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Performance Analysis and Heat Transfer Studies on Protruding Surfaces of Electronic Components through Forced Convection

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Abstract: Electronics equipment has made inroads in almost every aspect of modern life from toys and appliances to high power computer. Every electronic component depends on the passage of electric current to perform its duty, and it becomes the potential site of heat generation (I^2R). The continued miniaturization of electronic system has caused a drastic increase in the amount of heat generation per unit volume, which is comparable in magnitude to that in a reactor. This high rate of heat generation, unless controlled, jeopardizes the safety and reliability of the system. The failure rate of electronic component or equipment increases exponentially with temperature. The essence of thermal design of electronic components is the removal of internally generated heat to the surrounding medium. Several cooling techniques commonly used are conduction cooling, natural convection and radiation cooling, forced air cooling, liquid cooling, immersion cooling and heat pipes. In connection to the above in this project thermal system with efficient heat sinks (e.g., pin-finned heat exchangers) is to be analyze.

I. INTRODUCTION

The heat conducted through solids, walls or boundaries has to be continuously dissipated to the system in a steady state condition. In many engineering applications large quantities of heat have to dissipate from small areas. Attaching to the surface thin strips of metals called Fins or extended surface.

Extended surfaces (Fins) are frequently used in heat exchanging devices for the purpose of increasing the heat transfer between a primary surface and the surrounding fluid. Various types of heat exchanger fins, ranging from relatively simple shape such as Cylindrical Rectangular Diamon Tapered or Pin Fins to a combination of different geometry have been used. These fins protrude from either a rectangular or cylindrical base. One of the commonly used heat exchanger fins is the Pin Fin.

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The essence of thermal design of electronic components is the removal of internally generated heat to the surrounding medium. Several cooling techniques commonly used are conduction cooling, natural convection and radiation cooling, forced air cooling, liquid cooling, immersion cooling and heat pipes. The development of the microprocessor in the early seventies was another big event in the electronic industry. Large capacity memory chips helped to introduce affordable personal computers. From watches to household appliances and automobiles, electronic now plays an important role. Thousands or millions of components packed in a small volume generate so much heat that the temperature continues to rise, if the heat is not removed adequately.

Electronic components with no moving parts, very little wear and tear and high reliability however observed to fail under prolonged use at high temperatures. The failure rate increases almost exponentially with the operating temperature. The cooler the electronic device operates, the more reliable. If the temperature increases above 75 ºC the failure rate increases to 2, whereas the failure rate is 1 for the temperature below 70 ºC.

The selection of a cooling technique depends on environment in which the electronic equipment is to operate. For the cooling of low power-density electronics such as TV or VCR in a room, simple ventilation holes on the case may be used. A fan may be adequate for the safe operation of a home computer. The thermal environment in marine applications is relatively stable, since the ultimate heat sink is the atmospheric air, whose temperature varies from -50 ºC at Polar Regions to +50 ºC in desert climates.

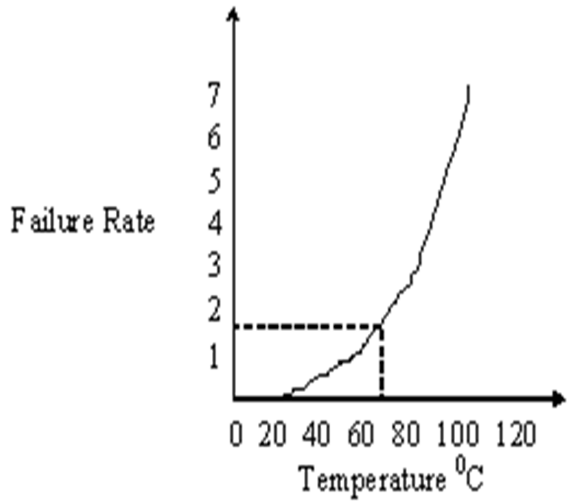

Fig.1 Temperature vs failure rate

Electronic components are rarely exposed to uncontrolled environmental conditions directly, because of the wide variations in the environmental variables. Instead a conditional fluid such as air or water, or a dielectric fluid is used to serve as a local heat sink. Conditioned air is the preferred cooling medium, since it is being relatively available and not prone to leakage.

For many industrial applications, internal heat generation can cause serious overheating problems sometimes leads to system failure. This is especially so in modern electronic systems, in which the packaging density of integrated circuits can be as high as 10^6 chips per square meter (Naik et al. 1987). According to a USAir Force Study (Reynell 1990), the four primary sources of stresses that cause failures in avionics systems are

Temperature (~55%)

Vibration (~20%)

Excessive Humidity(~19%) and

Dust (6%)

Humidity is also a temperature Phenomenon. Therefore, a total of ~74% of break downs resulted from thermal over stressing. For example, the temperature of semiconductor components should not exceed the manufacturers' recommendations, typically ~65ºC, so that reliable operations can ensure. For a microelectronic device, a 10ºC increases above 65ºC approximately halves its mean-time-to-failure (Babus'Haq et al 1992). To overcome this problem, the thermal systems with efficient heat sinks (e.g., pin-finned heat exchangers) are essential. Also, optimization of the heat exchanger design is desirable.

The heat transfer behaviors of pin-fin (or full cross pins) have also been of interest to designers of turbine cooling systems because of their potentially high heat transfer characteristics and surface area density, as well as their structural and cast ability attributes (Peng 1984). For example in air cooled turbine blades, such heat exchangers have made it possible for the blades to be operated at high cycle temperatures, resulting in high specific-power being achieved by modern gas turbines. A review of heat transfer and fluid flow data for arrays of pin-fins in turbine-cooling applications together with appropriate design recommendations is available (Armstrong and winstanley 1988).

II. LITERATURE SURVEY

In this chapter, the recent development and investigations in pin-fin arrays by considering various parameters were presented.

R.F.Babus Haq et.al. 1995,
investigated circular pin fin of
Diameter-6.35mm
Height-190mm
Base Plate-300mmx170mm
S_y-3.2mm to 69.6mm
S_x-1mm to 8.16mm For each inline or staggered combination of specified pin fins and air flow rate, the optional spacing to diameter ratios corresponding to the maximum rate of heat dissipation from the array have been deduced. The effect of changing the thermal conductivity of the pin-fin material has been discussed.

O.N.Sara, 2003, investigated square fins of
Diameter-10x10mm
C/H-0, 0.6and 1
Base Plate-320mmx140mm
S_y-2.5mm
S_x-1.58, 4.17 and 9.13mm
Reynolds number-10,000-34,000
The performance analysis was made under a constant pumping power constraint. The experiment results showed that the square cross-section pin fins may lead to an advantage on the basis of heat transfer enhancement. For higher thermal performance, lower inter fin distance ratio, clearance ratio and comparatively lower Reynolds number should be preferred for the staggered arrangements.

investigated circular pin-fin of
Diameter-8mm
Height-90mm
Base Plate-300mmx250mm
S_y-1.09mm to 83.92mm
S_x-9.86mm to 63.44mm
For inline arrangement, the steady state rate of heat loss raise as the Reynolds number was increases, but decreases with increasing pin-fin spacing for both the stream-wise and span-wise direction. The average heat transfer coefficient increases with Reynolds number for each pin-fin spacing. For staggered arrangement the steady-state rate of heat loss enhances with increase in Reynolds number and decreases with increase of pin-fin spacing in both stream wise and span wise directions.

Joseph J. Yeh and Mingking KChyu, [4], “ Heat transfer of staggered pin-fin arrays” investigated circular pin-fins of
Diameter-6.35mm
H/D=1 & 2.8 mm
Base Plate-762x88.9x12.7mm
S_y-16.5mm, 17.78mm & 22.86mm
S_x-16.5 mm(Constant)
Reynolds number-9,000-29,000
Due to casting limitations, short fins are utilized in the trailing edge section of the plane. The measured Nusselt numbers plotted against Reynolds number, found to have comparable values for both pin heights. These results agree well with previous studies. Heat transfer coefficients of the pins are approximately 0 to 10% higher than the end walls for H/D= 1.0 pins and 10 to 20% higher than the end wall for H/D=2.8 pins.

E.M.Sparrow and J.W. Ramsey, 1978[5], investigated circular pin-fins of
Diameter-3.1cm

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Base Plate-8.26 x1.91 cm

S_y-1.65 & 1.43cm

S_x-1.65 & 1.43cm

L=0.653cm

The heat transfer coefficient were obtained by applying the analogy between heat and mass transfer to mass transfer coefficients measured via the naphthalene sublimation technique. The row by row transfer coefficients were found to vary only in the initial rows and to attain a constantly fully developed value for the forth and all subsequent rows. The fully developed transfer coefficients are quite insensitive to cylinder height, increasing moderately as high as the height increases.

Jur ban et al, 1993[6], investigated circular pin-fins of

Diameter-6.35mm

Base Plate-300x175x30mm

S_y-15.5-124mm

S_x-7.95-71.5mm

C/H=0, 0.5, 1

H=60mm

Reynolds number= 5000-5400

The investigation tends to give higher heat transfer rate in staggered arrangements when compare to inline arrangements.

The summary of results of various authors about pin fin arrays were pointed below,

Due to casting limitations, only short pin-fins (Pin height to pin diameter ratio of less than four) can be utilized.

The pin-fins which have very close spacing have not been investigated before.

The rate of heat transfer from a pin-fin assembly to it surrounding environment depends on

The temperature distributions over the pin-fins as well as the assembly base.

The pin-fin geometry

he thermal conductivities of the material employed

The air flow rateIt is known that better heat transfer rate occurs at

Lower Reynolds number

Lower Inter Distance ratio.

The mechanism of electronic components are analyzed by considering the following parameters

Shape of the fin

Height of the pin-fin

Diameter/Size

Pin-fin arrangement (inline or staggered)

Pin fin spacing (Sx and Sy)

Reynolds number/ Mass Flow rate

III. EXPERIMENTAL SETUP

A. Pin Fin Assembly

The array consists of circular sectioned pin fin

Diameter-6mm

Height-190mm

S_x and S_y -30mm and 32mm

Base Plate- 300 x 250mm

The number of fins varied in accordance with the fin spacing. The pin fin can be easily removed and replaced with studs made from the same material as the assembly base; when fully screwed in, their heads are flush with the upper surface of the horizontal base plate. Thus, the air flows never flow over a hole in the base plate. The rectangular base as well as the pin-fin was manufactured from pure aluminum alloy.

The material aluminum has good electrical conductivity, high resistance to corrosion and non-toxicity. For each test, the pin fin

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height were kept constant with clearance between the tips of the pin fins and the shroud (i.e., they were in not full contact with the shroud)

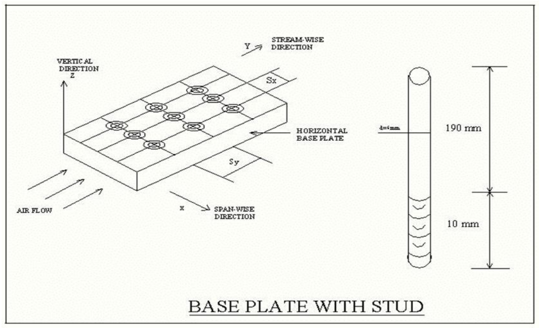

Fig 2 Base plate with stud

B. Heating System

The base of the heat exchanger is heated almost uniformly by two electric resistor strips, each rated at 500W, and this is the main heater. The base assembly is firmly bolted together to the bottom of the rectangular base. Te presence of thin layers of highly thermal conductivity heat-sink putty ensured that good thermal contact exists between the main heater and the rectangular base, as well as between the fin roots and the rectangular base. The lower horizontal surface and sides of the main heater block were thermally insulated with glass wool and asbestos sheet. The whole system of the heat exchanger base, heater with associated thermal insulator, is located in and protected by a well fitting open topped box. The horizontal edges of this box and the top surface of the laterally placed thermal insulate during each experiment, where flush with upper surface of the multi-component rectangular base, from which the fins protected upward. The power supplied to the main heater could be adjusted by altering the variac setting and it is measured by an inline electronic watt meter.

C. Temperature Measurement

The temperature measurement plays a major role; the temperatures at the base of the fin array were indicated by an approximately distributed two set of iron constant thermo junctions embedded within the rectangular base. All thermocouple junctions were bonded in a position with a thin layer of epoxy resin so as to ensure good thermal contact. The average values obtained from these appropriately located thermo junctions are regarded as the mean overall base temperature. This is maintained constant during each experiment at 45ºC.

The inlet and outlet air stream temperatures in the wind tunnel duct were measured by using four copper-constant thermocouples One is located immediately before the entrance of the pin-fin assembly

Another three was located downstream of the array

All the thermocouple as well as those indicating the ambient temperature were connected, to temperature sensor to indicate temperature until steady state conditions were attained.

D. Wind Tunnel

The main body of the rectangular cross sectioned wind-tunnel duct was manufactured from wood. Different duct heights were obtained by means of an adjustable roof. (Or shroud) Approximately halfway along the length of the wind tunnel is the test section. The roof and sidewalls of the test section were made up of 7mm thick plywood. A small opening is placed at the middle of the test section so enabling the fin array (and the air, via smoke flow visualization around it) to be observed.

A bell mouth is fitted at the entrance of the wind tunnel duct; followed by a resin impregnated, low porosity, card board honey comb flow straightened. The exhaust air from the pin-fin assembly is passed through an insulated chamber when mixing was accomplished by two resin-impregnated card board honey combs, one being of relatively low porosity and the other of high porosity. The latter is situated at the upstream of the former. The two honey combs were mounted perpendicular to the undistributed flow stream. At the exhaust end of the duct, a gradual area contraction section is attached. It is connected via a plastic pipe, to a blower and preceded by a throttle control valve.

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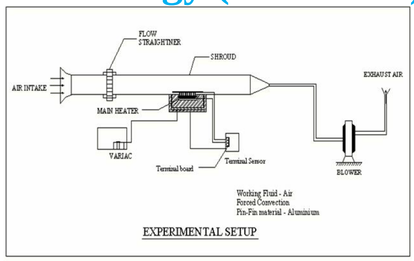

The wind tunnel is operated in the suction mode i.e., the fan sucked atmospheric air through the fin assembly and the test section via the bell mouthed entrance section, with the fan motor assembly on the exhaust side of the system. This avoided the air stream being heated by the motor prior to its passage through the exchanger assembly, this would thereby, have reduced the cooling period capability of the air.

IV. CONCLUSION

The theoretical analysis performed, provides a fundamental understanding of the heat transfer in the heat sink. The model formulation is general and only a few simplifying assumptions are made. Therefore, the results of the analysis as well as the conclusions can be considered as quite general.

The prime objective of a heat exchanger is to transfer the maximum rate of heat with the least amount of energy expended in accomplishing this transfer. The rate of heat transmission depends on the pin-fins as well as the assembly base, the pin-fin geometry, the air flow rate. Under the considered conditions of the investigation for a constant temperature of the base plate, and for zero clearance. By keeping the base plate temperature (52°C), constant mass flow rate, zero clearance the following results were obtained.

The heat transfer coefficient increases with increasing mass flow rate in both stream wise and span wise direction

The average heat transfer coefficient increases with higher Reynolds number both in inline and staggered arrangement

The rate of heat loss (Q_{conv}/A_b) increases with increase in Reynolds number

The results obtained both experimentally and analytically yield better results in circular fins when compared to square fins

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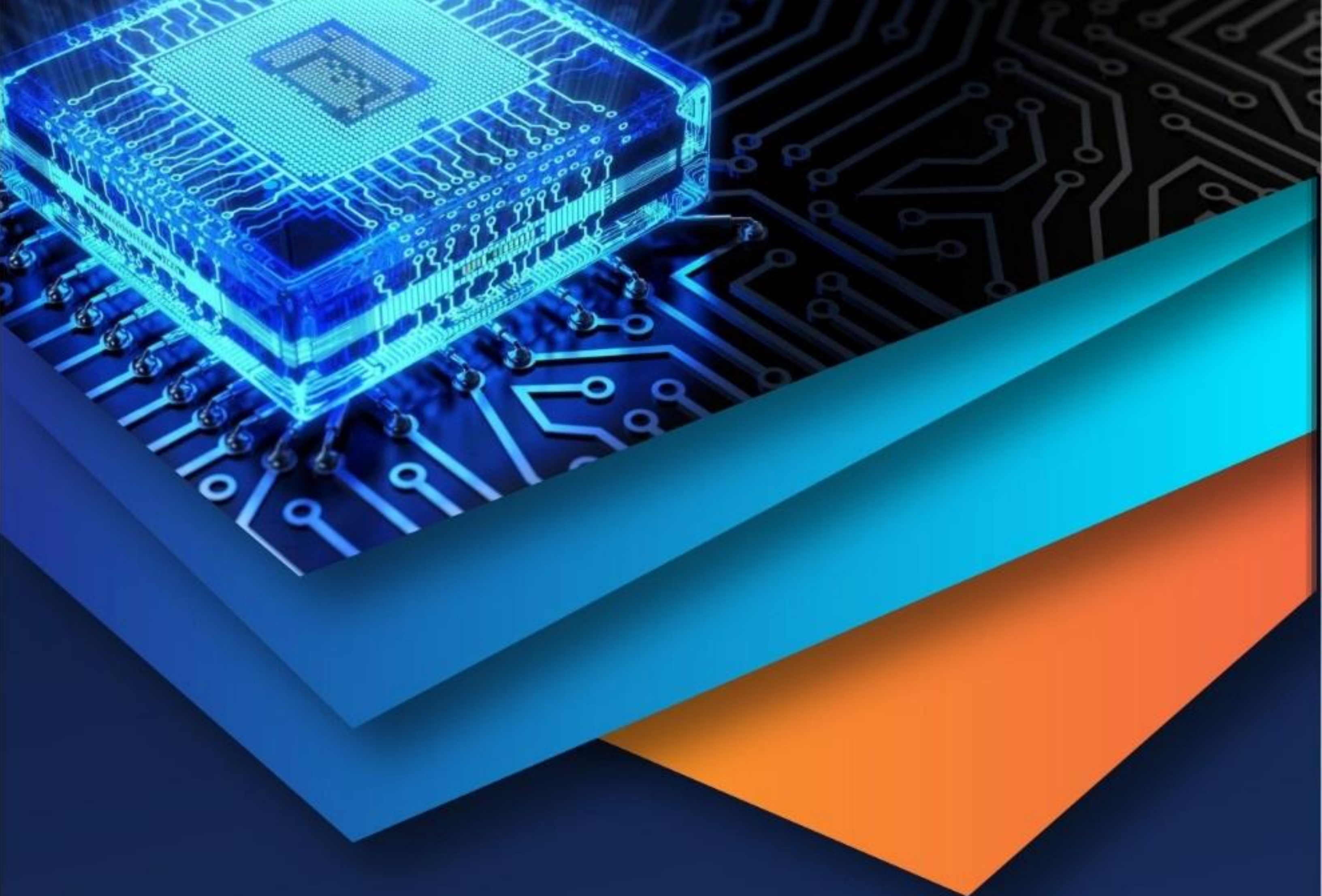

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