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Structural Simulation and Optimization of I C Engine Piton using FEM Method and Taguchi Method

Navneet Gautam[1], Rakesh Kumar[2]
[1]M.Tech. Scholar, Mechanical Engineering Department, Jagannath University, Jaipur
[2]Assistant Professor, Mechanical Engineering Department, Jagannath University, Jaipur

Abstract: In this research work piston design optimization is performed using DOE methods and simulate using Ansys FEM software. DOE method taguchi is selected for design of experiments for this research work. Total five factors which are following material of piston, crown temperature of piston, gas pressure of piston, thermal coating of crown head and last factor is geometrical design of piston. Each factor have four level. Orthogonal array for 16 experiments are solved for this research study. All 16 experiments are then solved using Ansys FEM software. One response parameters named thermal stress is selected for this research work. Signal to noise ratio analysis is performed for this responses and rank of factor and best case is identified for this study. In all cases factor design and temperature of crown surface is most identical and best suited boundary condition for piston design optimization.
Keywords: FEM method, DOE, taguchi method, Design optimization, Piston design, Optimization, ANOVA analysis

I. INTRODUCTION

The piston of I C engine is one of the most challenging components to successfully design and is certainlyquite critical to the performance and durability of the I C engine. Design and optimization of I C engine piston is most challenging task for engineers and designers. From previous decades the research is continue carry foreword by scientists. Various design improvements are find out by engineers and the same task is follow in this research work. It is found that most of the energy is waste due to piston reciprocating and thermal losses, so researchers [1,2,3] work on this problem and optimize the piston assembly. Moosayian et al. [4] investigated on piston assembly for natural vibration occur in piston due to combustion in I C engine cylinder. Buyukkaya et al. [5] studied on thermal coating on piston assembly using Ansys software. In their research study two type of materials Al alloy and SS is used. From their study Al alloy in most suitable materials for high temperature conditions for piston investigation. Singh et al. [6] studied on thermal stress generation due to temperature boundary condition using FEM techniques in piston assembly of I C engine. [7, 8, 9] investigated on maximum and minimum stress development during cycle stroke of I C engine. Most of the research papers found the effect of temperature on stress development on piston body. Lu et al. [10, 11] gave a new calculation method and observed that the area of contact between piston head and skirt also known as combustion chamber throat was the most danger prone area. The prime of this research work is to optimize the piston body using FEM technique. Experiments are designed by using taguchi method. Then analysis is performed by using the same method. Stress is calculated using both thermal and pressure effect using Ansys FEM software.

A. Factor and Level

For the present FEM simulation work the fivedesign parameters each at four levels have been decided for taguchi method. It is desirable to have four minimum levels of design parameters to reflect the true behavior of output parameters selected for this study. The design parameters are renamed as factors and they are given in the adjacent column. The levels of the individual design parameters/factors are given in Table 1.

Table 1design parameters and their Levels (Taguchi Method)

Factor	Parameter	Unit	Level			
			L1	L2	L3	L4
A	Piston-material	-	1	2	3	4
B	Piston Temperature	C	150	160	170	180
C	Cylinder Pressure	MPa	5	6	7	8
D	Thermal Coating	-	1	2	3	4
E	Piston Design	-	1	2	3	4

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All factors and their levels are selected on the basis of literature review. Although levels are different in real time I C engine experiments but these values show in general boundary conditions present in I C engine.

Factor	Parameter	Level			
		L1	L2	L3	L4
A	Piston-material	Al-6061	Al-4032	Al-2618	Hyper-eutectic Al
Factor	Parameter	Level			
		L1	L2	L3	L4
D	Thermal Coating	Normal	Metco 143 Powder	Metco 204C-XCL Powder	Metco 204 F Powder
Factor	Parameter	Level			
		L1	L2	L3	L4
E	Piston Design	Flat Head	Crown head	Bowl Head-I	Bowl Head-II

Last factor design of piston crown is another important design parameter in piston designing. Numerous research study are conducted on piston crown designing and various type of piston crown designs are available

B. *Orthogonal Array for Experiments*

The nearest four level orthogonal array available satisfying the criterion of selecting the OA is L16 having 15 DOF . For each trial in the L16 array, the levels of the design parameters are indicated in Table 2.

Table 2: Taguchi's L16 Standard Orthogonal Array

Sr. No.	A	B	C	D	E	Response (Stress)	S/N Ratio
						T1	
1	1	160	6	2	2	370.72	-51.38
2	1	170	7	3	3	379.37	-51.58
3	1	180	8	4	4	436.19	-52.79
4	2	150	6	3	4	449.82	-53.06
5	2	160	5	4	3	377.49	-51.54
6	2	170	8	1	2	417.77	-52.42
7	2	180	7	2	1	408.11	-52.22
8	3	150	7	4	2	450.05	-53.07
9	3	160	8	3	1	358.02	-51.08
10	3	170	5	2	4	387.79	-51.77
11	3	180	6	1	3	426.62	-52.60
12	4	150	8	2	3	445.57	-52.98
13	4	160	7	1	4	436.52	-52.80
14	4	170	6	4	1	466.00	-53.37

Sr. No.	A	B	C	D	E	Response (Stress) T1	S/N Ratio
1	1	160	6	2	2	370.72	-51.38
15	4	180	5	3	2	471.31	-53.47
16	1	160	6	2	2	488.93	-53.78

C. CAD Geometry for FEM Simulation

Import a CAD model, which was previously created in Autodesk Inventor design software. In this thesis Auto-desk Inventor 2015 was used for this step (Shown in fig 1).

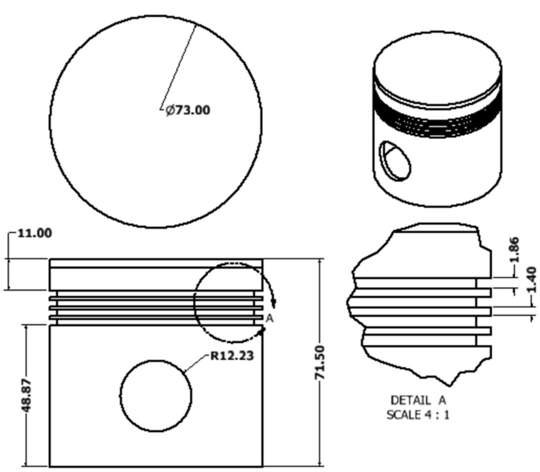

Figure 1 (a) Design-I

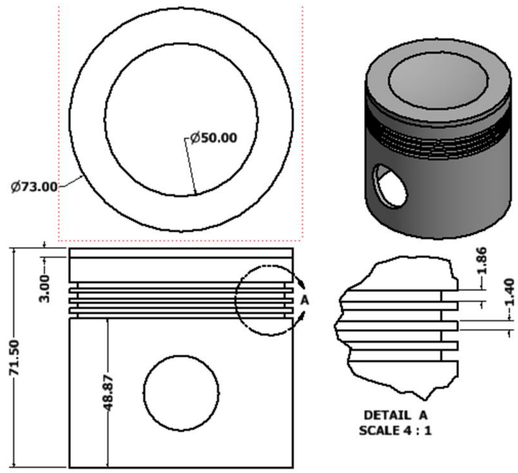

Figure 1 (b) Design-II

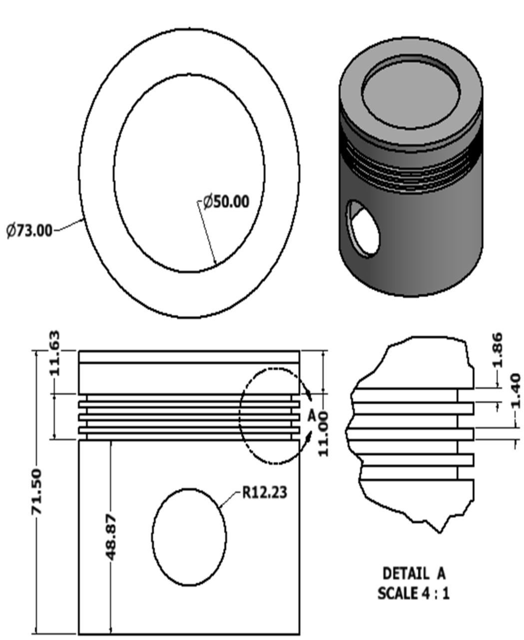

Figure 1 (a) Design-III

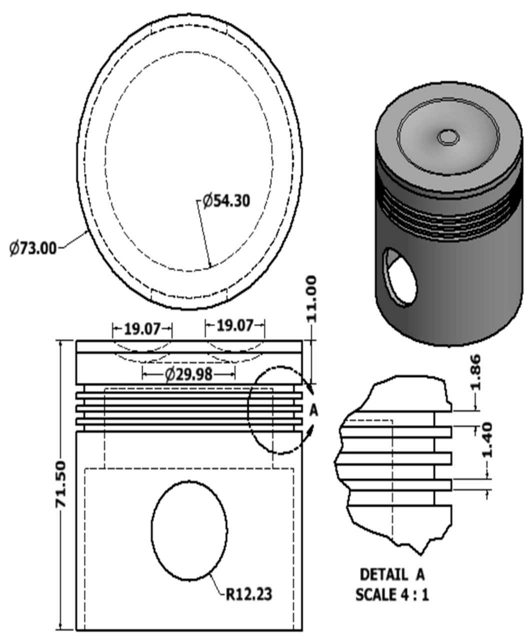

Figure 1 (b) Design-IV

D. Material Properties

In order to achieve the optimization of the piston used in diesel engine, piston material play important role in simulation and in this step material properties are presented for all four piston materials.

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Table 3Material Properties for piston FEM simulation

S.N.	Properties	Unit	Al-4032	Al- 2618	Al-6061
1.	Density (P)	kg/m^3	2690	2760	2680
2.	Poisson's Ratio (μ)	--	0.33	0.33	0.33
3.	Elastic Modulus (E)	GPa	70-80	70-80	70-80
4.	Ultimate Tensile Strength (σ_t)	MPa	380	440	310
5	Yield Strength (S_y)	MPa	315	370	276
6.	Shear Strength	MPa	260	260	207
7.	Fatigue Strength	MPa	110	125	96.5
8.	Thermal Expansion Coefficient	°C	$19.4*10^{-6}$	$22*10^{-6}$	$23.5*10^{-6}$
9.	Thermal Conductivity (K)	W/mk	154	146	173

II. RESULT AND DISCUSSION

A. Signal to Noise ratio analysis

In table 2 S/N ratio for thermal stress is solved using mini-tab software for option "smaller is better". S/N ratio helps to predict the rank of factors and the results are present in table 4 for thermal stress.

Table 4 S/N ratio analysis for Thermal stress

Level	A	B	C	D	E
1	-52.20	-51.70	-52.55	-52.49	-52.42
2	-52.31	-52.28	-52.39	-52.51	-52.16
3	-52.11	-52.77	-52.58	-52.47	-52.75
4	-53.35	-53.22	-52.46	-52.51	-52.64
Delta	1.25	1.52	0.19	0.04	0.58
Rank	2	1	4	5	3

The same result are present in figure 2 for S/N ratio smaller is better for thermal stress and this figure helps to predict optimum case for this research work. The optimum case is A3-B1-C2-D3-E2 for thermal stress.

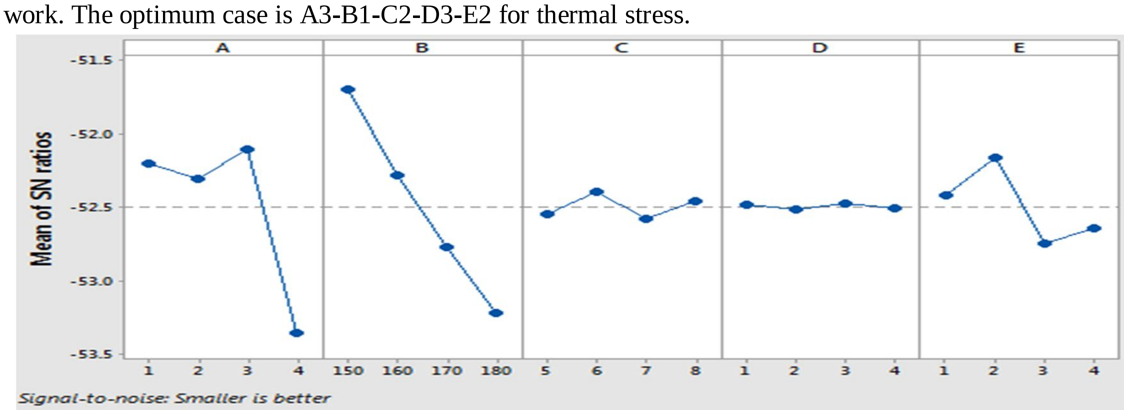

Figure 2 S/N ratio analysis for thermal stress

Interaction plots are generated for the same response thermal stress and present in figure 3 for all combinations of thermal stress. As seen in figure 3, the best contributed factor is temperature and design of piston assembly.

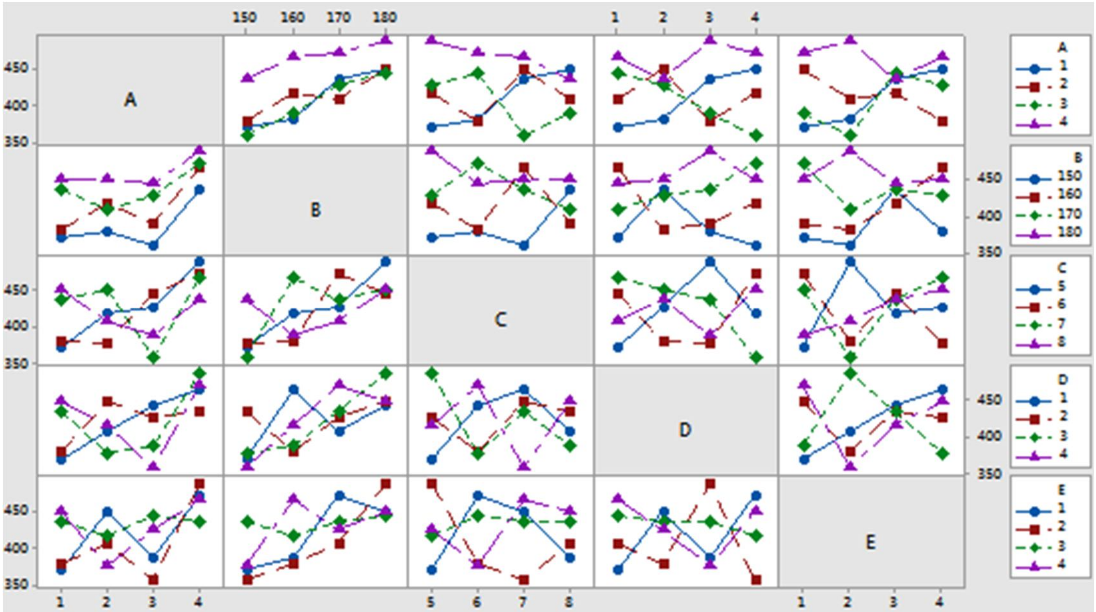

Figure 3 Interaction Plot for thermal stress

Estimation of best case predicted by using S/N ratio is now validated with optimum response technique which is present in next section for this work.

B. Estimation Of Optimum Response Charateristics

$$\mu_{TS} = \bar{A}_3 + \bar{B}_1 + \bar{C}_2 + \bar{D}3 + \bar{E}2 - 4\bar{T}$$

Where

T is average of thermal stress = 423.14

A_3 is average value of factor A for level 3 is = 404.50

B_1 is average value of factor B for level 1 is = 385.68

C_2 is average value of factor C for level 2 is = 418.43

D_3 is average value of factor D for level 3 is = 422.60

E_2 is average value of factor E for level 2 is = 408.60

Substituting the values of various terms in the above equation,

$$\mu_{TS} = 404.50 + 385.68 + 418.43 + 422.60 + 408.60 - 4 * 423.14 = 347.25$$

The 95 % confidence intervals of confirmation experiments (CI_{CE}) and population (CI_{POP}) are calculated by using the Equations

$$CI_{CE} = \sqrt{F_\alpha\,(1, f_e)\,V_e\left[\frac{1}{n_{eff}} + \frac{1}{R}\right]} \qquad \text{and}$$

$$CI_{POP} = \sqrt{\frac{F_\alpha\,(1, f_e)\,V_e}{n_{eff}}}$$

Where, Fα (1, fe) = The F ratio at the confidence level of (1-α) against DOF 1 and error degree of freedom fe.

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$$n_{eff} = \frac{N}{1+[\text{DOF associated in the estimate of mean response}]}$$

$$\eta_{eff} = \frac{16}{1+4} = 3.2$$

R = Sample size for confirmation experiments = 1
Ve = Error variance = 578.8 (see following table)
fe = error DOF = 10 (see following table)
$F_{0.05}$ (1, 10) = 4.97 (Tabulated F value ; Roy, 1990)
Substitute all values in formulas

$$CI_{CE} = \sqrt{F_{0.05}(1,10) * V_e * \left[\frac{1}{n_{eff}} + \frac{1}{R}\right]} = \sqrt{4.97 * 578.8 * \left[\frac{1}{3.2} + \frac{1}{1}\right]} = \pm 61.44$$

$$CI_{POP} = \sqrt{\frac{F_{0.05}(1,10) * V_e}{n_{eff}}} = \sqrt{\frac{4.97 * 578.8}{3.2}} = \pm 29.98$$

Therefore, the predicted confidence interval for confirmation experiments is:

$$Mean\mu_{TS} - CI_{CE} < \mu_{TS} < Mean\mu_{TS} + CI_{CE}$$
$$= 347.25 - 61.44 < 347.25 < 347.25 + 61.44$$
$$= 285.81 < \mu_{TS} < 408.69$$

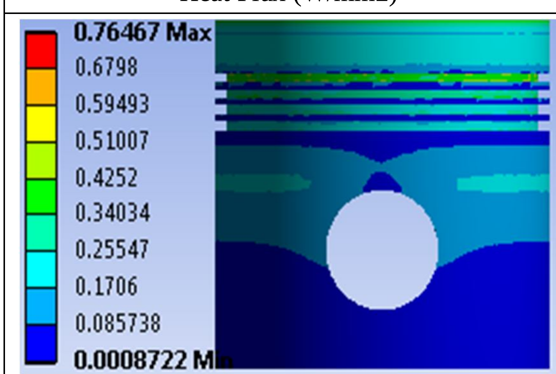
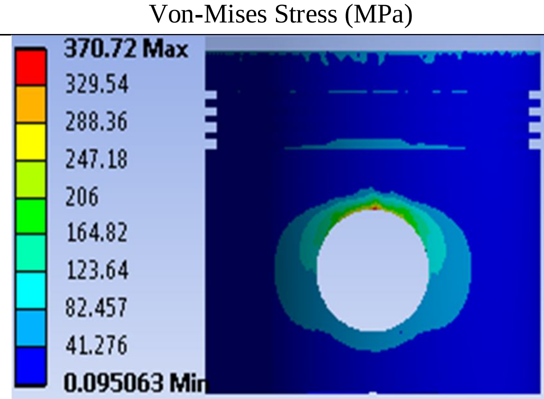
The 95% confidence interval of the population is:

$$Mean\mu_{TS} - CI_{POP} < \mu_{TS} < Mean\mu_{TS} + CI_{POP}$$
$$= 347.25 - 29.98 < 347.25 < 347.25 + 29.98$$
$$= 317.27 < \mu_{TS} < 377.23$$

C. Confirmation Experiment For Thermal Stress (Ts)

Response Parameter	Optimal Set of Parameters	Predicted Optimal Value	Predicted Confidence Intervals at 95% Confidence Level	FEM Value
Thermal Stress	$A_3B_1C_2D_3E_2$	347.25	CI_{POP}: $317.27<\mu_{TS}<377.23$ CI_{CE}: $285.81<\mu_{TS}<408.69$	357.58

Visual results for this research work are present in this section but only some sample cases are present due to repeat-ability of the same results.

Heat Flux (W/mm2)	Von-Mises Stress (MPa)
	
Total Deformation (mm)	Eq. elastic Strain (mm/mm)

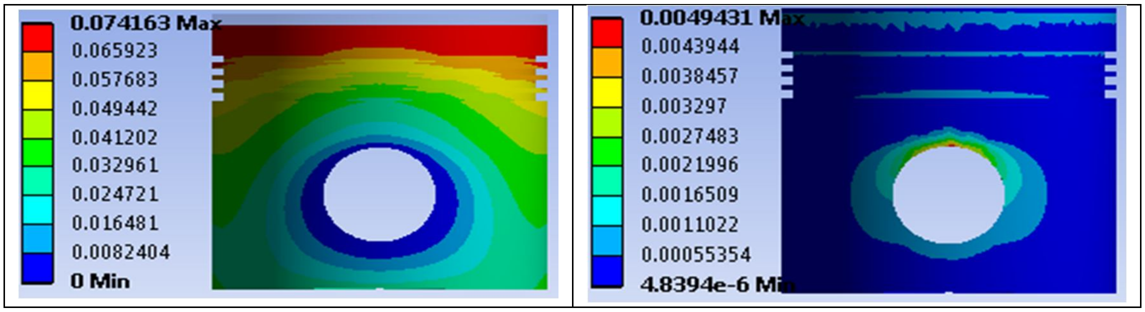


Figure 4 Case-I as per L 16

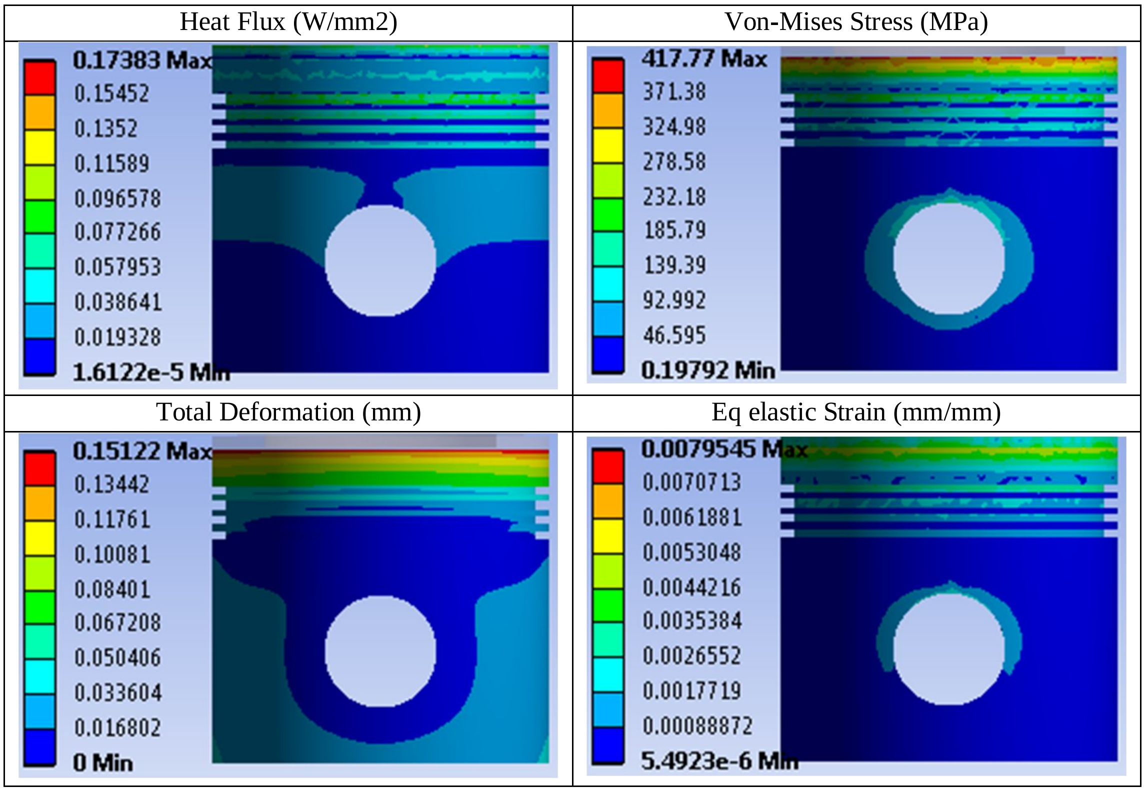


Figure 5 Case-VI as per L 16

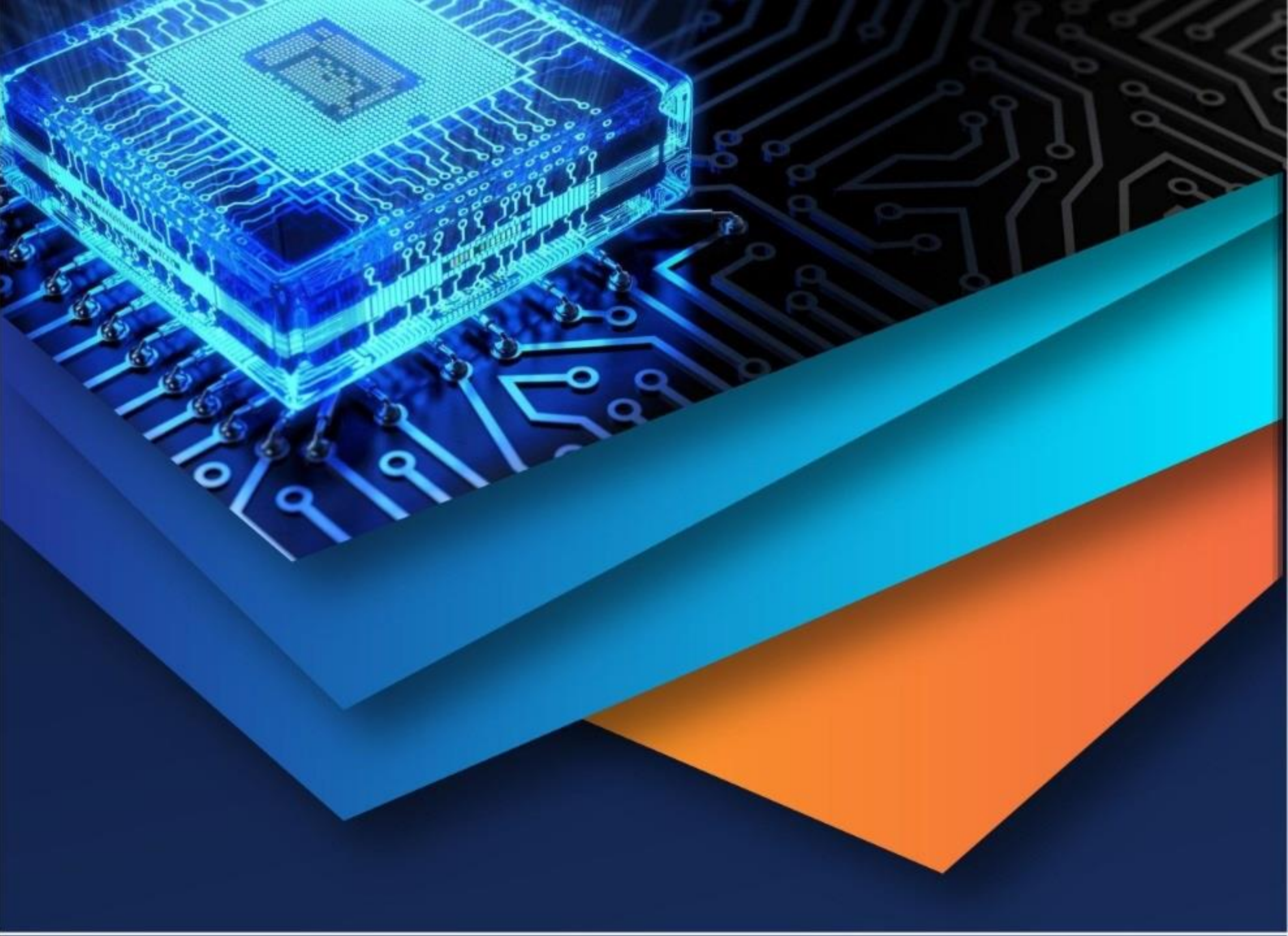
III. CONCLUSION

In this research work piston of I C engine is numerically solved for L16 orthogonal array made by five factors and four levels of piston design improvement. All simulation is carried out in Ansys software using work-bench management software. The main conclusion of this study is following As per signal to noise ratio analysis the best ranked factor is crown temperature of piston head and least factor is thermal coating material applied to piston head and side walls. As per signal to noise ratio analysis, the best case is for thermal stress is A3-B1-C2-D3-E2, and predicted value for this case is solved using optimal solution which is equal to 347 MPa for this research work. Visual analysis is performed for this research work is another outcome which helps to predict the full analysis of thermal stress.

REFERENCES

[1] P.C. Mishra, Modeling the root causes of engine friction loss: Transient elastohydrodynamics of a piston subsystem and cylinder liner lubricated contact,Applied Mathematical Modelling, 39 (2015) 2234-2260
[2] S. Balakrishnan, S. H. Smith, R. H. Rahnejat, D. Dowson, Investigation ofreciprocating conformal contact of piston skirt and ring-pack to cylinder linerunder transient condition, Transient Processes in Tribology, Elsevier, 43(2003) 265-273
[3] D. Dowson, Piston assemblies; background and lubrication analysis, in: C.M.Taylor (Ed.), Engine Tribology, Elsevier Science Publishers, 1993, 213-240.
[4] A. Moosavian, G. Najafi, B. Ghobadian, M. Mirsalim, S.M. Jafari, P. Sharghi,Piston scuffing fault and its identification in an IC engine by vibration analysis,Applied Acoustics, 102 (2016) 40-48

[5] N.A. Ghyadh, M.A.R.S.A. Baghdadi, S.S. Ahmed, Mechanical and thermalstresses anaysis in diesel engine piston with and without different thermalcoating layer on piston head, Asian transaction on engineering, 5 (2015) 6-18.
[6] M.L.S. D. Kumar, P. Poornima, Thermal analysis of diesel engine piston using3-D finite element method, International Journal of Manufacturing Tech. &Industrial Engineering, 42 (2011) 97-102
[7] D.Vhandik, A Pradhan, S. Mhaskar, N. Sukthankar, A. Dhale, Design analysis& optimization of piston and determination of its thermal stresses using CAETools, International Journal of Engineering sciences & Research Technology,104 (2014) 2277-9655
[8] Karuppasmy, M. Kumar, Manikandan, N. Arjun, The effect of thermal barriercoating on diesel engine performance, APRN Journal of science andtechnology, 04 (2013) 2225-7217
[9] E. Buyukkaya, M. cerit, Thermal analysis of a ceramic coating diesel enginepiston using 3-D finite element method, Surf. & coat Tech. 202 (2007)398-402
[10] Y. Lu, X. Zhang, P. Xiang, D. Dong, Analysis of thermal temperature fieldsand thermal stress under steady temperature field of diesel engine piston,Applied Thermal Engineering, 113 (2017) 796–812
[11] L.S.R. Krishna, N. Mahesh, N.Sateesh, Topology optimization using solidisotropic material with penalization technique for additive manufacturing,Materials Processing and Characterization, 04 (2017) 1414-1422



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