Steady State Thermal Analysis of Various Cylindrical Pin-Fin Configurations using Ansys

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Abstract— In this paper, the various cylindrical pin-fin configurations are analysed for its thermal performance using Ansys software in which the application of steady state thermal analysis. Usually, the pin-fin thermal analysis was taken under one of the thermal materials named Aluminium (Al). The 3D solid modelling was done by using the creo parametric which was published comes with the Parametric Technology Corporation (PTC). The solid modelling was converted into the general format and imported geometry was analysed. The Finite Element Method is used in meshing concept to subdividing the domain. Then the material properties are imported through Engineering Data from Ansys. Calculation of Temperature analysis and heat flux was done by developing the setup with the Convection heat transfer coefficient and temperature over the model.
Keywords: PTC, Pin-Fin Array, Meshing Model

I. Introduction

Fins are the extended surfaces, widely used to increase the heat transfer rate. According to the Newton's law of cooling, it is possible to increase the heat transfer rate by increasing the surface area, and by increasing the convection heat transfer coefficient, and by increasing the temperature distribution. Because of reducing the size of the electronic components, the fin concept or the heat exchanging concept was introduced in 19^{th} centuries. In this project the various cylindrical pin-fin configurations were studied for its thermal performance under a particular base temperature (T_b) and convection heat transfer coefficient (h). When the surface area (A_s) of the fin is increased the heat transfer rate (Q) will be increased. Thus, the analysis was continued under the following aspects.

II. Material

Mostly Aluminium materials and its alloys are used in fins. It is because of its high thermal conductivity when comparing to the economic aspects. It can be easily shaped with one form to another form because of its hardness and ductility. The aluminium material properties are imported from engineering data of the Ansys workbench which having the following specifications.

Thermal Conductivity - 237.5 W m^{-1} C^{-1}
Density - 2689 kg m^{-3}
Specific Heat - 951 J kg^{-1} C^{-1}

III. CAD Model

The design was done by using the Creo Software with the following specifications having the cylindrical pin-fin Array. The Base Plate of the Pin-fin Array having the size of (950 x 500 x 80) mm, which means the length, height and breadth of the fin base.

Type	Parameters (mm)	
Cylindrical Fins (no.perforations)	diameter (D) lengh (L)	35 350
Cylindrical Fins (2-perforations)	diameter (D) lengh (L) hole dia(d)	35 350 25
Cylindrical Fins (4-perforations)	diameter (D) lengh (L) hole dia(d)	35 350 25

Table 1: Design Parameters

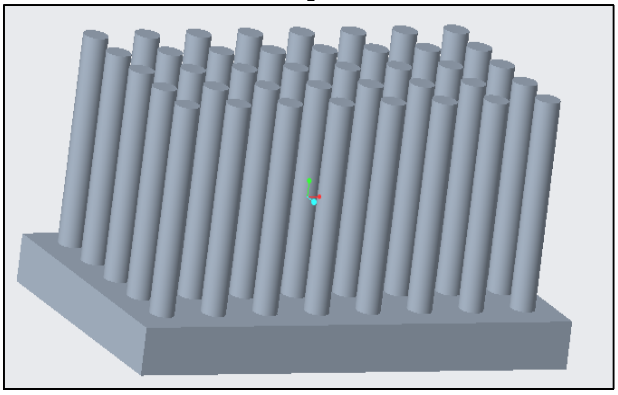


Fig. 1: Pin-fin Array without perforation

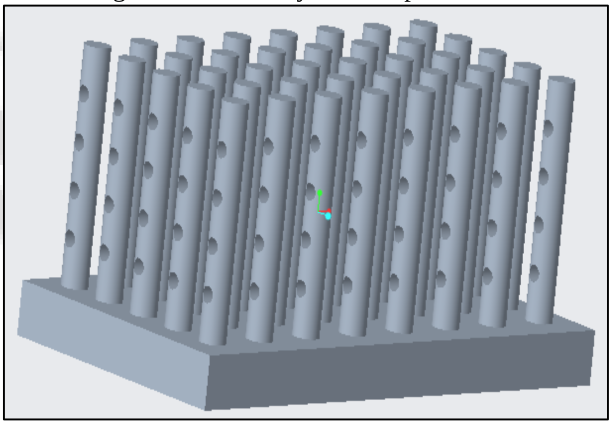


Fig. 2: Pin-fin Array with 2-side perforation

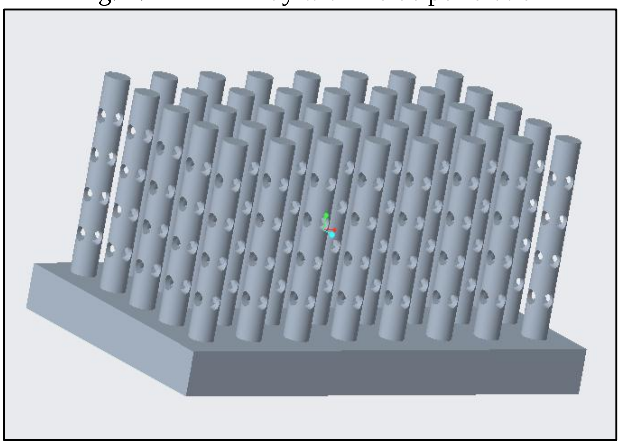


Fig. 3: Pin-fin Array with 4-side perforation

IV. MESHING MODEL

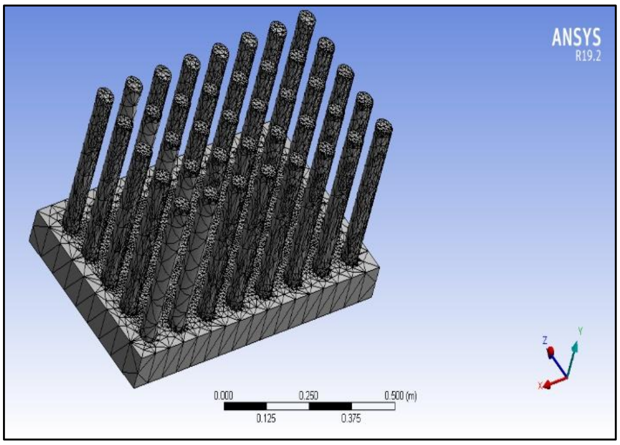


Fig. 4: Numerical Meshing of pin-fin array without perforation
[Nodes 99764 : Elements 56061]

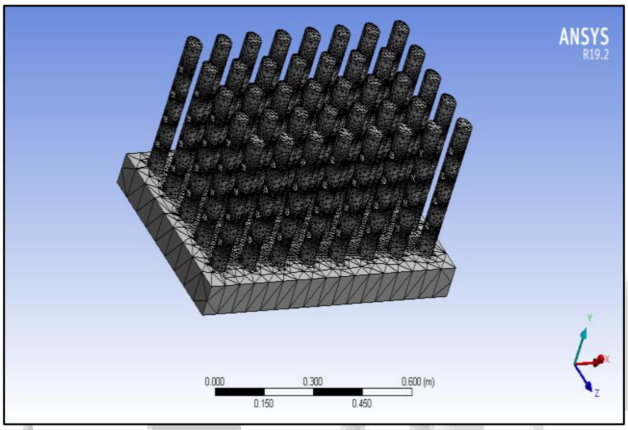


Fig. 5: Numerical Meshing of pin-fin array with 2-side perforation
[Nodes 466566 : Elements 251007]

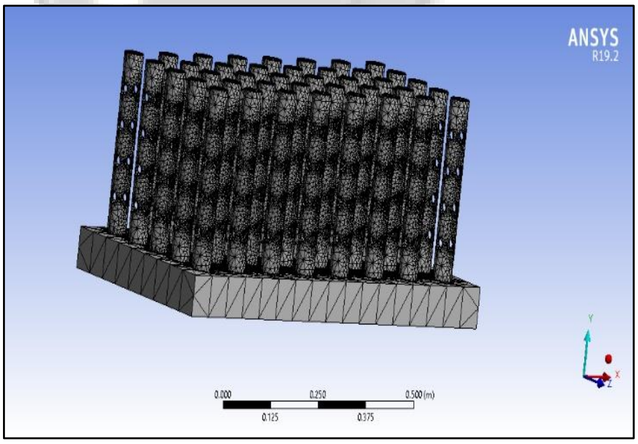


Fig. 6: Numerical Meshing of pin-fin array with 4-side perforation
[Nodes 643492 : Elements 337756]

The space angle, relevant centre accuracy is increased while meshing the object. It gives the proper result by finite element modelling. The fin base was initially meshed with normal meshing mode of Ansys. Then the cylindrical object meshing was done with increased accuracy which having more edges and relevant centres. When comparing to fig (d), the fig (e) having a greater number of edges. And similarly, when comparing to fig (e), the fig (f) having the greater number of edges. It is because of the number of holes presented over the cylinder. The perforations are inserted to increase the surface area of the fins.

V. STEADY STATE ANALYSIS

Steady state analysis was used to analyse the thermal phenomena of convection heat transfer mode over the cylindrical pin-fin array. It might vary depending upon the surface configurations & ambient characteristics. Workbench uses the Mechanical APDL as the target to analyse the performance. The convection film coefficient was specified for the ambient temperature as 20 w/m^{o}C. This parameter is undertaken for all three pin-fin configurations. And then the base temperature of the pin-fin was specified as the 500^{o}C. This could be kept as a constant value along the area of the pin-fin. Solid 87 node was chosen to calculate the appropriate results.

The initial temperature of the drawn model was kept as uniform for its length and area. Then the results were obtained from the 27^{o}C of the initial temperature. The problem is solved for maximum of 1000 iterations in the Ansys steady state thermal analysis application. While solving the problem the tolerance was assumed to be 0.1 W/m^2. The Flux convergence is obtained as 1×10^{-4} with the hemicube resolution of 10. The mks solver unit system was used.

Scoping Method	Geometry Selection	
Geometry	6 Faces	120 Faces (fig : 1) 290 Faces (fig : 2) 854 Faces (fig : 3)
Definition		
Type	Temperature	Convection
Magnitude	500. °C (ramped)	-
Suppressed	No	
Film Coefficient	-	22. W/m²·°C (step applied)
Ambient Temperature	-	22. °C (ramped)
Convection Matrix	-	Program Controlled

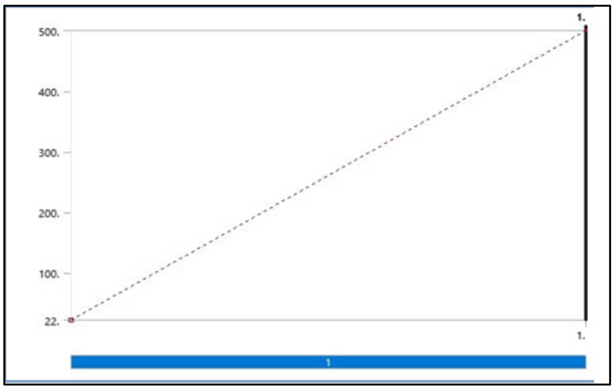
Table 2: Steady State Analysis Input Data

Steps	Time [s]	Convection Coefficient [W/m²·°C]	Temperature [°C]
1	0.	22	22
	1.	22	22

Table 3: Steady State Analysis Time Step Data

A. Temperature:

The temperature constantly raised to 500^{o}C from 20^{o}C. The time step figure shows that the temperature is raised from 293 K for a constant period of 1 second.



Graph (a): Steady state thermal -temperature

B. *Convection:*

The convection heat transfer remains constant over the time step. Hence it is kept to be straight line parallel to the X axis as show in below.

VI. RESULTS

The following figures got out from the Ansys R19.2 Workbench. The various configurations of fins having the several temperature and heat flux as show in fig. All the temperature and heat flux results were compared together to find out the best heat transfer rate of the pin-fin configurations.

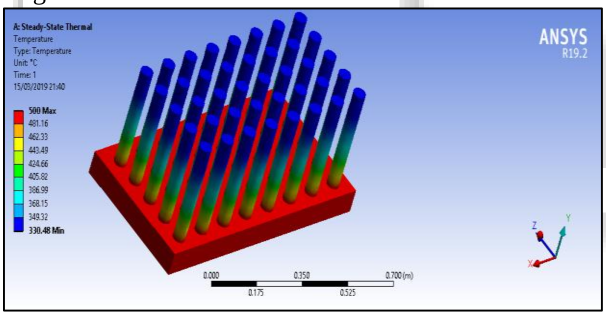


Fig. 7: Steady State Thermal Analysis – Temperature Difference
[Pin-fin Without Perforations]

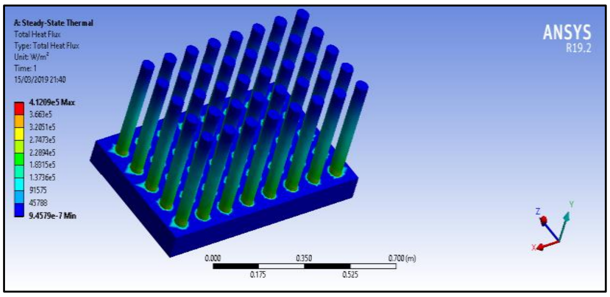


Fig. 8: Steady State Thermal Analysis – Heat Flux
[Pin-fin Without Perforations]

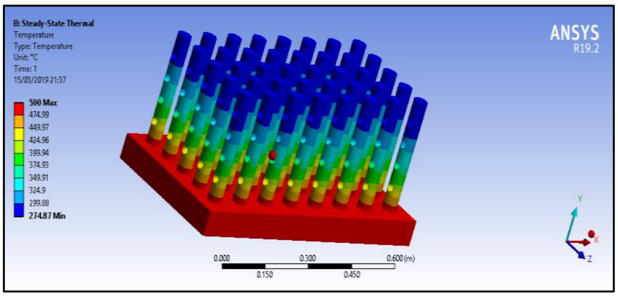


Fig. 9: Steady State Thermal Analysis – Temperature Difference
[Pin-fin with 2-side Perforations]

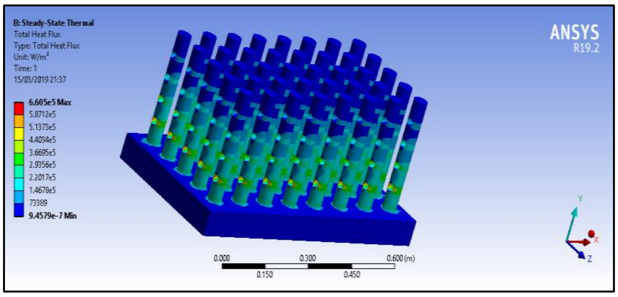


Fig. 10: Steady State Thermal Analysis – Heat Flux
[Pin-fin with 2-side Perforations]

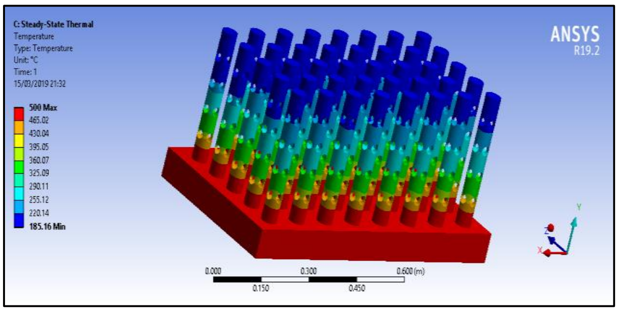


Fig. 11: Steady State Thermal Analysis – Temperature Difference
[Pin-fin With 4-side Perforations]

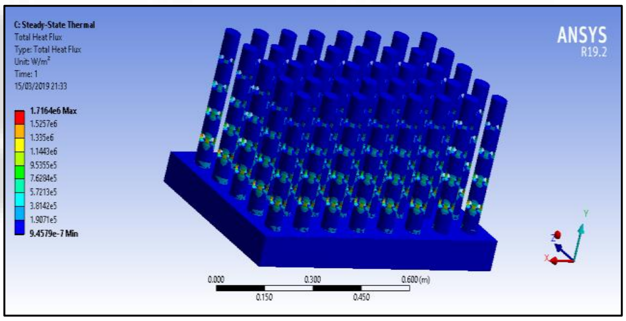


Fig. 12: Steady State Thermal Analysis – Heat Flux
[Pin-fin With 4-side Perforations]

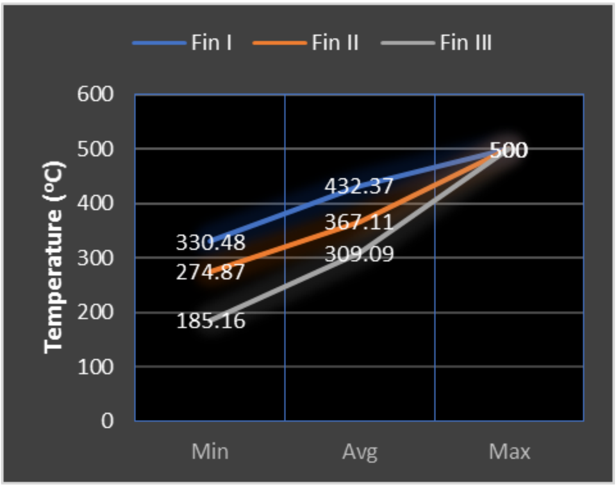
Pin-fin Type	Min. Temp. (ºC)	Max. Temp. (ºC)	Avg. Temp. (ºC)
I	330.48	500	432.37
II	274.87	500	367.11
III	185.16	500	309.79

Table 4: Temperature Comparison between the I, II, III Pin-Fin Shapes

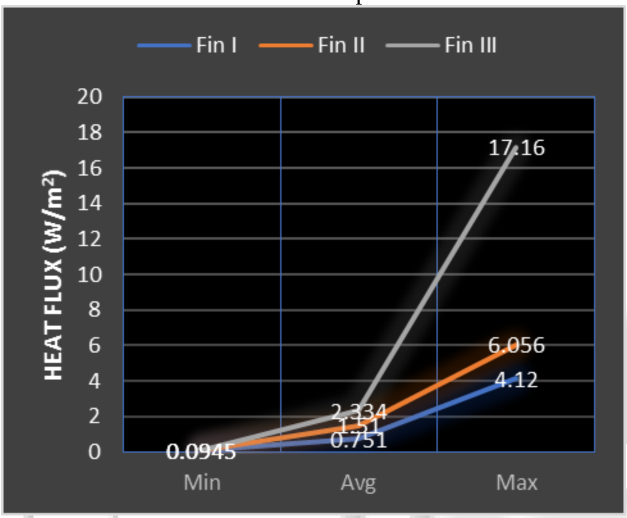
Note: I – Cylindrical Pin-fin Array without Perforations
II – Cylindrical Pin-fin Array with 2-side Perforations
III – Cylindrical Pin-fin Array with 4- Side Perforations

Pin-fin Type	Min. Heat Flux	Max. Heat Flux	Avg. Heat Flux
	(10^5 X W/m^2)		
I	0.0945	4.120	0.751
II	0.0945	6.056	1.510
III	0.0945	17.16	2.344

Table 5: Heat Flux Comparison between the I, II, III Pin-Fin Shapes



Graph (c): Temperature Comparison between the I, II, III Pin-fin Shapes



Graph (d): Heat Flux Comparison between the I, II, III Pin-fin Shapes

VII. RESULTS

The fins with various modelling and their configurations were done with Creo 5.0 software and analyses were done with Ansys R19.2. From the graphical result (c), it was cleared that the third fin configuration having the less temperature. And from the graphical result (d), it was cleared that the third fin configuration having the highest heat transfer rate. And similarly, second fin configuration is in the range of middle between the third and first fin configuration.

From this analysis, I concluded that, when some perforations are added over the surfaces of the pin-fins, the surface area will be increased. Hence from the Newton's Law of Cooling, the heat transfer rate will be increased by increasing the surface area. Thus, the rate of heat transfers or heat flux is maximum in the cylindrical pin-fins with 4 side perforations. This configuration also reduces the weight of the material because of perforations.

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