus tangential stress are shown in figure 7.39 above. The maximum tangential stress is observed for RL2 value ranging from 2.78mm to 2.85mm (with 2 bumps shown by red color) and RL1 value ranging from 2.78mm to 2.79 mm and 2nd set of value lies between 2.795mm to 2.805mm. The minimum value of tangential stress is observed for RL1 value ranging from 2.79mm to 2.82mm and RL2 value ranging from 2.8mm to 2.81mm.

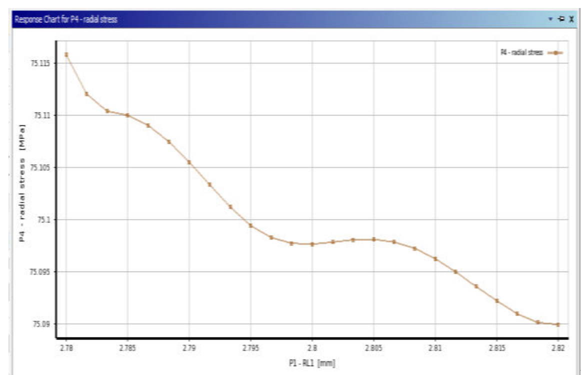

Figure 12: Radial stress vs ring land 1 (RL1)

The minimum radial stress is observed to be at RL1 value of 2.8mm and maximum radial stress is observed at RL1 value of 2.78mm. The curve shown linear variation decrease in radial stress value upto 2.8mm and then increases linearly up to 2.82mm.

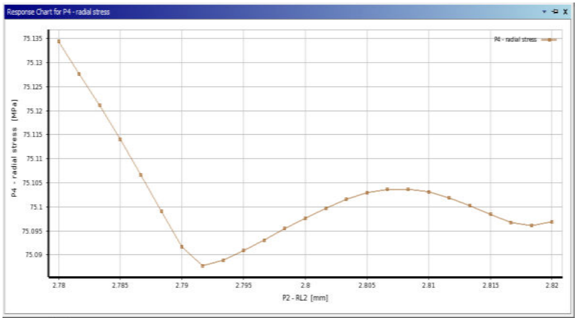

Figure 13:Radial stress vs ring land 2 (RL2)

The radial stress decreases linearly up to 2.792mm RL2 value and then increases. The minimum radial stress is observed to be at RL2 value of 2.792mm and maximum radial stress is observed at RL2 value of 2.78mm.

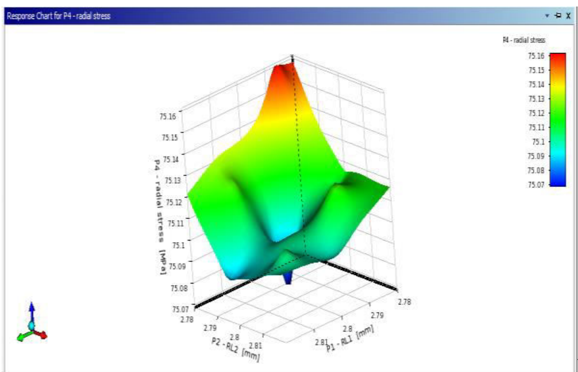

Figure 14: Response surface plot of radial stress in horizontal direction

The response surface plot of RL1 and RL2 variable versus radial stress are shown in figure 7.42 above. The maximum radial stress is observed for RL2 value ranging from 2.78mm to 2.79mm and RL1 value ranging from 2.78mm to 2.79mm.

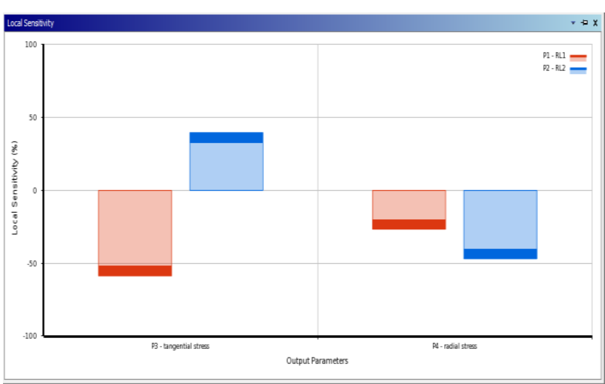

Figure 15: Sensitivity plot of tangential and normal stresses in horizontal and vertical direction

From sensitivity plot shown above, the RL1 has negative sensitivity of 58.63% for tangential stress and RL2 has positive sensitivity of 39.657% for tangential stress. Therefore, RL1 has higher effect on tangential stress and RL2 has lower effect on tangential stress generated.For radial stress in RL1 has negative sensitivity of 26.62% and RL2 has negative sensitivity of 46.89%. Therefore, RL2 has higher effect on radial stress and RL1 has lower effect on radial stress generated.

6. CONCLUSION

The use of MMC in piston could bring about significant improvement in strength of piston with considerable reduction in magnitude of tangential and radial stress. The design of piston is optimized using optimal space filling design scheme of Taguchi response surface method. The responses of optimization variables enabled to determine RL1 and RL2 values corresponding to lower stresses and higher stresses. The sensitivity percentage plot also enabled to determine the effect of each optimization variable on output parameter. The RL1 variable has higher effect on tangential stress and RL2 variable has higher effect on radial stress.

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