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# Optimization of heat sink for thyristor using particle swarm optimization

Veerasamarthswamy S. Bhandari *, Sanjeev H. Kulkarni

*Department of Mechanical Engineering, KLS Gogte Institute of Technology, Belagavi 590008, Karnataka, India*

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A B S T R A C T

The objective of this work is to optimize the geometry of the heat sink, which improves the performance. The geometrical parameter chosen for optimization is fin gap. The heat sink is under the condition of natural convection. The optimization method used is particle swarm optimization (PSO). Entropy generation minimization is the objective function. The constraints are set according to the design requirements. The idea of entropy generation minimization is employed to combine the effects of thermal resistance and pressure drop within the heat sink. The optimization problem is solved with the help of MATLAB. The optimized fin gap obtained is b = 6.5 mm. The value of entropy generation is 21.4365 W/K.

## Introduction

In the work of C.H.Liang, S. Zeng, Z.X.Li, D.G.Yang and S.A.Sherif i.e optimal design of plate fin heat sink under natural convection using a particle swarm optimization algorithm, they have taken three geometrical parameters fin height, fin thickness, and number of fins. In our work the only geometrical parameter i.e fin gap is considered for optimization. In the technical notes on stacked packaging laminar convection-cooled printed circuit using the entropy generation minimization method by Takahiro Furukawa and Wen Jei Yang [6] we found the work was on optimizing the fin pitch of the heat sink using entropy generation minimization as objective function and the optimizing technique used was newton raphson method. In the work by Orguz Emrah Turgut of title multiobjective optimization of pltefin heat sinks using improved differencial search algorithm [7] we find that, the objective functions entropy generation rate and total material cost. Total seven decision variables such as oncoming system velocity, number of fins on plate, gap between consecutive fins, base thickness of plate, width, length and height of plate fin heat sink are selected to be optimized. The optimization method used is differencial search algorithm. In design optimization of pin fin geometry using PSO algorithm by Nawaf Hamadneh and other researchers found that the work was on to examine the effect of governing parameters on overall thermal/fluid performance associated with different fin geometries, including, rectangular plate fins as well as square, circular and elliptical pin fins. Our work differs with these ones in choosing the number of parameters and also the parameter chosen. We have chosen fin gap only and have optimized it using particle swarm optimization. A thyristor is a solid state semiconductor device with four layers of alternating P and N-type materials. It acts exclusively as a bistable switch, conducting when the gate receives a current trigger, and continuing to conduct until the voltage across the device is reversed biased, or until the voltage is removed. Thyristors are mainly used where high voltage and currents are involved, and are often used to control alternating currents, where the change of polarity of the current causes the device to switch off automatically, referred to as zero cross operation. Working of thyristor device leads to an increasing heat generation rate. If the heat cannot be removed timely, the thyristor will accelerate ageing. Therefore thermal management becomes the fundamental but crucial element in electronic product design. Natural convection heat sinks have been widely used in cooling electronic components. The factors that affect the performance of a heat sink are the thermal conduction resistance, choice of material, protrusion design and surface treatment [1]. The geometry of the fin in our heat sink is rectangular plate geometry. The fin gap of this heat sink is optimized with the help of particle swarm optimization (PSO). The objective of this optimization would be to minimize entropy generation rate. Entropy generation rate combines the fundamental principles of thermodynamics, heat transfer and fluid mechanics and applies these principles to the modeling and optimization of the real systems and processes that are characterized by finite size and finite time constraints and are limited by heat and mass transfer fluid flow irreversibilities. Based on this theory, the minimization of entropy generation in the system leads to optimization of the system. The optimization technique followed is particle swarm optimization. This is one of the most widely used algorithms to find optimal values in order to minimize the expectations as a function. PSO is a trajectory based

* Corresponding author.
*E-mail addresses:* veersamarth1996@gmail.com (V.S. Bhandari), khsanjeev77@gmail.com (S.H. Kulkarni).

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metaheuristic optimization algorithm, which used the concept of distance to update the location of the solutions using a term called velocity [2] (see Fig. 1, Table 1).

## Entropy generation minimization

In thermal optimizations, the concept of entropy generation is very often used because it can measure the irreversibilities of thermal process. Irreversibility is an important characteristic of physical process in nature, which results in the symmetry and unidirectionality of the time. Therefore for any system with fixed boundary conditions, we can find a function that varies monotonically with time when an irreversible process happens. This function is called the Lyapovnov function and can be used to measure the irreversibility. Entropy is a lyapovnov function of the isolated system and is also widely used to measure irreversibilities of physical processes. Entropy was first introduced in analyzing the carnot cycle, and the main view angle of irreversibility of entropy generation may be related to heat work conversion although entropy has been applied to many other thermal problems. As the decrease of entropy generation means the decrease of irreversibility, it is believed that the entropy generation would decrease with increasing system performance [3].

## Particle swarm optimization (PSO)

Particle swarm optimization (PSO) was introduced by Kennedy and Eberhart in 1995, is a population based revolutionary computation technique. Here the population of solutions is called swarm, which is composed of a number of agents known as particles. Each particle is treated as point in d-dimensional search space, which modifies its position according to its own flying experience and that of other particles present in the swarm [4]. PSO is modeled on the asthetics of bird flocking choreography. PSO relies on manipulation of inter individual distances that is the synchrony of flocking behavior was thought to be a function of birds efforts to maintain an optimum distance between themselves and their neighbours. Velocities were adjusted according to their difference per dimension from best locations [5] (See Fig. 2).

$V_{id}(t+1) = WV_{id}(t)+C_1r_1(P_{id}-X_{id}(t))+C_2r_2(P_{gd}-X_{id}(t))$. [5]

$X_{id}(t+1) = X_{id}(t+1)+V_{id}(t+1)$. [5]

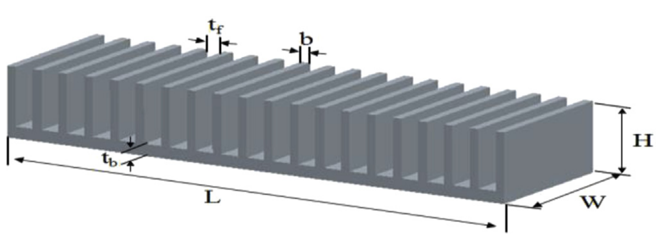


**Fig. 1.** The geometric parameters of the plate fin heat sink [1].

**Table 1**
Dimensions used to determine parameter of heat sink.

| Quantity | Dimension |
|---|---|
| Length of heat sink (mm) | 72.50 |
| Width of heat sink (mm) | 150 |
| Height of heat sink (mm) | 60 |
| Base plate thickness (mm) | 14.50 |
| Thickness of fin (mm) | 4.78 |
| Dynamic viscosity of air (Ns/m$^2$) | $1.983 \times 10^{-5}$ |
| Thermal conductivity of air (W/mK) | 0.0267 |
| Density of air (kg/m$^3$) | 1.177 |
| Coefficient of thermal expansion (K$^{-1}$) | $2.9282 \times 10^{-3}$ |
| Acceleration due to gravity (m/s$^2$) | 9.81 |
| Specific heat (J/KgK) | 900 |
| Density of solid (Kg/m$^3$) | 2.707 |
| Heat load (W) | 300 |
| Ambient temperature (°C) | 50 |

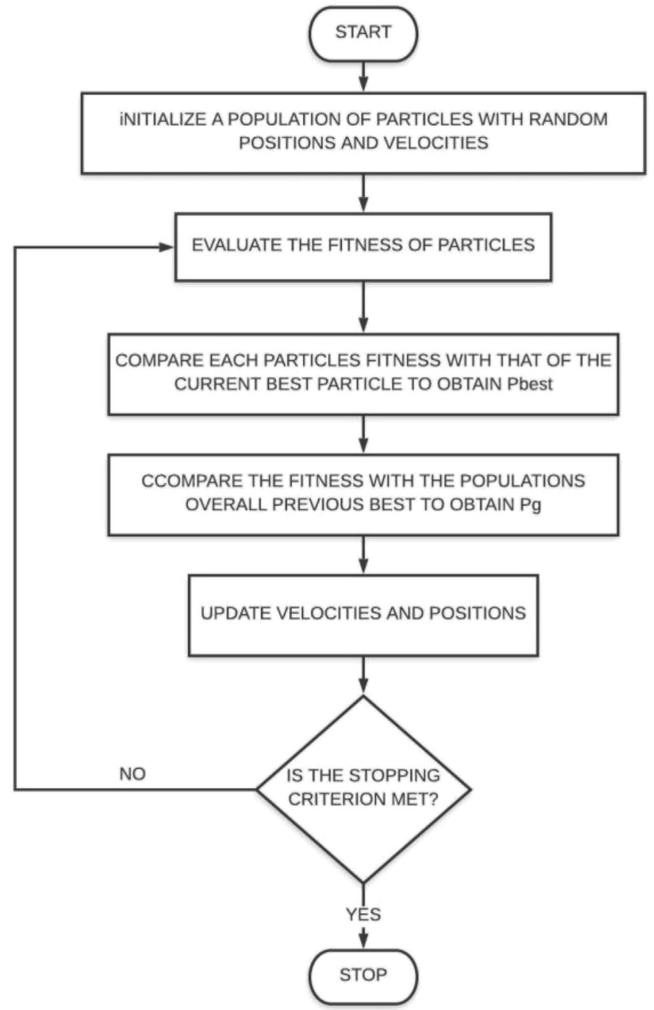


**Fig. 2.** Flowchart of a PSO algorithm [4].

## Mathematical modelling [1,8,10]

According to Bejan, entropy generation rate ($S_{gen}$) for extended surface under free convection is given by following relationship

$$S_{gen} = \frac{Q\theta_b}{T_b^2} \tag{1}$$

where $T_b$ is ambient temperature, Q and ($\theta_b$) are total heat dissipated from heat sink and the temperature excess of the heat sink base plate respectively. The relationship between the temperature excess of the heat sink ($\theta_b$) and the overall heat sink resistance is defined as,

$$\theta_b = Q^* R_{\mathrm{sink}} \tag{2}$$

$$S_{gen} = Q^2 * \frac{R_{sink}}{T_2^2} \tag{3}$$

The overall thermal resistance of the heat sink, ($R_{sink}$), is defined as

$$R_{sink} = R_{total} + R_{base} \tag{4}$$

($R_{total}$) is the total thermal resistance that is resulted from the fins and the exposed base plate and is given by,

$$R_{total} = \frac{1}{\left(\frac{n}{R_{fin}}\right) + h^* b^* L(n-1)} \tag{5}$$

where n is fin number, h is heat transfer coefficient, b,L are fin space and fin length respectively. And ($R_{fin}$) is the thermal resistance of a single fin. It will be modeled using the solution for a straight fin with an adiabatic fin.

$$R_{fin} = \frac{1}{(h^*P^*K_a{}^*A_c)^{0.5}{}^*\tanh(mH)} \tag{6}$$

where,

$$m = \left(\frac{hP}{K_a A_c}\right)^{0.5} \tag{7}$$

$$A_c = Lt \tag{8}$$

$$P = 2(L + t) \tag{9}$$

And 'H' is the height of the fin,'t' is the fin thickness of heat sink, ($K_a$) is the thermal conductivity of air.

Besides the bulk of heat sink materials thermal resistance ($R_{base}$) is given by,

$$R_{base} = \frac{t_b}{KLW} \tag{10}$$

where ($t_b$) is the fin thickness of the base plate, K is the thermal conductivity of heat sink. L,W are fin length and heat sink width respectively. The heat transfer coefficient of plate fin heat sink under natural convection is given by,

$$h = \frac{K_a}{b}\left[\frac{576}{EI^2} + \frac{2.873}{EI^{0.5}}\right]^{-0.5} \tag{11}$$

Here EI is Elenbass number, defined as,

$$EI = \frac{\rho^2 \beta g C_p b^4 \theta}{V_f K_a L} \tag{12}$$

($\theta$) is the average temperature difference between the heat sink and ambient air defined as,

$$\theta = T_1 - T_2 \tag{13}$$

If the amount of heat generation rate applied to the heat sink base is given, the most important design parameter of the plate-fin heat sink is it's fin gap. Therefore all parameters in the heat sink design except the fin gap are fixed and the entropy generation minimization method is applied to the fin gap optimization of plate fin heat sink.

## Optimization problem

Minimize,

$$S_{gen} = \frac{0.862655}{\left\{\left[\frac{b+0.07250}{b+0.00478}*\left\{\left(3.818*\frac{10^{-8}}{b}\right)*\left(\frac{576}{2.352*10^{21}*b^8}+\frac{2.873}{220.22*10^3*b^2}\right)^{-0.5}\right\}^{0.5}*\tanh\left(0.060*\left(\left(\frac{576}{2.352*10^{21}*b^8}+\frac{2.873}{220.22*10^3*b^2}\right)^{-0.5}*\frac{446.8619}{b}\right)^{0.5}\right]\right.} \\ \left. +\left[\left(\frac{b+0.07250}{b+0.00478}-1\right)*0.001935*\left(\frac{576}{2.352*10^{21}*b^8}+\frac{2.873}{220.22*10^{23}*b^2}\right)^{-0.5}\right]\right\} + 0.00515132$$

Subjected to,

$$g_1 : b - 0.0065 \le 0$$

$$g_2 : 1 - \left(\frac{b + 0.07250}{b + 0.00478}\right) \le 0$$

$$g_3 : \left(\frac{b + 0.07250}{b + 0.00478}\right) - 7 \le 0$$

## Results

The results are obtained in MATLAB by writing the code of PSO [9]. The maximum number of iterations is 1000. The PSO algorithm is run for 10 times. Result is obtained by plotting iterations versus fitness function value. The lower most entropy generation rate obtained is 21.4325 W/K. The corresponding fin gap value is 6.5 mm. When the obtained fin gap value is substituted into the objective function then we obtain the entropy generation rate as 21.4325 W/K. The same is represented in the graph. The heat sink will give the best performance when the fin spacing is equal to 6.5 mm. This is obtained by optimization considering minimization of entropy generation rate as objective function. When it is observed in the graph the entropy generation rate is minimum i.e 21.4325 W/K when fin gapo is equal to 6.5 mm (See Fig. 3).

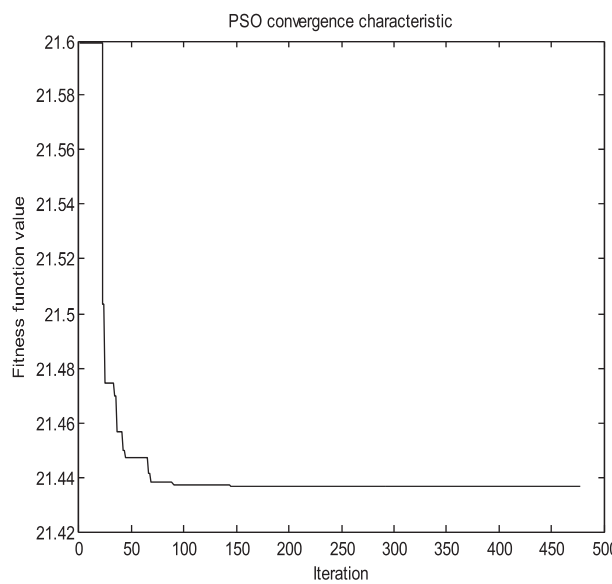


**Fig. 3.** The PSO progress with respect to iterations.

## Conclusions

In the present work, particle swarm optimization algorithm is used for optimizing non linear function. PSO algorithm method was discovered through simulation of a simplified social model. PSO has roots in two main component methodologies. Perhaps more obvious are its ties with artificial life (A-life) in general, and to bird flocking, fish schooling, and swarming theory in particular. Performance of PSO is then applied on optimization of a plate-fin heat sink. Overall, under given operating conditions the design of the presented strategy yields to economical structural size while dissipating considerable amount of heat by means of simultaneous minimization of entropy generation rate.

## Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Nomenclature

$A_c$: cross section area of fin, $m^2$
$b$: spacing between two fins, m
$C_1, C_2$: acceleration parameter (for PSO algorithm)
$C_p$: specific heat J/KgK
$El$: Elenbaas number
$g$: acceleration due to gravity, $m/s^2$
$g_i$: constraint
$H$: Height of fin, m
$h$: Heat Transfer coefficient, $W/m^2K$
$K$: thermal conductivity of heat sink, W/mK
$K_a$: thermal conductivity of air, W/mK
$L$: Heat sink length
$m$: fin parameter
$n$: fin number
$P$: cross section circumference of the fin, m
$P_x$: particle's position (for PSO algorithm)
$Q$: heat load, W
$R_{base}$: the thermal resistance of the bulk material, K/W
$R_{sink}$: the overall thermal resistance of the heat sink, K/W
$R_{total}$: the overall thermal resistance of the fins, K/W
$R_{fin}$: thermal resistance of each fin, K/W
$S_{gen}$: entropy generation rate, W/K
$T_1$: base temperature, K
$T_2$: ambient temperature, K
$t$: thickness of fin, m
$t_b$: base plate thickness, m
$v$: particle velocity (for PSO algorithm)
$w$: inertia weight (for PSO algorithm)
$W$: width of the plate-fin, m
$x_i$: design variables
$\beta$: Thermal expansion
$\rho$: density of air, $kg/m^3$
$\eta$: fin efficiency
$\theta$: average temperature difference between heat sink and ambient air, K
$\theta_b$: temperature excess of the heat sink base plate, K