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Application of Optimal Space Filling Optimization Technique in Design Optimization of Engine Cylinder

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Abstract: The engine cylinder is one of the vital components of an automobile. The cooling of engine cylinder is generally achieved with the aid of fins (or extended members). The design of fins have significant effect on heat dissipation characteristics of engine cylinder and therefore it's imperative to evaluate the effect of fin dimensions on thermal dissipation characteristics.The objective of current research is to investigate the effect of fin dimensions on temperature distribution across engine cylinder fins. The design of engine cylinder and analysis is conducted in ANSYS FEA software. The effect of fin dimensions on heat flux and temperature distribution is evaluated using response surface optimization (RSO). The simulation results have shown that intersection zone of cylinder and fins have maximum heat dissipation as compared to other regions. The optimization process enabled to evaluate the effect of each design variable on heat dissipation characteristics. For total heat flux, the fin1dia has lower sensitivity percentage of 58.093 and fin2dia has higher sensitivity percentage of 74.996. The higher sensitivity percentage of fin2dia signifies that fin2dia has higher effect on heat flux of engine cylinder as compared to fin1dia.

Keywords*: DOE, Optimization, Engine Cylinder.*

1. Introduction

To safeguard the engine cylinder against excessive temperatures and thermal stresses, cooling is essential. Liquid or air cooling is utilized by internal combustion engine cooling systems to remove excess heat from the IC engine cylinder block. Generally, engine surfaces are exposed to ambient air and its cooled with the process of natural convection. Increasing the heat transfer area is a direct and efficient approach to improving the heat transfer rate; nevertheless, in order to achieve this, larger surface areas or higher convective heat transfer coefficients are necessary. The engine cylinder fins aids in efficient dissipation of heat from the engine. Cylinder fins contribute to the overall cooling system of the engine, helping to maintain optimal operating temperatures. Efficient cooling is essential for preventing overheating, which can lead to engine damage and reduced performance. The design and arrangement of cylinder fins vary among different engines, with factors such as engine size, power output, and intended use influencing the fin configuration.

2. Literature Review

G. Bahadur Vali & Krishna Veni [1] They created and put together a cylinder and cylinder head for this project. Two different aluminum alloys, 7475 and 6061, were used. Analyzing the cylinder's thermal properties to understand how changing the thickness of the cylinder head impacts the aluminum alloys used in the original model. Furthermore, they mentioned that as the thickness of the component decreases, its weight also decreases. Research results show that the updated model exhibits a higher heat transfer rate than the original model. Aluminum alloy 6061 has a higher thermal discharge than aluminum alloy 7475.

Abhishek Mote at el [2] conducted research on heat transmission over finned surfaces using computational fluid dynamics software. Simulating heat transfer over the fins of an IC engine using CFD software provided an efficient alternative to the time-consuming experimental research done by previous researchers. Afterward, a comparison was drawn between the simulation and experimental results.

Shubham Shrivastava & Shikar Upadhyay [3] investigated a 3D-modeled cylinder block with fins using experimental techniques. The cylinder block fins of the engine were modified by reducing the thickness from 3 mm to 2 mm. Conducting a study on the thermal properties of aluminum alloy 1050 to find lighter replacement materials and determine the material with the best heat transfer rate. By maintaining the block's strength, they alter its composition to decrease its weight by 2.1% and 13.1%, respectively.

Vinay Kumar Attar & Himanshu Arora [4] investigated the piston skirt region, which often leads to a fracture at the upper end of the piston head and seems to deform while in operation. If the piston breaks due to insufficient rigidity, the situation could worsen and result in vertical fractures along the piston. To minimize stress concentration, the deformation of the piston plays a key role in influencing the stress distribution across the piston.

Chidiebere Okeke-Richard & Sunny Sharma [5] examined the thermal effects of combustion gases on the cylinder blocks of four-stroke SI engines produced by Honda, TVS, and Yamaha, focusing on heat flux and temperature changes. According to their data, the Honda Activa consistently produces higher temperatures than the TVS Wego. Despite differences in thermal properties, the Yamaha Ray Z produces the lowest amount of heat in winter.

KM Sajesh, Neelesh Soni and Siddhartha Kosti [6] conducted analysis of the engine's rectangular fins conducted using Computational Fluid Dynamics (CFD). They choose a two-wheeler engine based on ANSYS 16.0, like the Unicorn cycle engine, for their project. Modeler is used to create shapes. The material Al 6063, with a thermal conductivity of 200 W/mK, was used. They modify the engine's structure by creating holes in the fin. Performing a 400-second evaluation of the engine's transient and steady-state heat transfer. They are studying how different pore diameters, such as 6 mm, 10 mm, and 2 mm, affect temperature changes in fins. Moreover, a study was carried out to analyze the differences between an imperforate fin and a perforated fin. All fins reached a stable temperature within 400 seconds. By adding a hole to the fin measuring 10 mm in diameter, the temperature decreased from 1036.5 K to 989.03 K.

Mr. Manir Alam & Mrs. M. Durga Sushmitha [7] conducted research on cylinder fin body of motorcycle using CATIA design software. The initial model was adjusted with changes to the fin body design, thickness, and spacing, along with the addition of cast iron into the fin body. Analyzed the thermal properties of aluminum alloy 6082, cast iron, and copper. Based on the thermo investigation results, it appears that aluminum alloy has a higher heat discharge compared to the other two substances. Aluminum alloy 6082 leads to a reduction in total weight, making it a preferred option.

Swati Saini & Kagdi Dhruvin Nileshkumar [8] conducted a CFD simulation to assess the findings from the experiments conducted on single cylinder engine to enhance heat transfer characteristics. Various fin profiles can be utilized on a single cylinder to enhance heat transfer. We used CAD software to create a fin profile aimed at improving heat transfer. The simulation process closely resembled that of an experiment.

P.T. Nitnaware & Prachi S. Giri [9] analyzed the impact of fin configurations, evaluate the heat dissipation material utilized in air conditioning for an IC engine, and investigate the heat transfer coefficient. In terms of heat transmission efficiency per unit weight, conical fins exhibit superior performance over rectangular fins. Preferable to fins with a rectangular cross-section are conical fins. As the value of h increases, so does the rate of heat transfer. Particularly for small values of h, aluminum is an exceptional material for fabricating fins for air-cooled engines due to its light weight, high heat transfer rate, and cost-effectiveness.

H.Sumithra & B. Sandhya Rani [10] have conducted research on engine cylinder fins using FEA simulation package. The maximum stresses of three materials were ascertained through the utilization of three distinct materials in three independent coupled studies that examined both the thermal and structural aspects. Prior to modification, the highest temperatures recorded for Aluminum92, Aluminum96, and Aluminum Silicon Nitrate are 671.45°C, 665.74°C, and 505.73°C, respectively. Aluminum-92, Aluminum-96, and Aluminum Silicon Nitrate now have respective maximal temperatures of 459.91 oC, 294.95 oC, and 459.68 oC. In the end, they concluded that silicon nitrate was the cleanest substance in comparison to the other two options. Following the adjustment, the weight of the model decreased from 1.643 kg to 1.627 kg, while its density increased by 3000 kg/m^3.

3. OBJECTIVES

The objective of current research is to investigate the effect of fin dimensions on temperature distribution across engine cylinder fins. The design of engine cylinder and analysis is conducted in ANSYS FEA software. The effect of fin dimensions on heat flux and temperature distribution is evaluated using response surface optimization (RSO). The RSO algorithm used for the analysis is optimal space filling which is based on factorial model.

4. METHODOLOGY

The FEA simulation of engine cylinder encompasses different stages i.e. pre-processing, solution and post-processing. The CAD model of engine cylinder is developed in design modeler module of ANSYS workbench. The modeling process involves first sketching of cylinder followed by extrusion. The subsequent step involves modeling of fins. The developed CAD model of engine cylinder with fins is shown in figure 1.

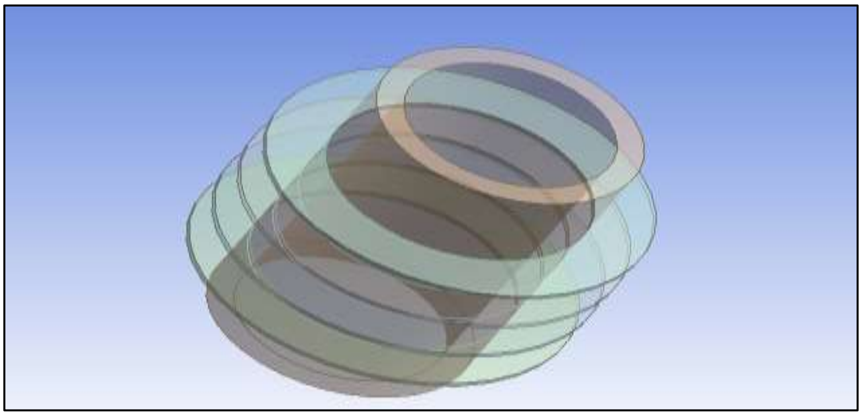

Figure 1: CAD model of engine cylinder with fins

After modeling of engine cylinder, the model is discretized using hexahedral element type. The model has topological consistency along the length which makes it well suited for hexahedral element meshing. The mesh relevance is set to fine sizing with growth rate of 1.1 and smooth transition. The discretized model of engine cylinder with fins is shown in figure 2.

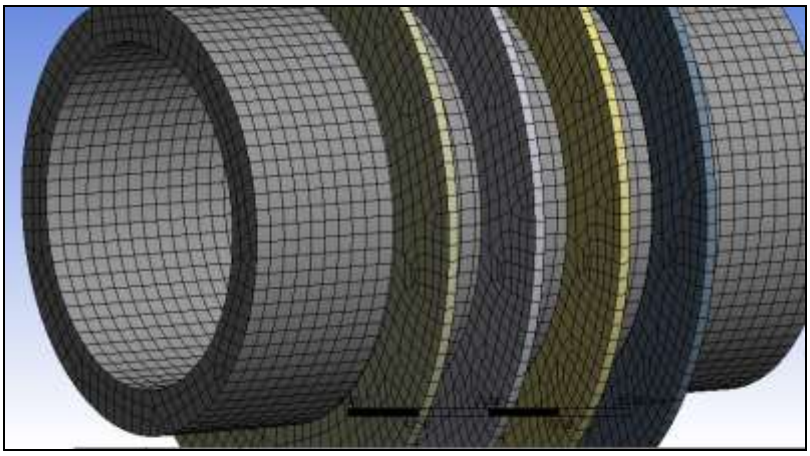

Figure 2: Selection of dimensions for design optimization

After discretization, the model is applied with thermal loads and boundary conditions as shown in figure 3. The inner wall surface of the engine cylinder is applied with 200^{0}C temperature and exposed surface of the fins are applied with convection of 3.01W/m^2K [11].

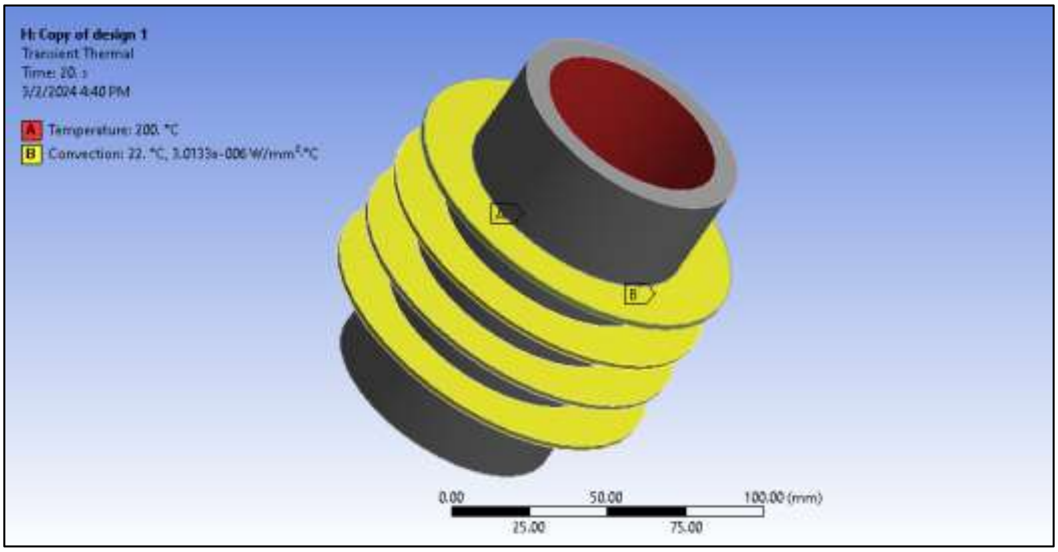

Figure 3: Thermal boundary conditions

After applying thermal loads, the simulation process is run. The simulation process involves formulation of element stiffness matrices, assemblage of global stiffness matrix. The calculations are performed at individual nodes and results are interpolated for entire element edge. The temperature distribution plots and heat flux plots are generated based on the thermal analysis results.

5. RESULTS AND DISCUSSION

From the thermal analysis conducted on engine cylinder, the thermal distribution plot is obtained as shown in figure 4. The thermal distribution plot shows higher magnitude of temperature on cylinder inner walls where in the magnitude is nearly 473K. The temperature on fins reduces radially as represented in yellow, orange colored bands where in the temperature magnitude is 468K.

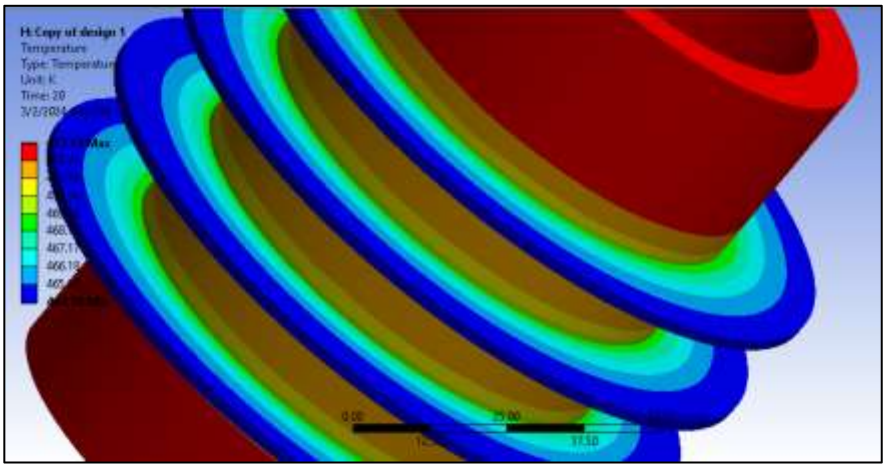

Figure 4: Temperature distribution across engine cylinder

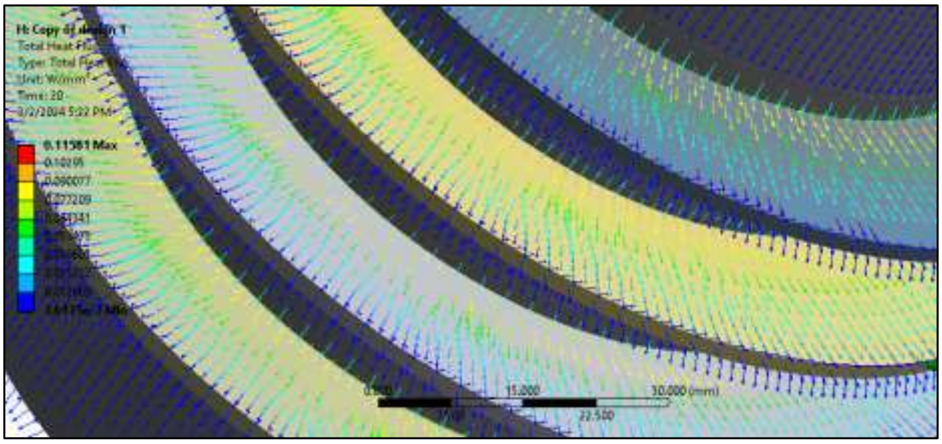

Figure 5: Heat flux vector plot

The thermal flux distribution plot is obtained for engine cylinder as shown in figure 5 above. The thermal flux plot shows higher magnitude of heat flux at the interface of cylinder and fins with magnitude of .115 W/mm^2. The heat flux reduces along radially and reaches minimal value at corner edges of fins wherein the magnitude is .0128W/mm^2.

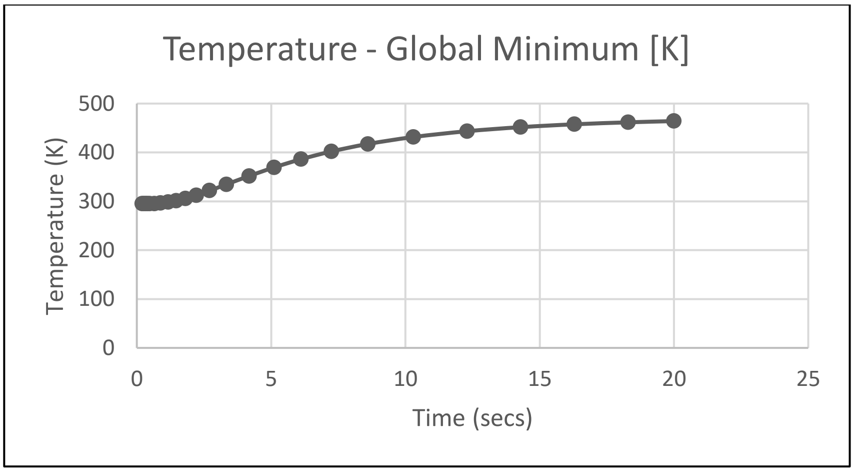

Figure 6: Temperature vs time

The variation of temperature vs time curve is developed for engine cylinder. As it can be observed in figure 6 above, the temperature increases exponentially with time. The initial temperature is 300K which reaches to 452K after 20 seconds of simulation. After running FEA simulation, the optimization process is run. The response surface optimization is conducted using optimal space filling algorithm. The optimization variables are defined for the simulation which includes diameter of fin1 i.e. fin1dia and diameter of fin2 i.e. fin2dia which is shown in figure 7.

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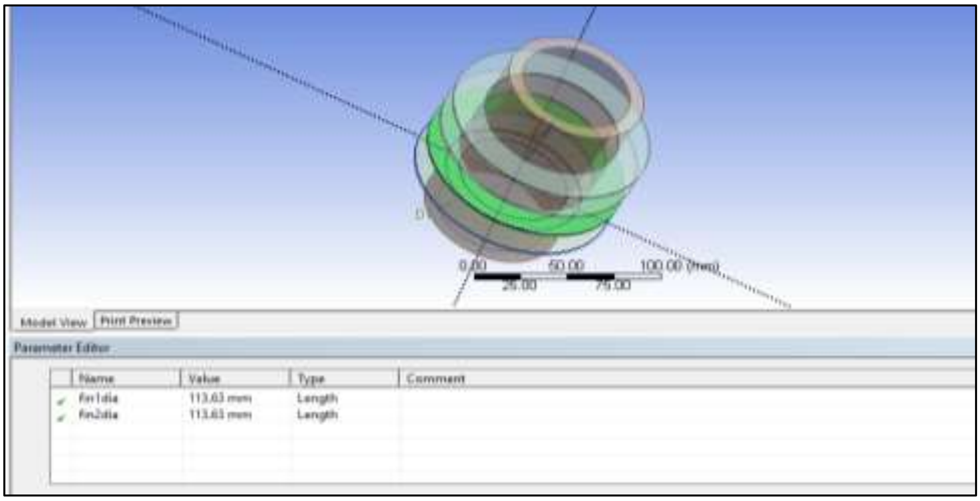

Figure 7: Selection of dimensions for design optimization

The DOE process is run based on optimal space filling algorithm of response surface optimization technique. For the optimization process, the lower bound and upper bound values are defined for the simulation. The lower bound value defined for both fin1dia and fin2dia is 102.27 and upper bound value defined for both fin1dia and fin2dia is 124.99. The lower bound and upper bound definition for both variables are shown in figure 8.

General	
Units	mm
Type	Design Variable
Classification	Continuous
Values	
Lower Bound	102.27
Upper Bound	124.99

Figure 8: Selection of dimensions for design optimization

	A	B	C	D	E
1	Name	P1 - fin1dia (mm)	P2 - fin2dia (mm)	P3 - Temperature Minimum (C)	P4 - Total Heat Flux Maximum Minimum Value Over Time (W m^-2)
2	1	118.68	106.06	186.87	324.5
3	2	123.73	111.11	180.44	236.07
4	3	108.58	118.68	186.51	325.21
5	4	116.16	116.16	188.88	401.28
6	5	106.06	103.53	191.24	292.83
7	6	111.11	108.58	191.28	292.86
8	7	113.63	123.73	180.19	236
9	8	121.21	121.21	183.33	334.98
10	9	103.53	113.63	191.2	265.83

Figure 9: DOE table obtained from optimal space filling design

The DOE process is run using optimal space filling method. From the optimization different values of P1 i.e. fin1dia and P2 i.e. fin2dia is generated as shown in figure 10 above. The software performs different set of simulations based on different set of values (fin1dia and fin2dia). From the simulation process, different values of temperature are obtained as shown in column P3 and total heat flux as shown in column P4. From the DOE table, the maximum heat flux is obtained for design point number 3 which signifies maximum heat dissipation. The dimensions corresponding to design point number 2 is fin1dia 123.73mm and fin2dia is 111.11mm.

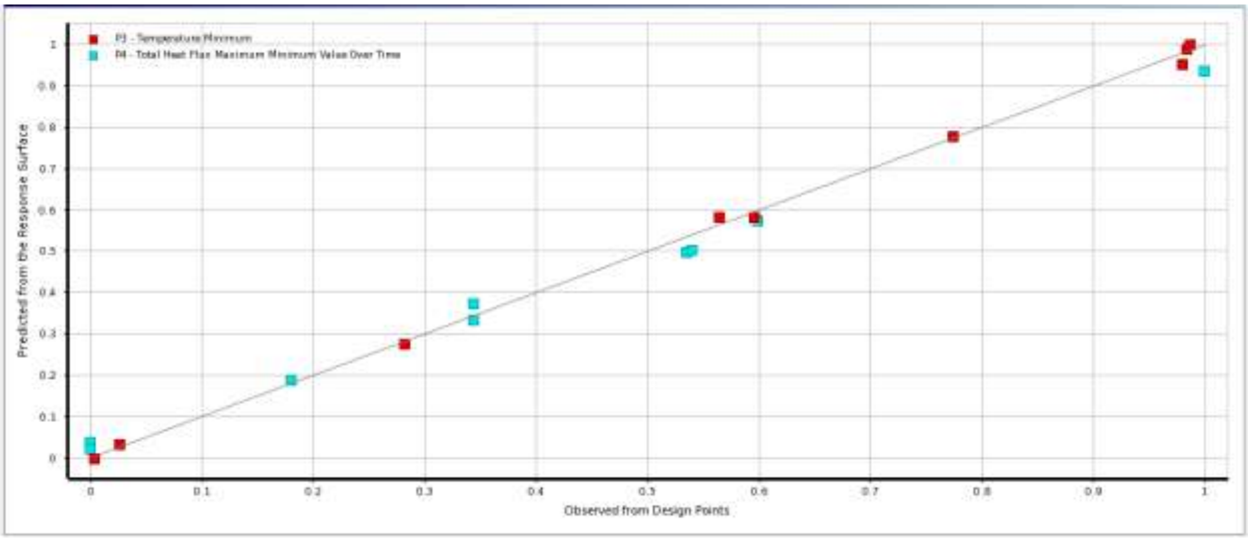

Figure 10: Goodness of fit curve

The goodness of fit curve is generated from the optimal space filling optimization process as shown in figure 10. The expected values are represented by straight line and observed values are represented by red and blue colored boxes. The goodness of fit curve shows lower variation of obtained values as compared to expected values which shows the results are reasonably accurate.

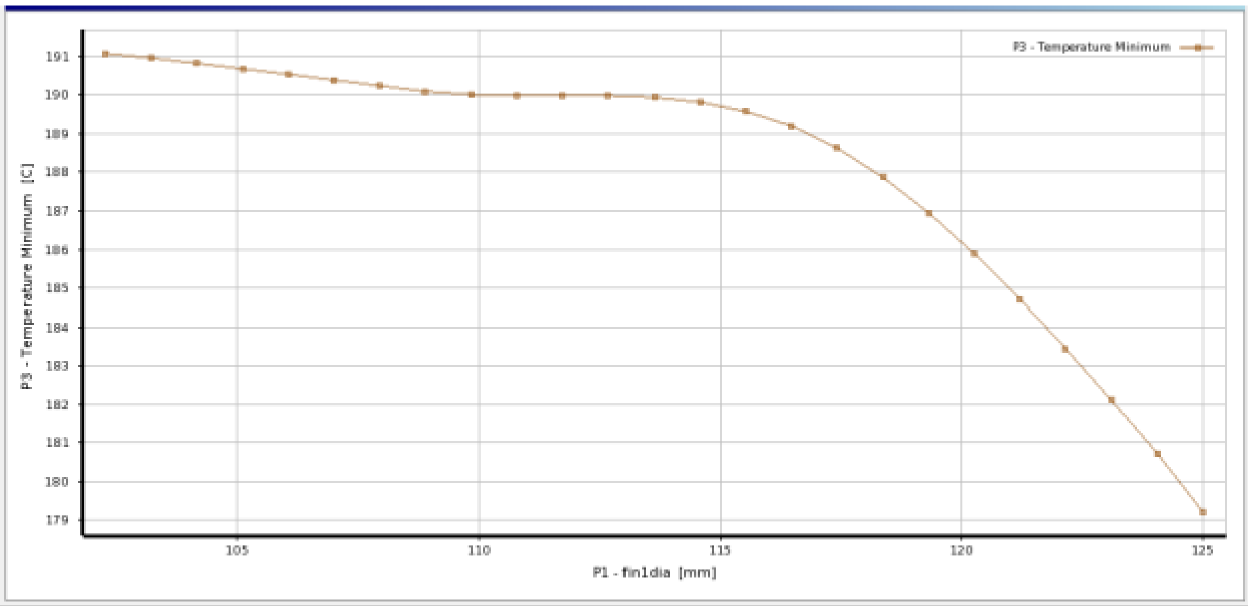

Figure 11: Variation of temperature vs fin1dia

The variation of temperature vs fin1dia is shown in figure 11 above. The plot shows slight variation of temperature with increase in fin1dia up to 115mm and thereafter temperature decrease is observed exponentially and reaches to 179^{0}C at 125mm fin1dia.

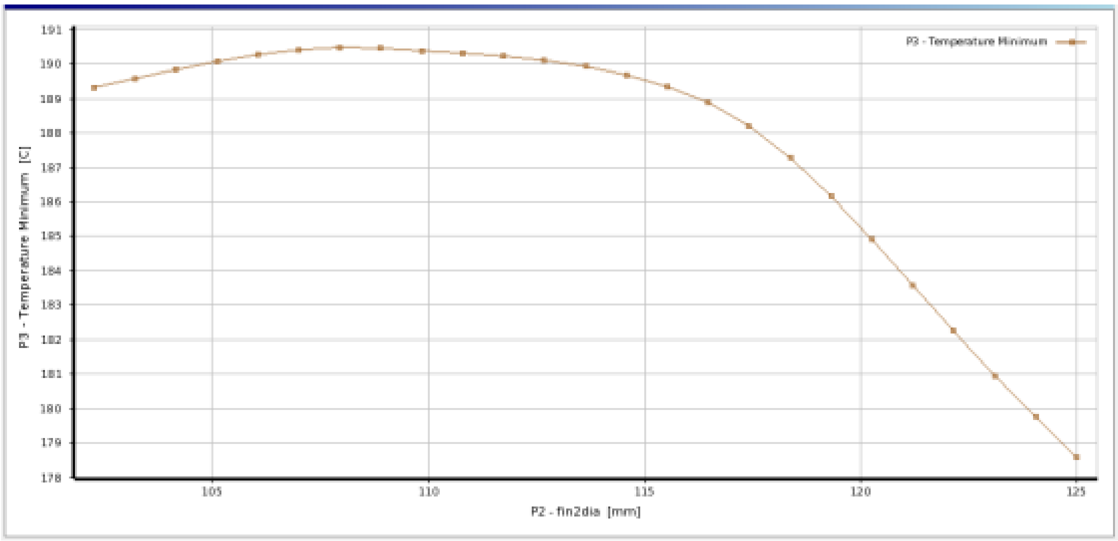

Figure 12: Variation of temperature vs fin2dia

The variation of temperature vs fin2dia is shown in figure 13 above. The plot shows slight increase in temperature with increase in fin2dia upto 108mm fin2dia and then decreases linearly and the temperature reaches minimum value at fin2dia of 125mm.

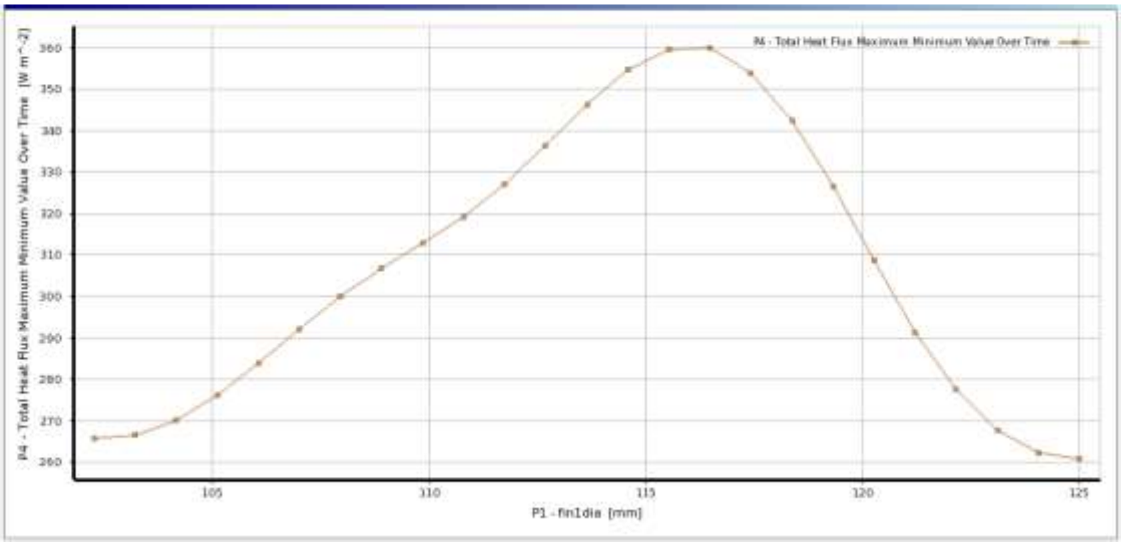

Figure 13: Variation of heatflux vs fin1dia

The variation of heatflux vs fin1dia is shown in figure 13 above. The plot shows linear increase in total heat flux upto 116mm fin1dia and decreases thereafter to reach minimal value at 125mm fin1 dia. The maximum heat flux obtained from the analysis is 360W/m^2.

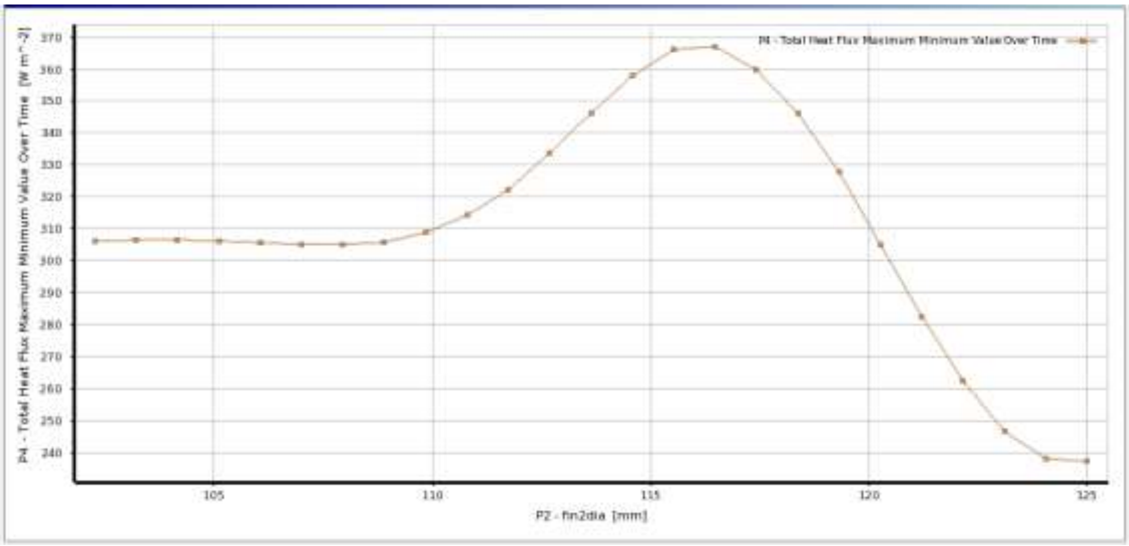

Figure 14: Variation of heatflux vs fin2dia

The variation of heat flux vs fin2dia is shown in figure 14 above. The plot shows no variation of heat flux upto 110mm fin2dia and thereafter gradual increase of heat flux is observed up to 117mm fin2dia followed by linear reduction. The minimum heat flux value obtained is 239 W/m^2.

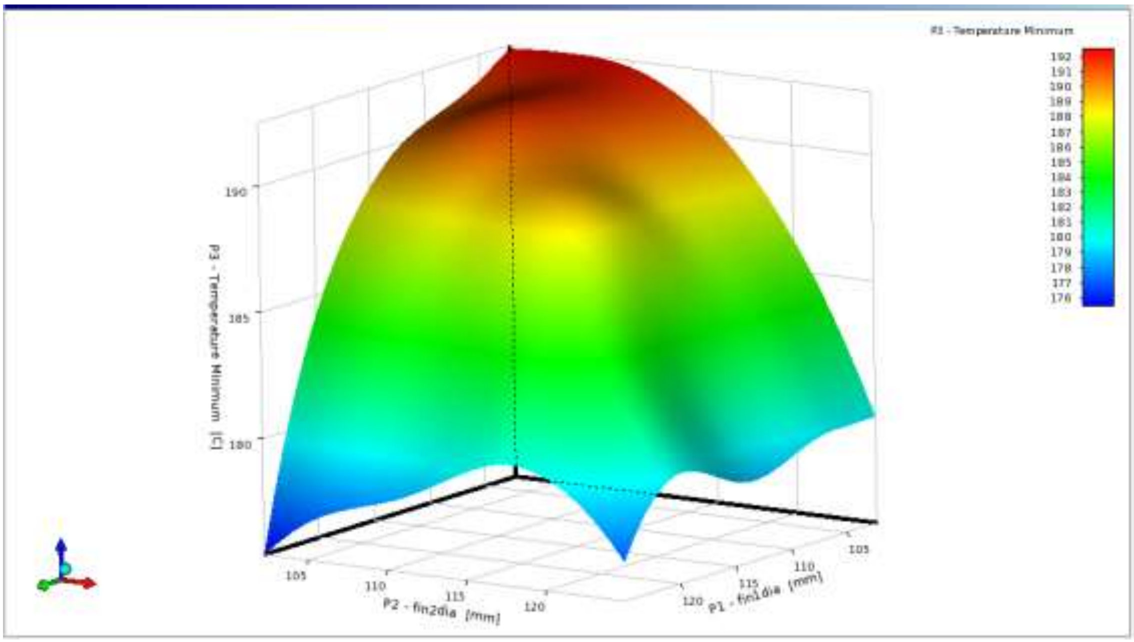

Figure 15: 3D response surface plot of temperature

The 3D response surface plot of temperature shows higher magnitude for fin1dia and fin2dia ranging from 102mm to 115mm. The high temperature magnitude is represented in red colored region whereas lower temperature magnitude region is represented by blue colored region.

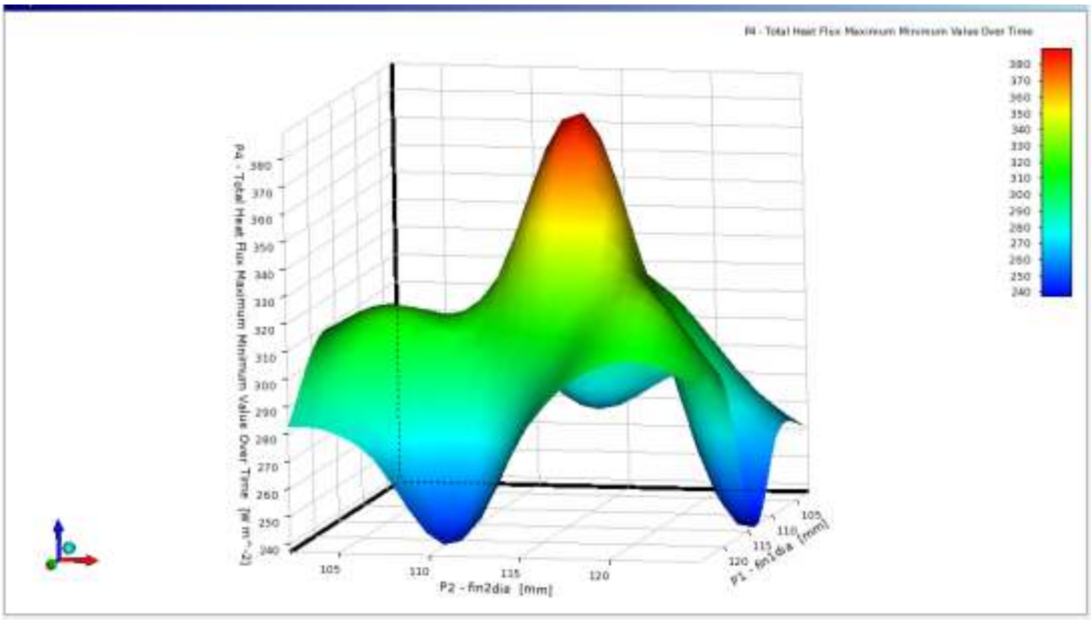

Figure 16: 3D response surface plot of heat flux

From the 3D response of heat flux (figure 17), the maximum heat flux is observed for fin2dia value ranging from 112mm to 117mm and fin1dia value ranging from 113mm to 117mm. The maximum heat flux zone is represented in red colored zone and minimal heat flux zone is represented by dark blue color.

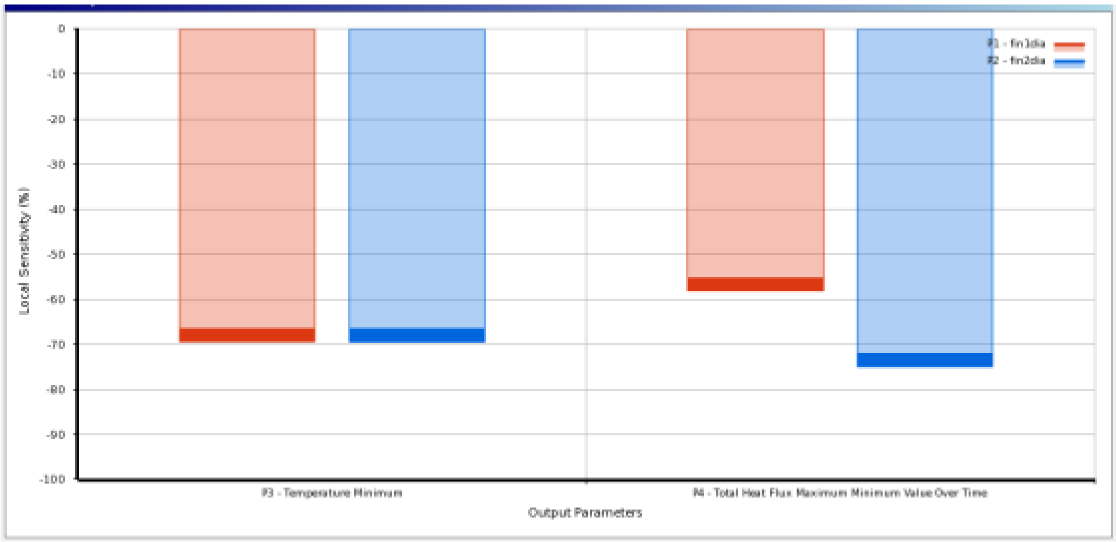

Figure 17: Sensitivity percentage plots

The sensitivity percentage plots are generated for both temperature and heat flux parameters. For both parameters i.e. temperature and heat flux, the sensitivity percentages are negative which signifies that any increase in variable values i.e. fin1dia and fin2dia would cause reduction of temperature and heat flux. For temperature parameter, fin2dia shows slightly higher sensitivity percentage (-69.496) as compared to fin1dia (69.429). The higher sensitivity percentage of fin2dia signifies that fin2dia has higher effect on temperature as compared to fin1dia. For total heat flux, the fin1dia has lower sensitivity percentage of 58.093 and fin2dia has higher sensitivity percentage of 74.996. The higher sensitivity percentage of fin2dia signifies that fin2dia has higher effect on heat flux of engine cylinder as compared to fin1dia.

6. CONCLUSION

From the thermal analysis on engine cylinder fins, the thermal characteristics and heat dissipation characteristics are evaluated. The simulation results have shown that intersection zone of cylinder and fins have maximum heat dissipation as compared to other regions. The optimization process enabled to evaluate the effect of each design variable on heat dissipation characteristics. The effect of each variable on heat dissipation characteristics are evaluated from 2D linearized plots of RSM. The accuracy of optimal space filling algorithm is found to be reasonably accurate and within close tolerances. For temperature parameter, fin2dia shows slightly higher sensitivity percentage (-69.496) as compared to fin1dia (69.429). The higher sensitivity percentage of fin2dia signifies that fin2dia has higher effect on temperature as compared to fin1dia. For total heat flux, the fin1dia has lower sensitivity percentage of 58.093 and fin2dia has higher sensitivity percentage of 74.996. The higher sensitivity percentage of fin2dia signifies that fin2dia has higher effect on heat flux of engine cylinder as compared to fin1dia.

Refrences

1. G.Bahadur Vali & Krishna Veni "Design/Modeling and Thermal Analysis on Cylinder Head of I.C Engine" International Journal & Magazine of Engineering, Technology, Management and Research, ISSN No. 2348-4845 Volume No.03 (2016), Issue No.05
2. Abhishek Mote at el "Analysis of Heat transfer through fins of an IC Engine using CFD" International Research Journal of Engineering and Technology (IRJET) e- ISSN: 2395 -0056, p-ISSN: 2395-0072 , Volume: 03 Issue: 04 | Apr-2016
3. Shubham Shrivastava & Shikar Upadhyay "Thermal Analysis of IC Engine Cylinder Block with Fins Perpendicular to the Axis of Piston Movement" International Journal of Mechanical and Industrial Technology ISSN 2348-7593 (Online) Vol. 3, Issue 2, pp: (139-149), Month: October 2015 - March 2016.
4. Vinay Kumar Attar & Himanshu Arora "Transient Thermal Analysis of Internal Combustion Engine Piston in Ansys Workbench By Finite Element Method" International Journal of Engineering Sciences & Research Technology, ISSN: 2277- 9655 Attar* et al., 5(6): June, 2016.
5. Chidiebere Okeke-Richard & Sunny Sharma " Thermal Analysis and Comparison of Cylinder Blocks of 4S, SITwo Wheeler Engine Using ANSYS" International Journal of Innovative Science, Engineering & Technology, ISSN 2348 – 7968 Vol. 3 Issue 5, May 2016.
6. KM Sajesh, Neelesh Soni and Siddhartha Kosti "Design Modification and Heat Transfer Analysis of Air Cooled Rectangular Fin Engine" International Journal of Recent Scientific Research ISSN: 0976-3031 Volume: 7(3) March -2016.
7. Mr. Manir Alam & Mrs. M. Durga Sushmitha "Design and Analysis of Engine Cylinder Fins of Varying Geometry and Materials" International Journal of Computer Engineering In Research Trends, ISSN (O): 2349-7084 Volume 3, Issue 2, February-2016, pp. 76-80.
8. Swati Saini & Kagdi Dhruvin Nileshkumar "Comparison of CFD Analysis of Heat Transfer Augmentation & Surface Heat Transfer Co efficient of I. C. Engine Fins at Different wind Velocities with Experimental Investigation" International Journal for Scientific Research & Development| Vol. 4, Issue 03, 2016 | ISSN (online): 2321-0613.
9. P.T. Nitnaware & Prachi S. Giri "Design Optimization Of An Air Cooled Internal Combustion Engine Fin Using CFD" Journal of Multidisciplinary Engineering Science and Technology (JMEST) ISSN: 3159-0040 Vol. 2 Issue 11, November - 2015.
10. H.Sumithra& B. Sandhya Rani "Design Optimization and Transient Thermal Analysis of Four Stroke Petrol Engine Cylinder Head" International Journal of Emerging Technology in Computer Science & Electronics (IJETCSE) ISSN: 0976-1353 Volume 18 Issue 2 – NOVEMBER 2015.
11. Akash M Vyas, Ruchir Parikh, “Analysis of I.C. Engine Fins for Effective Cooling Performance”IJSTE - International Journal of Science Technology & Engineering, Volume 5 | Issue 1