SIMULATION OF FIN GEOMETRIES FOR HEAT SINK IN FORCED CONVECTION FLOW

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Abstract

In recent decades peoples are moving towards high power density and smaller package size especially in electronic systems. This demands an effective cooling mechanism in order to prevent the electronics components from overheating. The CFD analysis is carried out on the performance of different pin fin heat sink in forced convection flow. In this paper, the overall performance of heat sink is designed and analysis for different parameters like the dimensions of the pin fin, fin density, longitudinal and transverse spacing and size of the heat sources, heat sink material, velocity and arrangement of pinfins. Finally the results are compared with the Computational Fluid Dynamics (CFD) software STARCCM+. The results from STARCCM+ software are in close arrangement with theoretical solutions.

Keywords: *CFD, Pin Fin, Forced Convection, Heat Sink.*

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I. INTRODUCTION

1.1 Basic Concept of Heat Sink

Heat sinks are widely used in many applications, and have become almost essential to modern electronic devices. In common use, it is a metal object brought in contact with an electronic component's hot surface. Microprocessor and semiconductors are examples of electronics that need a heat sink to reduce their temperature through increased thermal mass and heat dissipation (primarily by conduction and convection and to a lesser extent by radiation). Heat sinks have become almost essential to modern integrated circuits like microprocessor, DSP, CPU, and more.

Fig. 1: An active (fan cooled) heat sink used for the processor cooling on a PC motherboard

A heat sink is a material that absorbs and dissipates heat from another object using thermal contact (either direct or radiant). Heat sinks are used in a wide range of applications wherever efficient heat dissipation is required, major examples include refrigeration & air conditioning, heat engine and cooling electronic devices.

Heat is generated in many ways. Systems performing work give up their energy in the form of heat. Chemical reactions release potential energy in the form of heat. Electron flow through materials generates heat. Compression of gases generates heat. Radiation exciting matter creates heat. Heat is an energy associated with the random motion of atoms and molecules.

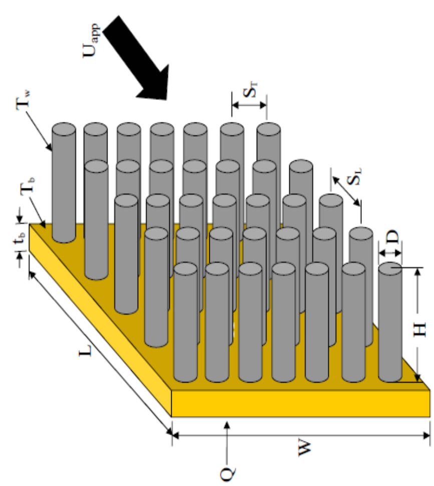

Fig. 2: In-Line Pin-Fin Heat Sink

The first law of thermodynamics states that the total heat input must equal the total heat output plus any heat energy stored or converted to other forms of energy in the system. The second law of thermodynamics further states that heat flows from a hotter to a colder body and never the other way around. These two laws are the foundation of heat transfer.

Although the basic laws of heat transfer are analogous to the fundamental equations of electricity, the transmission of heat in actual situations becomes rather complex. The three basic mechanisms of heat transfer are: Radiation, Conduction & Convection. In actual situations all three of these are taking place simultaneously.

1.2 Components of Heat Sinks

The main components of heat sinks are
1). Base Plate
2). Fins or Extendable surfaces

Base Plate: Base plate is part of heat sink on which the component is mounted. The base plate should be a good conductor of heat. It can be made of material, which has good thermal conductivity. The base plate should have minimum thickness so that riveting of screwing of the component on to the base plate is possible. If fins are machined as integral part of the base plate by which they are extended, we can avoid contact resistance at the base. However, more commonly, fins are manufactured separately and are attached to the base plate by a metallurgical or adhesive joint.

FINS: In any application, selection of a particular fin configuration may depend on available space, density, manufacturing difficulties and cost considerations as well as the extent to which the fins reduce the surface convection coefficient and increase pressure drop associated with flow of the fins.

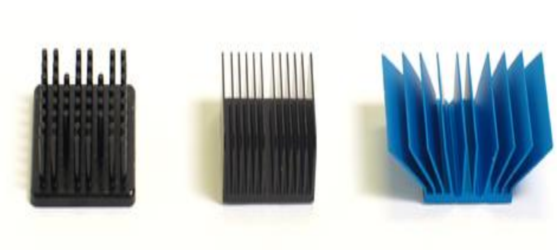

Fig.3: A pin-, straight- and flared fin heat sink types

A pin fin heat sink is a heat sink that has pins that extend from its base. The pins can be cylindrical, elliptical or square. A pin is by far one of the more common heat sink types available on the market. A second type of heat sink fin arrangement is the straight fin. These run the entire length of the heat sink. [6] A variation on the straight fin heat sink is a cross cut heat sink. A straight fin heat sink is cut at regular intervals but at a coarser pitch than a pin fin type. In many engineering situations, means are often sought to improve heat dissipation from a surface to its surroundings. [7]The surface area exposed to the surroundings is requisitely increased by the attachment of protrusions, and the arrangement provides a means by which heat transfer can be substantially improved. The protrusions are called fins or spines and these extensions can take a variety of forms.

1.3 Applications of Heat Sinks

Due to recent developments in the technology and public interest, the retail heat sink market has reached an all time high. In the early 2000s, CPU's were produced that emitted more and more heat than earlier by providing effective cooling system. Capable heat sinks are very important for longer period for working computer systems since cooling rate of microprocessors are high, usually quicker operations gives higher performance. At present lot of companies contend to suggest the good heat sink for PC over locking enthusiasts.

2. LITERATURE REVIEW

There exists important work carried out in the thermal analysis of heat sink design. An analytical approach was made by Keyes [1] developed formulas for the fin and channel dimensions that provide optimum cooling under various forced convection cooling circumstances. Wirtz et al. [2] was surrounded by the most basic ones to compute the performance of a pin fin heat sinks. In his work, experimental results were reported on the thermal performance of model fan-sink assemblies consisting of a small axial flow fan. Cylinder, square, and diamond shape cross-section pin-fins were considered. The overall heat sink thermal resistances, R, were evaluated at fixed applied pressure rise and fixed fan power. They concluded that cylindrical pin fins give the best overall fan-sink performance. Elliptical pin fin arrays were not studied in their investigation. Sparrow and Larson [3] performed experiments to determine per-fin heat transfer coefficients for a pin fin array situated in an oncoming longitudinal flow that turns to a cross-flow. [4]They varied the geometric parameters of round fins including the fin height to diameter ratio (H/D) and the inter-fin pitch to diameter ratio (P/D). The pressure drop across the array was also measured and presented in dimensionless form relative to a specially defined velocity head, which gave a universal pressure drop result for all operating conditions. Subsequent to this study, they also compared the performance of different pin fin geometries. However, the objective was to determine which fin height and inter-fin spacing yield the lowest overall thermal resistance for the array. Obviously, there will be an optimal fin configuration (fin density and height) that maximizes the UA-product. Wirtz and Zheng [5] have described a methodology for determining this optimum. Proper design requires knowledge of both the assembly fan characteristic, and the heat transfer / pressure drop characteristic of the heat sink.

3. OBJECTIVES OF THE PRESENT STUDY

Most of the previous studies on pin fins or parallel plate fin heat sinks have considered an individual geometry. Although Chapman et al. compared elliptical pin fin heat sink with crosscut pin fins and parallel plates only in staggered arrays of different geometries of fins are considered. They used an equal volume of fins as the fixed parameter. Further, they did not include circular, square and elliptical (In-Line array) pin fins in their study. In this study, some of the issues not considered in the previous works will be addressed. The objective is to numerically investigate the thermal performance of circular and elliptical pin fin, heat sinks and compare the results on a meaningful and fair basis.

The basic equations describing fluid flow and heat transfer in forced convection are complicated by being non-linear in nature. From a mathematical point of view, the theoretical investigations for fluid flow and heat transfer from cylinders have mainly centered upon asymptotic solutions. They do not provide the values of all the relevant variables throughout the domain of interest. For each new heat sink, a new model has to be constructed and experiments run. Analytical study related to the fluid flow and heat transfer could be found that can be used for low to moderate Reynolds numbers as well as for a wide range of Prandtl numbers. In light of these facts, it is necessary to develop analytical models for the fluid flow and heat transfer from cylinders (circular and elliptical) and pin-fin heat sinks for a range of Reynolds numbers, Prandtl numbers, base plate thickness, longitudinal and transverse spacings. Although it is very difficult to obtain an analytical solution due to the non-linear governing differential equations and complex geometry, it is the challenge in solving this problem analytically that provides the motivation for this work.

Further the results from analysis done using CFD software STARCCM+ are compared with the results available in literature.

3.1 Defining the Geometry

Once the problem specifications are determined, the actual specification can be made. It is vital to explain the physical boundaries that contain the fluid when we see at any flow problems. Where the man-made object is some part of the boundary it is very vital for engineering flow problems and it is a guess of the outcome of this object on a flow that is necessary from a CFD examination.

From such sources most of the bounding surfaces of the flow domain may be determined precisely. During the specification stage it is sufficient to know generally where these surfaces are in relation to each other and how they fit together. It is also worth remembering that when we build the computational model a total explanation of the bounding surfaces is necessary, and that some of these surfaces may not be physical surfaces.

3.2 Modeling and Meshing

The meshing for the various models used in for analysis is done using STARCCM+

- Surface is meshed by surface Remesher: This creates mesh over the entire surface of both fluid and fin regions.
- Volume mesh is done by polyhedral mesh: this creates total volume mesh of fluid and the fin is volume meshed with trimmer.

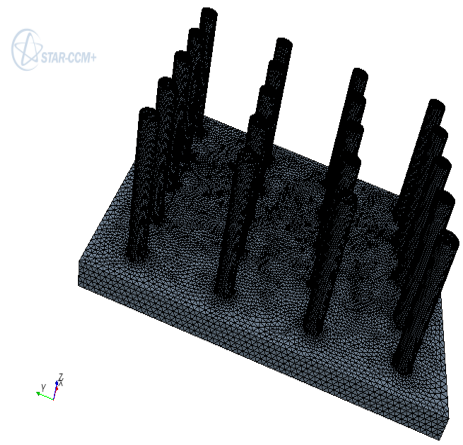

Fig 4: Model of Elliptical pin fin

4. METHODOLOGY

In order to compare the theoretical values with the numerical solution computational fluid dynamics Soft ware like STARCCM+ is used.

The following detail gives the details about the heat sink.

Thickness of fin	:	2.54 mm
Number of fins	:	5*4
Space between the fins	:	15.3 mm
Height of the fins	:	25.4 mm

The above specified Heat sink was developed in STARCCM+. Following procedure is observed in developing the model.

4.1 Building the Geometry

The various essential models required for the analysis were done by the using an very user friendly and innovative modeling software called CATIA V5.

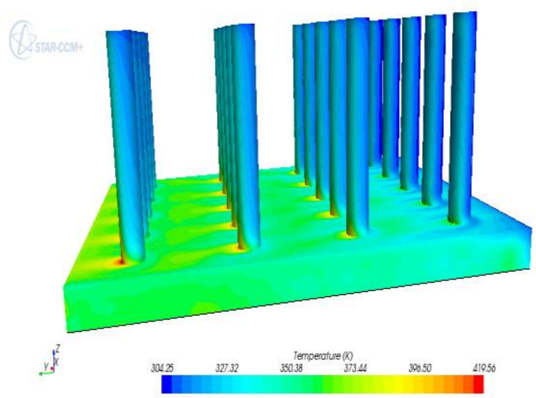

Fig.5: Temperature contour for elliptical pin fin

4.2 Grid Generation

First, the fin volumes are discretised, using volume mesh technique. The number of elements in each fin volume is 105554, a TETRAHYDRAL uniform type of mesh elements used in the grid. A similar approach is used in the meshing of the volume between the fins but with non uniform size elements are used. Near the walls of the fin fine size of elements are used and at the middle courser size elements are used. Each volume contains 615620 numbers of elements. Finally base plate is meshed with TETRAHYDRAL, uniform size elements. The overall mesh of the geometry consists of 17,86,825 elements.

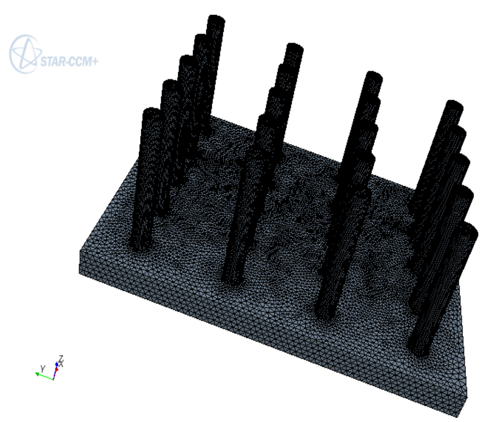

Fig.6: Heat Sink Mesh

4.3 Specification of Zone Types

This includes defining,
1. Continuum type
2. Boundary type.

Continuum type is defined for volumes. The base plate and fin volumes are declared as solid continuum and the flow volume is declared as fluid continuum.

Boundary types are declared for different faces. Before doing this, those faces with similar boundary properties are grouped and the group is given the boundary specification.

Basic Numerical Formulation in STARCCM+ for Analysis

Governing equations

4.3.1 Continuity Equation

$$\frac{\partial \rho}{\partial t} + div(\rho u) = 0$$

4.3.2 Momentum Equation (Navier-Stokes Equation)

X-momentum

$$\rho \frac{Du}{Dt} = -\frac{\partial p}{\partial x} + \frac{\partial}{\partial x}\left[2\mu \frac{\partial u}{\partial x} + \lambda div u\right] + \frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)\right] + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)\right] + S_{Mx}$$

Y-momentum

$$\rho \frac{Dv}{Dt} = -\frac{\partial p}{\partial y} + \frac{\partial}{\partial x}\left[\mu \frac{\partial u}{\partial x} + \frac{\partial v}{\partial x}\right] + \frac{\partial}{\partial y}\left[2\mu \frac{\partial v}{\partial y} + \lambda div u\right] + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right)\right] + S_{My}$$

Z-momentum

$$\rho \frac{Dw}{Dt} = -\frac{\partial p}{\partial z} + \frac{\partial}{\partial x}\left[\mu \frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}\right] + \frac{\partial}{\partial y}\left[\mu\left(\frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}\right)\right] + \frac{\partial}{\partial z}\left[2\mu \frac{\partial w}{\partial z} + \lambda div u\right] + S_{Mz}$$

Where SMx, SMy, SMz are sourse terms,include contribution due to body forces only (for example the body force due to gravity would be modeled by S_{Mz}=- ρ g) and τ is viscous stress

4.3.3 Energy Equation

$$\rho \frac{DE}{Dt} = -div(\rho u) + \left[\begin{array}{l} \frac{\partial(u\tau_{xx})}{\partial x} + \frac{\partial(u\tau_{yx})}{\partial y} \frac{\partial(u\tau_{zx})}{\partial z} + \frac{\partial(v\tau_{xy})}{\partial x} + \frac{\partial(v\tau_{yy})}{\partial y} \frac{\partial(v\tau_{zy})}{\partial z} + \frac{\partial(w\tau_{xz})}{\partial x} \\ + \frac{\partial(w\tau_{yz})}{\partial y} \frac{\partial(w\tau_{zz})}{\partial z} + \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) + S_E \end{array}\right]$$

Where $div(\rho u) = \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z}$, S_E the sourse of energy per unit volume per unit time and E is the sum of internal and gravitational potential energy

4.4 Selection of Heat Sink Material

The material required for heat sink should have good thermal conductivity, high machine ability, low cost, high specific heat and resistance to corrosion. There are a number of metals that can be used like copper, aluminum etc but Aluminum is chosen because of light weight, low cost, good properties etc.

5. RESULTS AND DISCUSSIONS

In this paper results obtained using STARCCM+ software and theoretical calculations of the heat sink are compared.

5.1 Variations of the Temperature along the Sink

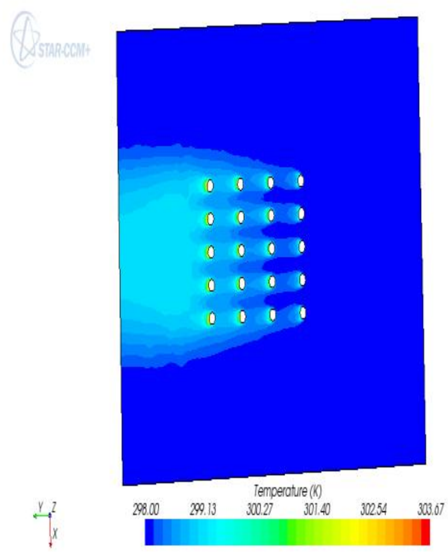

Fig.7 Variations of the Temperature along the Sink

The figure represents the temperature variation along the sink using STARCCM+ CFD solver. Here the sink receives heat from the chip which is placed at the top so more temperature is observed at the top of the sink i.e. at the base plate. At the inlet of the sink the temperature is less compare to the rear end of the sink because the front end of the sink is exposed to the cold inlet air. At the bottom of the sink temperature is less compared to the top of the fin because due to conduction heat is transferred from base to fins and from fins heat is transferred to air by convection.

5.2 Residual for Conversions

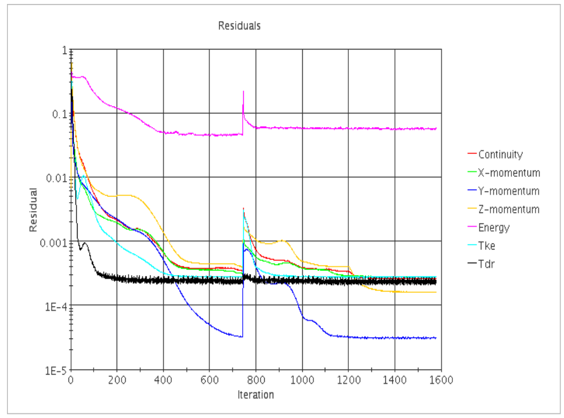

Fig.8: Show residuals for differential equations

In order to compare the fan power requirements of each geometry, the friction coefficient was plotted in Figure. The relative differences are nearly constant for all geometries throughout the range of velocities

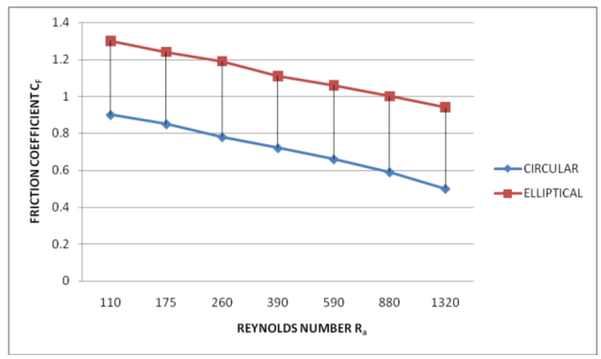

Fig. 9: Friction Coefficient versus Reynolds number for various fins

In order to compare the fan power requirements of each geometry, the friction coefficient was plotted in Fig. The relative differences are nearly constant for all geometries throughout the range of velocities.

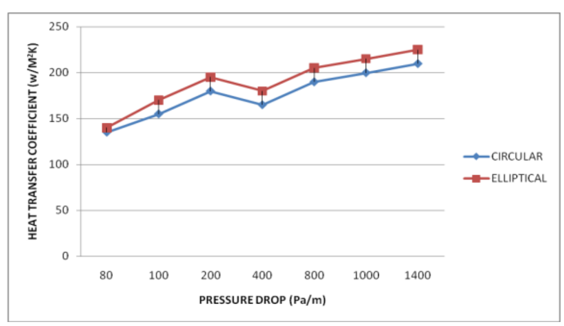

Fig. 10: Variation of pressure drop versus heat transfer coefficient.

The heat transfer coefficient versus pressure gradient is shown in Figure. It is noted that the results are presented in this figure in dimensional form.

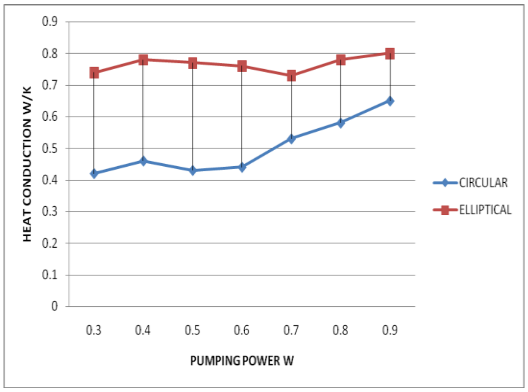

Fig. 11: Variation of pumping power versus heat conductance.

Fig shows heat transfer plotted against pumping power. This results in shifts in the relative performance of the various geometries. The elliptical fin configuration offers the highest conductance at fixed pumping power throughout the range of flow rates studied.

6. CONCLUSIONS

An elliptical pin-fin heat sink is analyzed using CFD software STARCCM+ for the effect of inline arrangement on heat transfer Further CFD analysis for the elliptical pin-fin is carried for the effect of different Reynolds on friction coefficient and compared with the circular pin-fin arrangement. The analysis for elliptical pin-fin is carried for the effect of pressure drop on the convective heat transfer and compared with the circular pin-fin. The elliptical pin heat sink analyzed represents only one set of design parameters relating pin spacing and shape based upon minor and major axes. There may exist other designs which produce better results in overall thermal performance. A study looking at reduced spacing, pin alignment and an array of ellipse axis ratios would be advantageous to the heat sink industry

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