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Numerical Analysis of Temperature Depression in A Multi-Fin Array

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Abstract: The purpose of the present study is to analyze two-dimensional heat transfer analysis in arrayed fins with thermal dissipation. The heat conduction equation for the multi-fin array is solved employing finite element method with the convective boundary conditions. The finite element analysis can conveniently solve complex multi fin array assembly. Furthermore, the present study will also discuss the effects of dimensions of the fin assembly, heat transfer coefficient, material of the fin on the temperature distribution in the fin. A numerical analysis is carried out to determine the temperature depression caused by multi-fin array attached to the base plate. It is found that the temperature depression is a function of convective heat transfer coefficient, geometry of fin and fin material. Optimization of the fin geometry can reduce the temperature depression in the fin array.
Keywords: Convection, heat transfer, extended surface, fin array, temperature depression

INTRODUCTION

Extended surfaces are extensively used in cooling of automobile engines, computer processors, and other electronic devices. In various applications heat from the fins is dissipated by natural as well as forced convection and radiation. Fins are used as arrays in all the applications. Fin is frequently used to increase heat transfer rates from one fluid to another separated by solid wall to surrounding. The differences in heat transfer rates from un-finned and finned parts are to examine errors involves in computing the heat transfer rates from fins of uniform base temperature.

All electronic equipment needs cooling, whether it uses only a few low-power transistors or many high-power tubes. In most equipment, the heat transfer analysis is as important as the electronic design itself. The heat dissipation of an electronic device is essentially by radiation from the space vehicle to the surrounding space. The electronic subsystem and other equipment work at their maximum efficiency under specific temperature conditions. It is therefore necessary to maintain the temperature of the various sub-systems within the appropriate temperature limits by balancing the heat input from various sources with heat loss to its sinks. Moreover, it is also desirable to minimize the mass of the fins placed on the electronic device.

Although many investigators have studied the heat transfer by natural and forced convection from extended surfaces. In this paper, the interaction of thermal radiation with convection is numerically investigated, and a numerical solution is presented for temperature distribution of multi fin array. The influence of considering heat transfer coefficient, geometry of the fin array is also investigated. The results revealed the temperature depression and it is function of heat transfer coefficient, fin geometry and fin materials) profile is uniform-fin. Also the temperature depression is examined by several case studies. If a surface, at a temperature above that of its ambient, is located in stationary air at the some temperature as the surrounding then heat will be transferred from the surface to the air. This transfer of heat will be a combination of naturally/ forced convection to the air. Convection heat transfer problems are found in many situations, such as cooling of electronic device.

Finned surfaces are usually designed on the assumption that the temperature distribution is one-dimensional. But due to difference in heat transfer rates from un-finned and finned parts – two-dimensional effects exist. Investigators [1, 2] have shown that the presence of the fin will act both to depress the level of the base temperature and to create spatial non-uniformities. Further studies of the temperature depression in multi-fin arrays have revealed that fin heat fluxes can be lower 80% than those predicted by the one-dimensional approach. Therefore heat transfer rate from the fin cannot be properly accounted without due consideration of the thermal interaction between the fin and the wall to which it is affixed. Suryanarayana [3] has also shown that a one-dimensional analysis over estimated in heat flow rates. They observed that the two-dimensional effects on heat transfer rates from an array of straight fins and examined the errors involved in computing the heat transfer rates from fins on the basis of uniform base temperature. In another study [4], comparisons are made between one-and two-dimensional heat flow though longitudinal fin assemblies over a wide range of system parameters. in the above studies, finite difference method is employed to find out temperature drop caused by conductive transport through the fin.

Heggs and Stones [5] investigated the effects of dimensions on the heat flow rate through extended surfaces, comparing one- and two-dimensional heat flows through longitudinal and annular fin assemblies for a wide range of system parameters. Heggs et al. [6] investigated the two-dimensional analysis of fin assembly heat transfer by a series truncation method. They showed that the series truncation method yields accurate solutions even for problems for which the finite-difference and finite-element methods fail to provide acceptable results. Lau and Tan [7] investigated the errors in one-dimensional heat transfer analysis in straight and annular fins. Compare one-dimensional analysis with two-dimensional analysis. Performance of the fins is described in the text books [8, 9]. An analysis of temperature depression in a multi-fin array is analyzed numerically by Mehta [10]. Optimum design of heat sinks has been carried out using finite difference scheme in conjunction with optimization algorithm [11]. The heat flow rate through the multi-fin array depends on the fin characteristics as well as on the participating heat transfer coefficients [12]. The two-dimensional heat transfer analysis in arrayed fins with the thermal dissipation substrate has been presented by Hu [13] using Laplace transformation. Bilitzky [14] investigated the vertical base plate and horizontal fin arrays for the parameters such as fin length versus total heat dissipated if the fins on one side of sink and non-finned side of sink were adiabatic.

In the above studies, finite difference method is employed to find out temperature drop caused by conductive transport through the fin. To the author best knowledge, so far no attempt is made to solve this two dimensional problem using finite element method. Moreover the finite element method will give more quantitative information on this complex geometrical problem. Thus, the purpose of this paper is to analyze heat transfer problem of multi-fin array using finite element technique

Finite element formulation

The steady-state temperature distribution in a two-dimensional body satisfy the following two-dimensional heat conduction equation

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial T}{\partial y}\right) + Q = 0, \qquad \text{in region } V \tag{1}$$

with boundary condition

$$k_x \frac{\partial T}{\partial x} n_x + k_y \frac{\partial T}{\partial y} n_y + q + h(T - T_a) = 0, \qquad \text{on } S \tag{2}$$

where Q, q, h and T_a are internal heat generation, surface heat flux, heat transfer coefficient, and ambient temperature, respectively.

The solution domain V is divided into triangular elements of N nodes each. By using variational principle [15], the behavior of the unknown function T within each element can be expressed as

$$T^e(x,y) = \sum_{i=1}^{n} N_i(x,y)\phi_i = [N]\{\phi\}^e \tag{3}$$

where ϕ_i is the nodal value of ϕ at i.

After assembly of the element equations, a set of ordinary equation in $\{\phi\}$ are of the form

$$[K]^e\{\phi\}^e = \{R\}^e \tag{4}$$

where the coefficient of matrices $[K]$ and $\{R\}$ are given by

$$k_{ij} = \int_V \left(k_x \frac{\partial N_i}{\partial X}\frac{\partial N_j}{\partial X} + k_y \frac{\partial N_i}{\partial Y}\frac{\partial N_j}{\partial Y}\right) + \int_S N_i N_j h dS \tag{5}$$

A FORTRAN IV computer program has been prepared for the calculation of temperature distribution in the fin assembly. The computations have been performed on an IBM 360/44 digital computer for various geometrical parameters, heat transfer coefficient and thermal conductivity of fin material.

Numerical results and Discussion

Figure 1 is a cross-section through an assembly where *x* and *y* are Cartesian coordinate for longitudinal fin on a plane wall. The temperature distribution through a fin assembly is computed using the above mentioned numerical technique. We have selected triangular element. The fin is having 32 elements and 27 nodes for numerical solution.

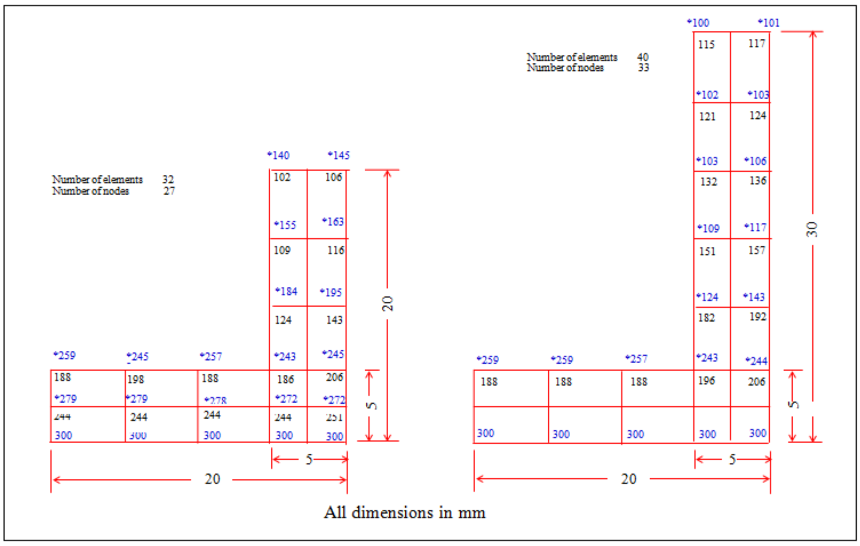

Fig-1: Temperature distribution in aluminum fin (case I)

The heat flows through a fin assembly is function of heat transfer coefficient, thermal conductivities of fin and base materials, and dimension of the fin assembly. To investigate all combinations of these parameters is beyond the scope of this paper, however a detailed study for aluminum and stainless steel (SS − 304) fins for various values of heat transfer coefficient (free convection to boiling) and also with different boundary conditions at the fin base has been accomplished for longitudinal system. Figure 1 shows temperature distribution in aluminum fin assemblies and they are marked with black and *blue color to depict the temperature for heat transfer coefficient of 10000 W/m^{2}K and 30000 W/m^{2}K, respectively, as in Table - 1. It can be seen from the figure that the temperature depression is observed 9 to 15% which is independent of fin geometry. Further investigation of Fig. 1 indicates that the base temperature varies somewhat transverse position being highest at the centre and lowest at the sides. Figure also reveals that the transverse temperature variations are not very large. It is found that the one-dimensional analysis gives satisfactory results for high thermal conducting fin material.

Table-1: Temperature distribution in the fin

Parameters	Case - I	
	Fin side	Base side
Heat transfer coefficient, W/m^{2}K	10000	*50000
Ambient temperature, K	100	300

The effect of heat transfer coefficient in the range free to forced convection is made for various value of fin height, inter fin spacing, wall thickness in case of stainless steel fin system. Figure 2 (a) depicts temperature distribution in the fin assemblies and Table-2 (a) gives the operating parameters. It is observed that the temperature depression is found as high as 20% in some cases. The temperature depression increases as well as the fin spacing and ratio of un-finned to finned side heat transfer coefficient decrease. The temperature depression at the fin base is substantial for small fin height to thickness ratio. . Figure 2 (b) displays temperature distribution in the fin assemblies and Table-2 (b) gives the corresponding operating parameters.

Table-2 (a): Temperature distribution in the fin

Parameters	Case - II		Case - III	
	Fin side	Base side	Fin side	Base side
Heat transfer coefficient, W/m^{2}K	10000	30000	10000	30000
Ambient temperature, K	100	300	100	300

Table-2 (b): Temperature distribution in the fin

Parameters	Case - IV	
	Fin side	Base side
Heat transfer coefficient, W/m^{2}K	10000	*50000
Ambient temperature, K	100	300

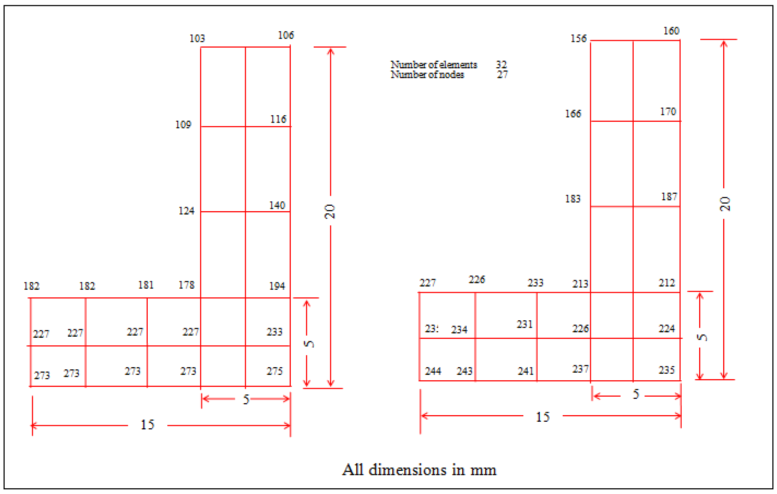

Fig-2(a): Temperature distribution in stainless steel fin (case II and III)

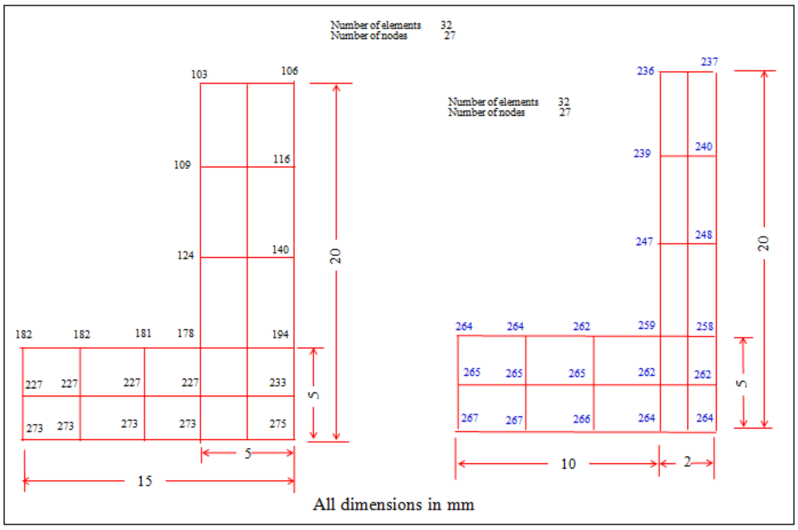

Fig-2(b): Temperature distribution in stainless steel fin (case IV)

Figure 3 (a) shows the dimensional details of a parallel fin arrays. *t* is the thickness of the base, *b* is the thickness of the fin, *A* is the distance between the fins and *L* is the length of the fin and *H* is the height of the fin. The finite element technique is used for thermal design of an extended heat sink made of aluminum. On its top, a transistor is mounted. It is required to maintain the temperature of the plate below 110^{0}C and 10W energy is to be dissipated to the ambient. Temperature distribution in the fin assembly is shown in Fig. 3.

Table-2(c): Temperature distribution in the fin array

Parameters	Case - V
Heat transfer coefficient, W/m^{2}C	100
Thermal conductivity, W/mC	208
Ambient temperature, C	30

It can be seen from the figure that the effect of fin assembly on the base temperature. Constant base temperature method may over estimate heat flow rates for such complex geometrical problem. The fin array is having elements 48 and 50 nodes to obtain temperature distribution.

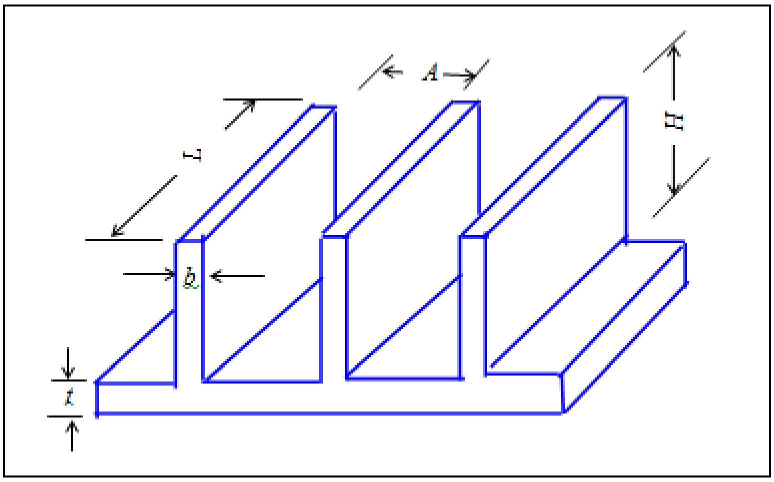

Fig-3 (a): Dimensional details of parallel fin array

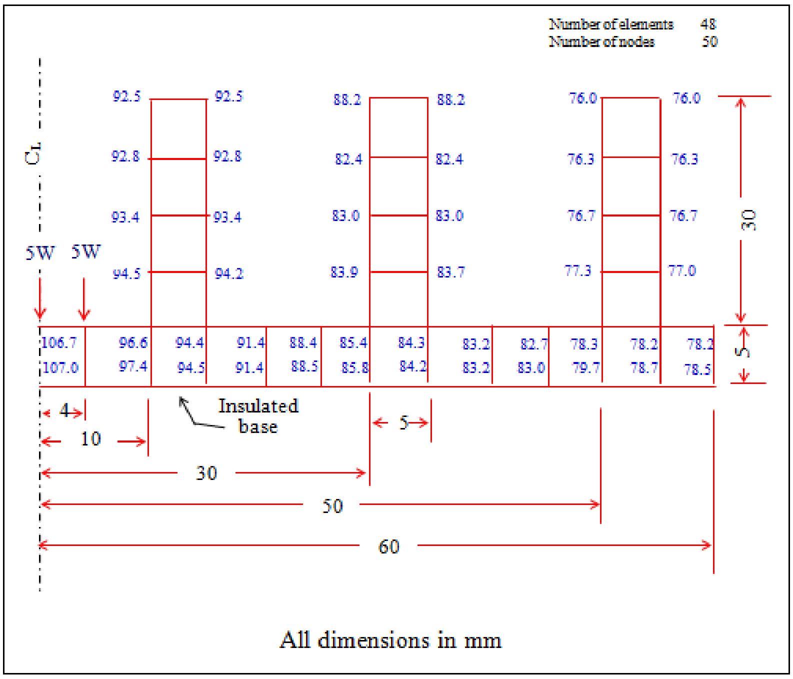

Fig-3 (b): Temperature distributions in a heat sink (case VI and V)

CONCLUSIONS

The finite element method is a well established and powerful finite element method to analysis the complex geometrical problem. The fin assembly can be designed more efficiently for a given situation using this numerical technique. One-dimensional heat flow assumption in high conducting material is found satisfactory. However temperature depression is more in case of shorter fin to longer fin. The present paper solves heat conduction equation using finite element method with various values of heat transfer coefficient. The numerical algorithm employs triangular elements that can accommodate complex multi fin array subsystems. The paper presents five test cases to study the temperature depression in the fin. An example is presented to study the depression of temperature in the cooling of an electronic device. It is found that the temperature depression is found as high as 20% in some cases. The temperature distributions inside the fin can be used select proper fin array in order to maintain required temperature limit for satisfactory performance of the device. Due to complex shape of the heat sink, Biot number can be selected as a local variable.

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