Study of Thermal Hydraulic Performance of Various Pin Fin Heat Sink by using Computational Fluid Dynamics

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Abstract— A computer's CPU may perform millions of calculations every second .As the Processor continues to work at a rapid pace, it begins to generate heat. If this heat is not kept in check, the processor could overheat and eventually destroy itself. Fortunately, CPUs include a heat sink, which dissipates the heat from the processor, preventing it from overheating with the increase in heat dissipation from microelectronic devices and the reduction in overall form factors, thermal management becomes a more and more important element of electronic product design. Both the performance reliability and life expectancy of electronic equipment are inversely related to the component temperature of the equipment. The relationship between the reliability and the operating temperature of a typical silicon semiconductor device shows that a reduction in the temperature corresponds to an exponential increase in the reliability and life expectancy of the device. Therefore, long life and reliable performance of a component may be achieved by effectively controlling the device operating temperature within the limits set by the device design engineers.

Key words: Pin Fin Heat Sink, Electronics Cooling Simulation, Fin Profiles, Thermal Resistance

I. INTRODUCTION

The Power Heat Sink is designed to solve the heat problems of high performance computer systems. With a weight per volume less than half that of a traditional solution, and with its smaller base surface area, the Power Heat Sink is a powerful thermal solution to the problems faced by designers of high performance computer systems. The Power Heat Sink's weight per volume is less than 50% of that of an extrusion, yet its performance capability is much higher than an extruded or bonded fin heat sink. Its lower weight allows the Power Heat Sink to reduce the problem of excessive stress on the board and processor.[2] Compact and highly efficient, the Power Heat Sink fin assembly consists of one or more heat pipes and several bonded fins. Because it is much more compact than an extruded heat sink, it allows the designer more room for other components, making the layout challenge easier to deal with. The dimensions of the Power Heat Sink can be tailored to fit inside a limited space. The heat pipes in the Power Heat Sink are used to maximize the efficiency of the fins by taking heat from the bottom of the sink and transferring it to the top of the sink. The heat sink volume per watt of heat dissipated can be as low as 0.25 in3/watt in an airflow driven by a common axial fan. The Power Heat sink is designed to remove between 50 and 300 watts of heat generated by a high performance computer system. To achieve cost effectiveness, Engineer's has developed a proprietary fabricating process that can manufacture any Power Heat Sink within the customer's requested lead time.

II. HEAT SINK SELECTION

In selecting an appropriate heat sink that meets the required thermal criteria, one needs to examine various parameters that affect not only the heat-sink performance itself, but also the overall performance of the system. The choice of a particular type of heat sink depends largely on the thermal budget allowed for the heat sink and external conditions surrounding the heat sink. It is to be emphasized that there can never be a single value of thermal resistance assigned to a given heat-sink, since the thermal resistance varies with external cooling conditions. When selecting a heat sink, it is necessary to classify the air flow as natural, low flow mixed, or high flow forced convection. Natural convection occurs when there is no externally induced flow and heat transfer relies solely on the free buoyant flow of air surrounding the heat sink, Forced convection occurs when the flow of air is induced by mechanical means, usually a fan or blower. There is no clear distinction on the flow velocity that separates the mixed and forced flow regimes. It is generally accepted in applications that the effect of buoyant force on the overall heat transfer diminishes to a negligible level (under 570) when the induced air flow velocity exceeds 1 to 2 m/s (200 to 400 lfm). The next step is to determine the required volume of a heat sink. Table 2showsapproximate ranges of volumetric thermal resistance of a typical heat sink under different flow conditions

III. HEAT SINK TYPES

A. Active Heat Sink:

Active heat sinks, like passive ones, can come either attached to the processor with adhesive, or using clips. When clips are used, heat sink compound should be placed between the processor and the heat sink to ensure good thermal conductivity and hence proper cooling of the processor.

B. Passive Heat Sink:

Passive heat sinks use a mass of thermally conductive material to move heat away from the device into the air stream, where it can be carried away. Heat sink designs include fins or other protrusions to increase the surface area, thus increasing its ability to remove heat from the device.

C. Stampings:

Copper or aluminum sheet metals are stamped into desired shapes. They are used in traditional air cooling of electronic components and offer a low cost solution to low density thermal problems. They are suitable for high volume production, and advanced tooling with high speed stamping would lower costs. Additional labor-saving options, such as taps, clips, and interface materials, can be factory applied to help reduce the board assembly costs.

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D. Extrusions:

These allow the formation of elaborate two-dimensional shapes capable of dissipating large heat loads. They may be cut, machined, and options added. A cross-cutting will produce Omni-directional, rectangular pin fin heat sinks, and incorporating serrated fins improves the performance by approximately 10 to 2070, but with a slower extrusion rate. Extrusion limits, such as the fin height-to-gap aspect ratio, minimum fin thickness to-height, and minimum base to fin thicknesses usually dictate the flexibility in design options. Typical fin height-to-gap aspect ratio of up to 6 and a minimum fin thickness of 1.3 mm are attainable with a standard extrusion. A 10 to 1 aspect ratio and a fin thickness of 0.8 mm can be achieved with special die design features. However, as the aspect ratio increases, the extrusion tolerance is compromised.

E. Bonded/Fabricated Fins:

Most air cooled beat sinks are convection limited, and the overall thermal performance of an air cooled heat sink can often be improved significantly if more surface area can be exposed to the air stream. These high performance heat sinks utilize thermally conductive aluminum filled epoxy to bond planar fins onto a grooved extrusion base plate.

F. Castings:

Sand, lost core and die casting processes are available with or without vacuum assistance, in aluminum or copper/bronze. This technology is used in high density pin fin heat sinks which provide maximum performance when using impingement cooling.

G. Folded Fins:

Corrugated sheet metal in either aluminum or copper increases surface area and, hence, the volumetric performance. The heat sink is then attached to either a base plate or directly to the heating surface via epoxying or brazing. It is not suitable for high profile heat sinks due to the availability and from the fin efficiency point of view. However, it allows fabricating high performance heat sinks in applications where it is impractical or impossible to use extrusions or bonded fins.

IV. CONSTRUCTION AND MATERIALS OF HEAT SINK

A heat sink usually consists of a base with one or more flat surfaces and an array of comb or fin-like protrusions to increase the heat sink's surface area contacting the air, and thus increasing the heat dissipation rate. While a heat sink is a static object, a fan often aids a heat sink by providing increased airflow over the heat sink thus maintaining a larger temperature gradient by replacing the warmed air more quickly than passive convection achieves alone this is known as a forced air system. Heat sinks are made from a good thermal conductor such as copper or aluminum alloy.[4] Copper (401 W/(m·K) at 300 K) is significantly heavier and more expensive than aluminum (237 W/(m·K) at 300 K) but is also roughly twice as efficient as a thermal conductor. Aluminum has the significant advantage that it can be easily formed by extrusion, thus making complex cross-sections possible. The heat sink's contact surface (the base) must be flat and smooth to ensure the best thermal contact with the object needing cooling. Frequently, thermally conductive grease is used to ensure optimal thermal contact; such grease usually contains ceramic materials such as beryllium oxide and aluminum nitride, but may alternatively contain finely divided metal particles, e.g. zinc oxide and colloidal silver. Further, a clamping mechanism, screws, or thermal adhesive hold the heat sink tightly onto the component to maximize thermal conductivity, but specifically without pressure that would crush the component.

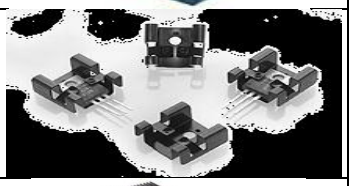
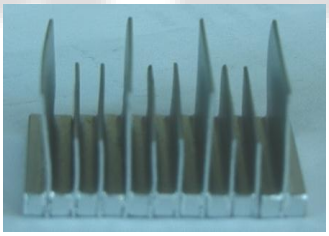
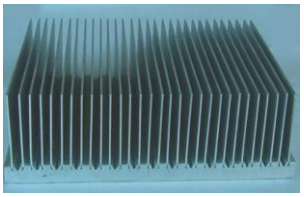
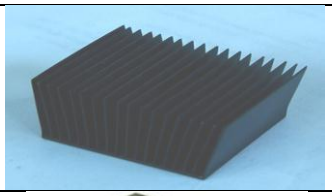
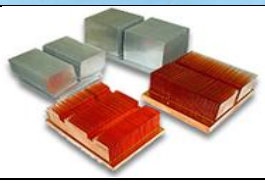
Heat Sink Types	Heat Sinks	Process of Manufacturing
Extruded		Heated metal is forced through a profiled die
Stamped		Metal stamped to form a particular shape
Bonded		Individual fins are bonded with epoxy to a pre-grooved base
Folded fin		Fins are pre-folded and then brazed or soldered to a plate base
Single fin assembly		Individual pieces of fin and spacer material are stacked and then brazed to create the desired shape
Sewaged		Individual fins are placed in a pre-grooved base and then a roller or punch will swage the sides to the fins
Forged		Heated metal is compressed into a form mold to the desired shape
Skived		Fins are "skived" from a solid piece of material, usually copper

Fig. 1: Materials of Heat Sink

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A. Heat Sink Geometries:

1) Rectangular fins have better performance than square fins, whose back edges have poor air flow past them.
2) Rectangular fins also have better performance than round fins; however, pressure drop is also higher for rectangular fins.
3) Round fins are good if you don't know which direction your airflow will be from or if airflow may not be straight through the heat sink (its Omni-directional).
4) For natural convection/radiation, solid black anodized fins mounted in a vertical direction tend to work best

B. Fin Arrangements:

Three types of fin arrangements in heat sink. First type of pin fin heat sink fig. (a) is a heat sink that has pins that extend from its base . The pins can be cylindrical, elliptical or square. A second type of heat sink fin arrangement is the straight fin fig. (b) .These run the entire length of the heat sink.

Pin fin heat sink performance is significantly better than straight fins when used in their intended application where the fluid flows axially along the pins rather than only tangentially across the pins. Another configuration is the flared fin heat sink; its fins are not parallel to each other, as shown in figure 5.1(c). Flaring the fins decreases flow resistance and makes more air go through the heat sink fin channel; otherwise, more air would bypass the fins. Slanting them keeps the overall dimensions the same, but offers longer fins

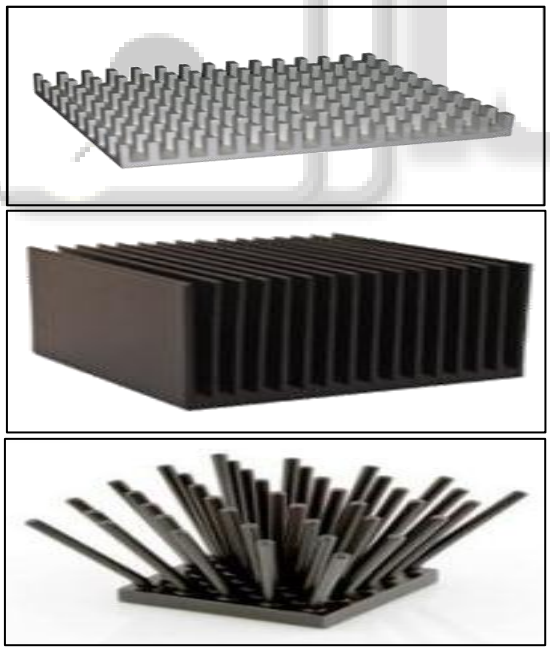

Fig. 2: Pin fin heat sink performance

C. Fin Shapes:

Tapered straight fins, splines, Pin fins (spines), uniform straight fins, and annular fins are possible [31]. The most common ones are pin fins whose cross-section can be round, square, elliptical, Trapezoidal, hexagonal or any other suitable geometry. But this project semicircular fin is chosen. Depending on the spacing among the fins of a heat sink, flow requirements, pressure drops and thermal resistance may differ. Design engineers try to achieve the minimum thermal resistance with the pressure drop as low as possible by modifying the fin shapes.

D. Heat Transfer from Extended Surfaces (Fins):

The heat conducted through solids, walls or boundaries has to be continuously dissipated to the surroundings or environment to maintain the system in a steady state condition [17, 21]. In many engineering application large quantities of heat have to be dissipated from small areas. Heat transfer by convection between a surface and the fluid surroundings it can be increased by attaching to the surface thin strips of metals called *fins*. The fins increase the effective area of the surface there by increasing the heat transfer by convection. The fins are also referred to as 'extended surface'.

The fins may be of uniform or cross-section. They have many different practical applications, viz. Economizers for steam power plants ; Radiators of automobiles; Air-cooled engine cylinder heads; Cooling coils and condenser coils in refrigerators and air conditioners; cooling of electronic components; small capacity compressors ; electric motors, transformer; high-efficiency boiler superheated tubes, etc. Solid gas turbine blades often act as fins, conducting heat down their length to a cool disc. Use of the fin theory is also made in estimating the error in temperature measurement by thermometers or thermocouples.

The following assumptions are made for the analysis of heat flow thought the fin:

1) Steady state heat conduction.
2) No heat generation within the fin.
3) Uniform heat transfer coefficient (h) over the entire surface of the fin.
4) Homogeneous and isotropic fin material (i.e. thermal conductivity of material constant).
5) Negligible contact thermal resistance.
6) Heat conduction one-dimensional. Negligible radiation.

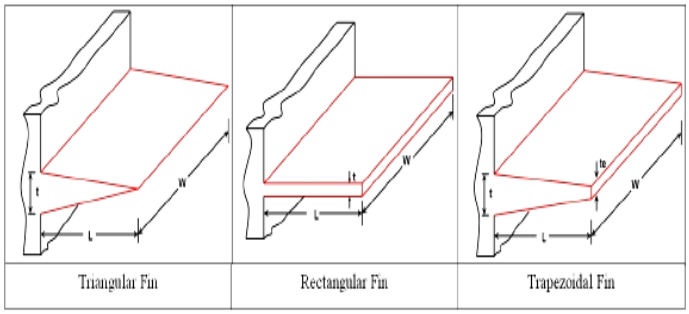

Fig. 3: Fins

V. ANALYSIS PERFORMED IN VARIOUS PROFILE OF HEAT SINK

A. Numerical and Experimental Investigation:

M. M. Rahman [2000] The paper presents new experimental measurements for pressure drop and heat transfer coefficient in microchannel heat sinks. Tests were performed with devices fabricated using standard Silicon 100 wafers. Two different channel patterns were studied. The parallel pattern distributed the fluid through several parallel passages between the inlet and the outlet headers located at two ends of the wafer. The series pattern carried the fluid through a longer winding channel between the inlet and the outlet

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headers. Channels of different depths (or aspect ratios) were studied. Tests were carried out using water as the working fluid. The fluid flow rate as well as the pressure and temperature of the fluid at the inlet and outlet of the device, and temperature at several locations in the wafer were measured. These measurements were used to calculate local and average Nusselt number and coefficient of friction in the device for different flow rate, channel size, and channel configuration.

J. Richard Culham et al [2001] This paper the specification and design of heat sinks for electronic applications is not easily accomplished through the use of conventional thermal analysis tools because "optimized" geometric and boundary conditions are not known a priori. A procedure is presented that allows the simultaneous optimization of heat sink design parameters based on a minimization of the entropy generation associated with heat transfer and fluid friction. All relevant design parameters for plate fin heat sinks, including geometric parameters, heat dissipation, material properties and flow conditions can be simultaneously optimized to characterize a heat sink that minimizes entropy generation and in turn results in a minimum Operating temperature. Examples are presented that demonstrate the robust nature of the model for conditions typically found in electronic applications. The model is shown to converge to a unique solution that gives the optimized design conditions for the imposed problem constraints.

Chine-Nan lin, Jiin-yuh jang [2002] This paper presents a two-dimensional analysis for the efficiency of an elliptic fin under the dry, partially wet and fully wet conditions of a range of value for axis ratios, Biot numbers, and air humidifies. It is shown that the fin efficiencies increase as the axis ratio Ar is increased. For a given axis ratio Ar, the fin efficiency decreases as the fin height or Biot number is increased. The conventional 1-D sector method overestimates the fin efficiency resulting in increasing error as the axis ratio Ar is increased. In addition, using experimentally determined heat transfer coefficients, it is found that both the fully dry and wet elliptic fin efficiencies are up to 4–8% greater than the corresponding circular fin efficiencies having the same perimeter.

W. Leonard, P. Teertstra, et al.[2002] In this report Experimental testing has been performed on two plate fin heat sinks in order to examine flow bypass phenomenon. The present study examines pressure drop and thermal resistance as well as flow velocities within the heat sinks. Tests are performed for bypass channel/fin height ratios of 0.25, 0.5, 0.75 and 1 with approach velocities from 2 to 8 m/s. By examining flow behavior within the heat sinks and the bypass channel, a model for predicting flow bypass is presented that incorporates only the significant pressure drop mechanisms that affect the flow path. This model allows for a simple prediction of flow bypass for plate fin heat sinks based solely on geometry. For all of the heat sinks tested the agreement between model and experimental data is ±8%.

Weilin Qu, Issam Mudawar [2002] In this study, the three-dimensional fluid flow and heat transfer in a rectangular micro-channel heat sink are analyzed numerically using water as the cooling fluid. The heat sink consists of a 1-cm^2 silicon wafer. The micro-channels have a width of 57 μm and a depth of 180 μm, and are separated by a 43 μm wall. For the microchannel heat sink investigated, it is found that the temperature rise along the flow direction in the solid and fluid regions can be approximated as linear. The highest temperature is encountered at the heated base surface of the heat sink immediately above the channel outlet. The heat flux and Nusselt number have much higher values near the channel inlet and vary around the channel periphery, approaching zero in the corners. For a relatively high Reynolds number of 1400, fully developed flow may not be achieved inside the heat sink. Increasing the thermal conductivity of the solid substrate reduces the temperature at the heated base surface of the heat sink, especially near the channel outlet. Although the classical fin analysis method provides a simplified means to modeling heat transfer in micro-channel heat sinks, some key assumptions introduced in the fin method deviate significantly from the real situation, which may compromise the accuracy of this method.

Sukhvinder Kang et al [2003] This paper presents a physics based analytical model to predict the thermal behavior of pin fin heat sinks in transverse forced flow. The key feature of the model is the recognition that unlike plate fins, stream wise conduction does not occur in pin fin heat sinks. Thus, the heat transfer from each fin depends on its local air temperature or adiabatic temperature and the local adiabatic heat transfer coefficient. Both experimental data and simplified CFD simulations are used to develop the two building blocks of the model, the thermal wake function and the adiabatic heat transfer coefficient. These building blocks are then used to include the effect of the thermal wake from upstream fins on the adiabatic temperature of downstream fins in determining the fin-by-fin heat transfer within the pin fin array. This approach captures the essential physics of the flow and heat transport within the fin array and yields an accurate model for predicting the thermal resistance of pin fin heat sinks. Model predictions are compared with existing experimental data and CFD simulations. The model is expected to provide a sound basis for a consistent performance comparison with plate fin heat sinks.

Yu Xiaoling, Feng Quanke,Liu Qipeng [2003]The Study of this paper a new type of composite heat sink, in whose each tunnel two rows of circular pins are staggered at proper positions between two plate fins, is suggested to improve electric and electronic device cooling. The heat transfer and flow performance is investigated experimentally. The experimental results show that, under the same conditions of heat dissipation and wind velocity, the thermal resistance of the composite heat sink is 10%~20% lower than that of the current plate-fin heat sink. When wind velocity is 2 m/s, the flow resistance is about 10% higher than that of the plate-fin heat sink, but much lower than that of the staggered pin fin heat sink. While the wind velocity and the temperature of heat sink base remain the same, the heat dissipation per square centimeter of the composite heat sink is almost the same as that of staggered pin fin heat sink, and 10%~17% higher than that of the plate-fin heat sink.

Poh-Seng Lee, Suresh V. Garimella *, Dong Liu 2004 An experimental investigation was conducted to explore the validity of classical correlations based on conventional sized channels for predicting the thermal

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behavior in single-phase flow through rectangular micro channels. The micro channels considered ranged in width from 194 lm to 534 lm, with the channel depth being nominally five times the width in each case. Each test piece was made of copper and contained ten micro channels in parallel. The experiments were conducted with deionized water, with the Reynolds number ranging from approximately 300 to 3500. Numerical predictions obtained based on a classical, continuum approach were found to be in good agreement with the experimental data (showing an average deviation of 5%), suggesting that a conventional analysis approach can be employed in predicting heat transfer behavior in micro channels of the dimensions considered in this study. However, the entrance and boundary conditions imposed in the experiment need to be carefully matched in the predictive approaches

G.Hetsroni, A.Mosyak et al.[2005] This paper considers experimental and theoretical investigations on single-phase heat transfer in micro-channels. It is the second part of general exploration ‘‘Flow and heat transfer in micro-channels’’. The first part discussed several aspects of flow in micro-channels, as pressure drop, transition from laminar to turbulent flow.

In this paper, the problem of heat transfer is considered in the frame of a continuum model, corresponding to small Knudsen number. The data of heat transfer in circular, triangular, rectangular, and trapezoidal micro-channels with hydraulic diameters ranging from 60 μm to 2000 μm are analyzed. The effects of geometry, axial heat flux due to thermal conduction through the working fluid and channel walls, as well as the energy dissipation are discussed. We focus on comparing experimental data, obtained by number of investigators, to conventional theory on heat transfer. The analysis was performed on possible sources of unexpected effects reported in some experimental investigations.

Xiaoling Yu , Jianmei Feng [2005] ,These Paper Based on plate fin heat sinks (PFHSs), a new type of plate-pin fin heat sink (PPFHS) is constructed, which is composed of a PFHS and some columnar pins staggered between plate fins. Numerical simulations and some experiments were performed to compare thermal performances of these two types of heat sinks. The simulation results showed that thermal resistance of a PPFHS was about 30% lower than that of a PFHS used to construct the PPFHS under the condition of equal wind velocity. Another obvious advantage of PPFHSs is that users can change an existing unsuitable PFHS into a required PPFHS by themselves to achieve better air-cooling results. This paper proposed a special solution for improving heat transfer performance of a PFHS by planting some columnar into flow passages of the PFHS to disturb airflows passing through the heat sink. So a PPFHS was constructed. Numerical simulation and experimental results show that the thermal resistance of a PPFHS is 30% lower than that of a PFHS used to construct the PPFHS with the same blowing velocity, and the profit factor of the former is about 20% higher than that of the latter with the same pumping power.

W. A. Khan, J. R. Culham et al [2005] Analytical models are presented for determining heat transfer from in-line and staggered pin-fin heat sinks used in electronic packaging applications. The heat transfer coefficient for the heat sink and the average temperature for the fluid inside the heat sink are obtained from an energy balance over a control volume. In addition, friction coefficient models for both arrangements are developed from published data. The effects of thermal conductivity on the thermal performance are also examined. All models can be applied over a wide range of heat sink parameters and are suitable for use in the design of pin-fin heat sinks. The present models are in good agreement with existing experimental/ numerical data. Finally result is heat transfer from and pressure drop across the heat sink increases with the increase in approach velocity, pin diameter, and number of pins. Heat transfer also increases with the thermal conductivity of the material and with the pin height. In-line arrangement gives higher heat sink resistance and lower pressure drop than the staggered arrangement. Heat transfer models for in-line and staggered arrangements are suitable in designing pin-fin heat sinks.

N. Sahiti, A. Lemouedda et al [2006] In his studies pin fin arrays are frequently used for cooling of high thermal loaded electronic components. Whereas the pin fin accomplishment regarding heat transfer is always higher than that of other fin configurations, the high pressure drop accompanying pins seriously reduces their overall performance. In order to check how the form of pin cross-section influences the pressure drop and heat transfer capabilities, six forms of pin cross-section were numerically investigated. Two geometric comparison criteria were applied so that the conclusions derived from numerical computations were valid for various possible geometric parameters and working conditions. Both staggered and inline pin arrangements were investigated as these are common in practical applications. The heat transfer and pressure drop characteristics are presented in terms of appropriate dimensionless variables. The final judgment of the performance of the pin fin cross-section was performed based on the heat exchanger performance plot. Such a plot allows the assessment of the pin performance including their heat transfer and the pressure drop.

Kourosh Mousavi Takmai, Jafar Mahmoudi,[2007] The study of this paper heat sinks operate by conducting heat from the processor to the heat sink and then radiating it to the air. The better the transfer of heat between the two surfaces (the CPU and the heat sink metal) the better the cooling. Some processors come with heat sinks glued to them directly, ensuring a good transfer of heat between the processor and the heat sink. In this paper author have simulated a new copper heat sink and heat pipe (is a simple device that can quickly transfer heat from one point to another) that has a best heat transferring. A three Dimensional finite element is used for simulations of temperature behaviour on around of heat sink. Analytically approach is applied to determine of heat transfer coefficients. The method has a good convergence and is adaptive with other best designed heat sinks. And so we examine the use of activity migration which reduces peak junction temperature by moving computation between multiple replicated units.

B.Kundu, P.K.Das [2007] the performance of elliptic disc fins has been analyzed using a semi-analytical technique. It has been shown that the efficiency of such fins can also be predicted very closely using the sector method.

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However, the equivalent annulus method is not suitable for this fin geometry. A method for the optimum design of fins, using a constraint of either fin volume or rate of heat dissipation has also been suggested. Optimum elliptical fins dissipate heat at a higher rate compared to an annular fin when space restriction exists on both sides of the fin. Even when the restriction is on one side only, the performance of elliptical fin is comparable to that of eccentric annular fin for a wide parametric range.

Kyoungwoo Park, Keun-HoRew et al [2007] The study of these papers the Performance improvement of a heat sink, which is widely used in electro-equipment systems as a cooling device, can be achieved by maximizing the heat transfer rate and minimizing the pressure loss, simultaneously. For this purpose, it is a very common way to use the optimization technique. In the present study, the comparison of optimal solutions for a 7 × 7 pin-fins heat sink with different cross-sectional fin shapes is performed by integrating the computational fluid dynamics (CFD) and a mathematical optimization technology. In the pin-fins heat sink, the optimum values of the design variables such as fin height (h), fin width or fin diameter (D), and fan-to-heat sink distance (c_j) at the junction of a heat sink and a heat source (i.e., CPU in a computer), and the overall pressure drop (ΔP) are minimized. To complete the optimization, the finite volume method for calculating the objective functions (pressure drop and thermal resistance) and SQP method that is one of the gradient-based opti mization algorithms for solving the constrained nonlinear optimization problem are used.

Kai-Shing Yang, Wei-Hsin Chu[2007] This study performs an experimental study of pin fin heat sinks having circular, elliptic, and square cross-section. A total of twelve pin fin heat sinks with inline and staggered arrangements were made and tested. The effect of fin density on the heat transfer performance is examined. For an inline arrangement, the circular pin fin shows an appreciable influence of fin density whereas no effect of fin density is seen for square fin geometry. This is associated with the unique deflection flow pattern accompanied with the inline circular fin configuration. For the staggered arrangement, the heat transfer coefficient increases with the rise of fin density for all the three configurations. The elliptic pin fin shows the lowest pressure drops. For the same surface area at a fixed pumping power, the elliptic pin fin possesses the smallest thermal resistance for the staggered arrangement. One of the reasons for superior performance of circular pin fin under inline arrangement is associated with the unique deflection flow. For a staggered arrangement where deflection flow pattern vanishes, the elliptic pin fin yields slightly better performance than circular pin fin surface.

Anuradha, Sanyal and Pradip, et al [2008] The work reported in this paper is an attempt to enhance heat transfer in electronic devices with the use of impinging air jets on pin-finned heat sinks. The cooling performance of electronic devices has attracted increased attention owing to the demand of compact size, higher power densities and demands on system performance and re-liability. The problem arises due to restriction of space and also due to high heat dissipation rates, which have increased from a fraction of a W/cm2to 100s of W /cm2. As a result, efficient cooling of electronic chip remains a challenge in thermal engineering. Heat transfer can be enhanced by several ways like air cooling, liquid cooling; phase change cooling etc. The heat transfer can be increased by two ways. First, increasing the heat transfer coefficient (forced convection), and second, increasing the surface area of heat transfer (finned heat sinks). A steady jet often stabilizes the boundary layer on the surface to be cooled. Enhancement in the convective heat transfer can be achieved if the boundary layer is broken. In the present study the combined effect of pin-finned heat sink and impinging slot jet, both steady and unsteady, has been investigated for both laminar and turbulent flows. The effect of fin height and height of impingement has been studied. From the studies carried out it was found that: a) beyond a certain height of the fin the rate of enhancement of heat transfer becomes very low with further increase in height, b) the heat transfer enhancement is much more sensitive to any changes at low Reynolds number than compared to high Reynolds number, c) for a given total height of impingement the use of fins and pulsated jet, increases the effective heat transfer coefficient by almost 200% for the same average Reynolds number, d) for all the cases it was observed that the optimum frequency of impingement is around 50 − 100 Hz and optimum duty cycle around 25-33.33%, e) in the case of turbulent jets the enhancement in heat transfer due to pulsations is very less compared to the enhancement in case of laminar jets.

VI. CFD Governing Equations Solve by Fluent

This section is a summary of the governing equations used in CFD to mathematically solve for fluid flow and heat transfer, based on the principles of conservation of mass, momentum, and energy. These equations solve by the fluent software. The conservation laws of physics form the basis for fluid flow governing equation

Law of Conservation of Mass

$$\frac{\partial(\rho u_i)}{\partial x_i} = 0 \dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (3.1)$$

Momentum Equation:

$$\frac{\partial}{\partial x_i}(\rho u_i u_j) = \frac{\partial}{\partial x_i}\left(\mu \frac{\partial u_i}{\partial x_i}\right) - \frac{\partial p}{\partial x_j} \dots\dots\dots\dots\dots\dots\dots\dots\dots (3.2)$$

Energy

$$\frac{\partial}{\partial x_i}(\rho u_i T) = \frac{\partial}{\partial x_i}\left(\frac{k}{C_p}\frac{\partial u_i}{\partial x_i}\right) \dots\dots\dots\dots\dots\dots \quad (3.3)$$

The fluid behavior can be characterized in terms of the fluid properties velocity vector u (with components u, v, and w in the x, y, and z directions), pressure p, density ρ, viscosity μ, heat conductivity k, and temperature T. The changes in these fluid properties can occur over space and time But for simplification we use changes occurs only in space. Using Fluent, these changes are calculated for the fluid, following the conservation laws of physics listed above. The changes are due to fluid flowing across the boundaries of the fluid element and can also be due to sources within the element producing changes in fluid properties.

A. Solution Techniques:

After create geometry and meshing, incorporate boundary conditions as per model and then export this file as an .msh file. Now the problem is ready to solve by using fluent software. The solution algorithm SIMPLE (semi-implicit

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method for pressure-linked equations) is used to solve for the velocity field in all three directions and the pressure

VII. CONCLUSION

The present study proposes the inverse method and the commercial software of FLUENT in conjunction with the experimental temperature data to determine the average heat transfer coefficient h, heat transfer coefficient based on the fin base temperature and fin efficiency for various fin spacing's. An interesting finding is that the calculated fin temperatures obtained from the commercial software are in good agreement with the experimental temperature data at various measurement locations. The inverse results of h and hb also agree with those obtained from the commercial software or the correlation. This implies that the present results have good accuracy. It is worth mentioning is that the selection of approximate grid points may not be negligible in order to determine a more accurate numerical result. The total number of grid points may increase with the fin spacing. Thus the commercial software in conjunction with the inverse method and experimental temperature data may help to the future development of the heat sink.

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