

Experimental Analysis of Rectangular Fin Arrays with Continuous Fin and Interrupted Fins Using Natural and Forced Convection

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ABSTRACT An experimental study was made to investigate the thermal performance of different rectangular fin arrays such as continuous and interrupted fins. During the experiment the fin dimensions are ($h=18\text{mm}$, $l=200\text{ mm}$, $w=99\text{ mm}$, $S=9.5\text{ mm}$ and $t=6\text{ mm}$) and interrupt length are kept constant ($G = 20\text{mm}$), and the number of interrupts was varied from 1, 3 and 4. The experimental data's are obtained by supplying constant heat of 80 W and by varying the Reynolds number from 30000 to 80000. Results show a significant increase in heat transfer coefficient, efficiency and effectiveness for 4 interrupted fins with increase in velocity when compared to other models and in addition to that there is a remarkable reduction in weight of the heat sink when compared to continuous fins. So the fin with 4 interrupts has a heat sink was recommended for use in order to dissipate heat more effectively, using forced convection in heat transfer applications

KEYWORDS: Heat transfer, Natural and forced convection, Interrupted fins, Optimum number of interrupts and Heat sink.

I. INTRODUCTION

In most of the engineering system the thermal management system place a most important role because, while operating most of the systems will generate excess amount of heat, this heat should be dissipated to atmosphere very effectively and rapidly in order to ensure the safe operating condition and also for longer operating life.

Now-a-days the electronic devices shows a tendency for smaller, faster and denser chips and it also have computational demands to operate in continues for longer time. As the transistor density in chips get smaller and powerful the chips will generates more heat, so the thermal management places a vital role. In the electronic, microelectronic and telecommunication devices the heat generation during operation is increased due to shrinking of size of the component which results in increase in operating temperature. So we need a better and cost effective solutions for dissipation of excess temperature or heat from device to surrounding atmosphere^[1]. The heat transfer will takes place in all the substances like solid, liquid, and gases for heat dissipation. Heat transfer explains the transfer of heat between two bodies or physical systems depending on the temperature and pressure by dissipating heat. For effective and efficient heat dissipation the convective heat transfer is best technique compare to other available technique. In this present work the enhancement of heat transfer coefficient and other characteristics of rectangular fin arrays of continuous and interrupted fins were investigated using natural and forced convection.

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Nomenclature

N	Kinematic viscosity	T_m	Mean temperature
μ	Dynamic viscosity	L	Length of fins
B	Bulk temperature	D_h	Hydraulic diameter
P	Density of air	B	Breadth of duct
C_p	Specific heat	H	Height of duct
K	Thermal conductivity	L	Length of duct
H	Heat transfer co-efficient	N	Number of fins
V_{max}	Maximum velocity of air	A_p	Area of fins
Re	Reynolds number	H	Height of fin
Nu	Nusselt number	L_p	Perimeter length of fin
Gr	Grashof's number	V_f	Volume flow inside the duct
Pr	Prandtl number	A_f	Area of wetted perimeter
G	Acceleration due to gravity	A_s	Cross section area of rectangular fin
T_s	Fin body surface temperature	N_f	Number of fin
T_a	Ambient temperature	h_f	Height of fin
ΔT	Temperature difference		

II. RELATED WORK

Mehranahmad, gonooshmostafavi et.al[2] studied comparative analysis of rectangular fins by both experimental and numerical in order to know the effective fin spacing and effect of interrupts on heat transfer and they finally develop the correlation to calculate the optimum interruption length for rectangular continuous fin. M Doge and sevirgiolu[3] conducted study on the convective heat transfer of natural and forced heat transfer from longitudinal fins which are placed inside the horizontal channel. The conducted experiments by varying parameters like fin height, fin spacing and they considered a wide range of modified Reynolds number that is $3 \times 10^7 < Re > 8 \times 10^3$. Finally they concluded that the fin spacing should be 8-9 mm for better enhancement of heat transfer and they also found that the fin spacing is more dependent on the Rayleigh number than other parameters. Md. Farhad Ismail, M.O. Reza, M.A. Zobaer, et.al[4] carried out the numerical investigation of micro rectangular heat sink with circular and rectangular perforation on rectangular heat sink. They observed that the fin having circular perforation shows the greater enhancement of heat transfer and it shows the lesser pressure drop compared to solid as well as fin having rectangular perforations. M R Sheari, M Yahoube et.al [5] did the comparative numerical analysis of solid and perforated rectangular fins which are mounted on plate the small size square perforations is made on fin surface along the stream length. The obtained result shows that the perforated rectangular fin has a considerable enhancement in heat transfer as well as weight reduction compared to fins without perforation. Azarkish, S.M.H. Sarvari, A. [6] did the comparative studies for determining the optimization of geometrical parameters of fin array which are in longitudinal. They conducted different test on fin arrays by using the genetic algorithm in order to find the optimum fin geometry as well as to enhance the heat transfer through the free convection. Golnooshmostafavi, mehranahmadi et al [7] carried out analytical analysis of rectangular fin array with interrupts which are in vertically mounted position and in free convective heat transfer. For analytical analysis they use the softer of COMSOL multiphase to generate the 2-D numerical model in order to determine effect of interruptions for verification of numerical and analytical results a customised test environment is developed to conduct the experimental analysis. They got the results that show the increment in heat transfer by adding the interrupts in longitudinal fins and it also reduces the weight of the heat sink

2.1 Present work

The present experimental analysis computes the enhancement of heat transfer coefficient due to interrupts with varying its numbers (i.e. 1,3&4) in rectangular fin arrays. The forced convective heat transfer performance of interrupted fin arrays was compared with equivalent of continuous fin arrays by studying their Nusselt numbers, heat output, heat

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transfer coefficient, efficiency and effectiveness of fin arrays. The experiment is conducted for different velocities ranging from 1.5 to 4.5 m/s and heat input of 80 W was maintained constant throughout the experiment.

III. EXPERIMENTAL SETUP

3.1 Rectangular fins and heater

In the present analysis experiments were conducted for different fin patterns, such as continuous and without interrupts, fin dimensions and interrupt length was kept constant and number of interrupts is varied from 1, 3 and 4. All the fins are shown in fig 1 and the dimensions are tabulated in Table 1. Fins are heated by mica induction heater of dimensions are 200×99×2 mm, the bottom of the heater was insulated with 5 mm thick of glass-wool which is having thermal conductivity of 0.04 W/m K and heater is further insulated with asbestos of 5 mm thickness having thermal conductivity 0.08 W/m K. The insulation is provided in order to prevent the heat loss to bottom of heater and it was attached to the rectangular duct with suitable fittings.

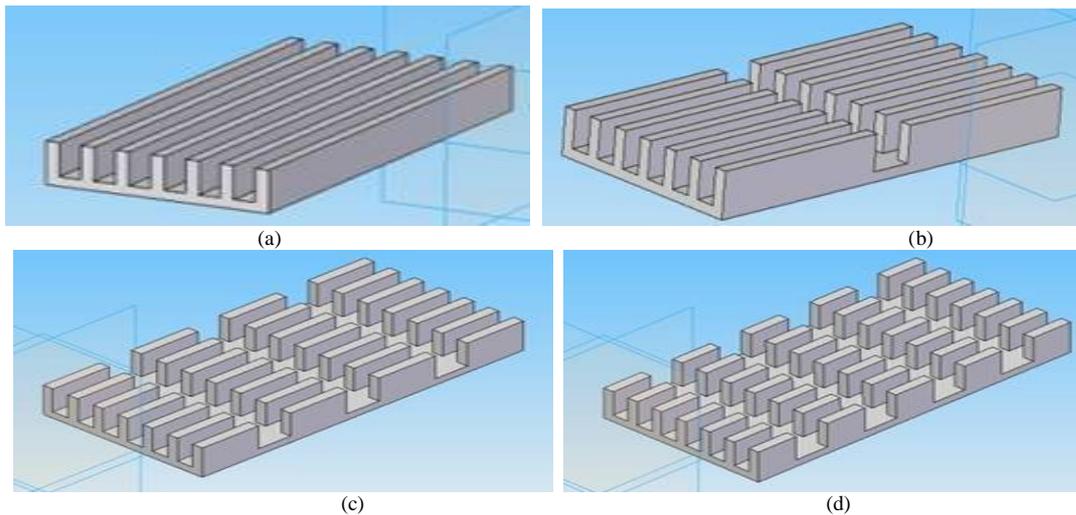


Fig.1 (a) Continuous fin (b) fin with 1 interrupt (c) fin with 3 interrupts (d) fin with 4 interrupts

Table 1 Rectangular fin dimensions

Type	No. Of fins	No of interrupts	Width of interrupts	Length (l) in mm	Width (w) in mm	Fin spacing (s) in mm	Fin Height (h) in mm	Fin thickness (t) in mm
(A)	7	0	0	200	99	9.5	18	6
(B)	7	1	20	200	99	9.5	18	6
(C)	7	3	20	200	99	9.5	18	6
(D)	7	4	20	200	99	9.5	18	6

3.2 HEAT TRANSFER EQUIPMENT

The heat transfer equipment was designed in order to conduct a natural and forced convective heat transfer experiment is as shown in fig 2. The experimental setup consists of separate display units for showing the temperature readings and

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for voltmeter as well as ammeter readings. The heat transfer equipment has a rectangular duct made up of M S sheet, the heater assembly was placed in the duct and insulators was placed at the bottom of the heater in order to prevent the heat losses from heater to atmosphere. The dimmer-stats are used to control the voltage input to the heater and also it was used for controlling of blower speed. The dimension of test section is 250×110×25 mm



Fig. 2 Experimental setup for heat transfer

3.3 MEASUREMENT EQUIPMENT

The experiments are conducted with varying the air velocities of 1.5, 2.5, 3.5, and 4.5 m/s. The air flow velocities are measured using the digital anemometer. The supplied voltage and current was measured by using digital voltmeter and ammeter. All the surface temperatures of fins and heater plate are measured using k-type thermocouples.

IV. EXPERIMENTAL PROCEDURE

In the present analysis experiments was conducted for different fin patterns, such as with interrupts and continuous fin, fin dimensions and interrupt length was kept constant and number of interrupts is varied from 1, 3 and 4. The K-type thermocouples was used to measure surface temperature at various points on the fins patterns (15 thermocouples on fin surface and one on bottom of base plate) and constant heat of 80 W was supplied to the base plate by using mica heater and dimmer-start is used to control the heater. To determine the forced convective heat transfer co-efficient centrifugal blower was used to vary the velocity of air from 1.5, 2.5, 3.5 and 4.5 m/s. Variation in temperature was measured at every 10 min interval and at some point base plate and fin temperature reaches steady state. At that point experiment was stopped and final steady state temperature was measured for further calculations. All the properties of air and material are taken at film temperature of fin surface and bulk temperature of air.

V. ANALYTICAL METHOD

5.1 For natural convection

Heat transfer coefficient calculation for fin array

The Grashoff number (Gr) is calculated by using the formula

$$Gr = \frac{g\beta\Delta Tl^3}{\nu^2} \quad (1)$$

All properties are taken at mean temperature

$$T_m = \frac{T_s - T_\infty}{2} \quad (2)$$

The bulk mean temperature is given by

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$$\beta = \frac{1}{T_m}$$

Difference in temp $\Delta T = T_b - T_s$

The Prandtl number (P_r) is given by

$$Pr = \frac{\mu c_p}{K} = 0.6913 \quad (3)$$

The Nusselt number (Nu) is given by

$$Nu = 0.59(GrPr)^{0.25} \quad (4)$$

The Heat transfer coefficient is given by

$$h = \frac{Nu k}{l} \quad (5)$$

4.2 Forced convection

The actual effective velocity at the measurement section in the rectangular duct,

$$V_{avg} = \frac{V}{A_d - A_f} \quad [\text{m/s}] \quad (6)$$

The average velocity is found using effective flow area $A_d - A_f$

Volume flow rate of air, $V_f = A_d \times v \quad [\text{m}^3/\text{s}]$

Area of Rectangular duct, $A_d = L_d \times W_d \text{m}^2$

- L_d = Length of the duct
- W_d = width of the duct

Exposed area, $A_s = (1 \times H \times 2) + (t \times H \times 2) + (1 \times t)$

Totally exposed fin area, $A_f = n \times A_s + 1 \times s \times (n - 1) \text{m}^2$

The Reynolds number, Re is given by

$$Re = \frac{V_{avg} \times D_h}{\nu} \quad (7)$$

The Hydraulic diameter, $D_h = \frac{4P}{A_s} \text{m}$

Perimeter of fin, $P = 2(w + 1)$

The dimensionless Nusselt number is given by

$$Nu = 0.453 Re^{0.5} Pr^{0.333} \quad (8)$$

The heat transfer co-efficient is given by

$$h = \frac{Nu \times K}{D_h} \quad (9)$$

The efficiency of fin

$$\eta_{eff} = \frac{h A_s (T_s - T_\infty)}{h A_b (T_b - T_\infty)} \quad (10)$$

$$\text{The effectiveness of fin } \varepsilon = \eta_{eff} \times \frac{A_s}{A_b} \quad (11)$$

V. RESULTS AND DISCUSSION

In the present work experimental analysis was performed with five different fin patterns. Forced convection experiment was carried out for Reynolds number ranging from 30000 to 800000 i.e. under turbulent flow conditions. Using centrifugal blower forced air was supplied over rectangular fins through the duct with different velocity such as 1.5, 2.5, 3.5 and 4.5 m/s. Constant heat rate was maintained of 80 W to the base plate and all heat losses was measured to obtain actual heat dissipated from fin array by convection. By using the suitable correlation the heat transfer rate and performance characteristics of fin patterns is calculated and obtained results are computed. The performance characteristic graphs were plotted as shown below for different Reynolds no with respect to Heat transfer coefficient, Nusselt no, efficiency and effectiveness.

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5.1 Natural Convection

In this section, a comprehensive parametric study was performed to investigate the effect of each fin parameters on natural convection heat transfer coefficient. For each case a wide range of the targeted fin array parameter is considered, while the other geometric parameters are kept constant

5.1.1 Effect of Number of Interrupts on Heat Transfer Co-Efficient

The effect of number of interrupts on heat transfer coefficient in natural convection is as shown in Fig 3 as the number of interrupts increases the heat transfer coefficient increases. There is an increase in heat transfer coefficient with introducing number of interrupts, because the interrupts disturb the development of thermal and hydrodynamic boundary layers this will reduce the thermal resistance, which lead to increase in heat transfer to the atmosphere. In case of continuous fins the development of thermal and hydrodynamic boundary layer is continuous and the thermal resistance is more so heat transfer coefficient is less compared to fins having interrupts. From fig.3 shows that the fins having 4 interrupts shows the considerable increase in heat transfer co-efficient compared to the continuous fin, 1, and 3 interrupts respectively.

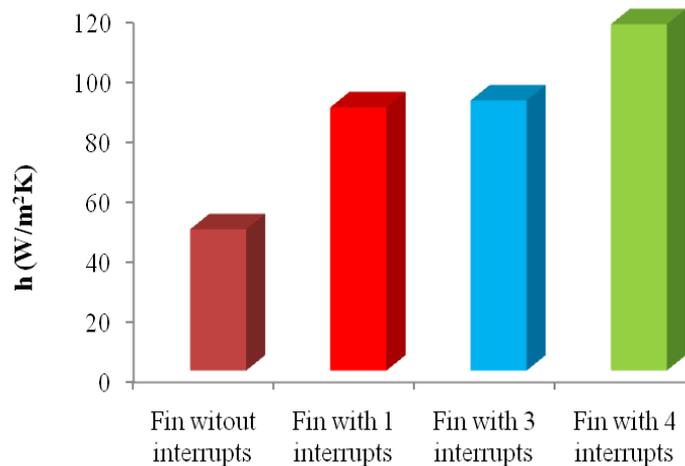


Fig 3 Effect of number of interrupts on heat transfer co-efficient

5.2 Forced Convection

In the present analysis forced convection experiment was carried out for Reynolds number ranging from 30000 to 800000 i.e. under turbulent flow conditions. Using centrifugal blower forced air was supplied over rectangular fins through the duct with different velocity such as 1.5, 2.5, 3.5 and 4.5 m/s. Constant heat rate was maintained of 80 W to the base plate and all heat losses was measured to obtain actual heat dissipated from fin array by forced convection.

5.2.1 Effect of velocity on film temperature and heat input

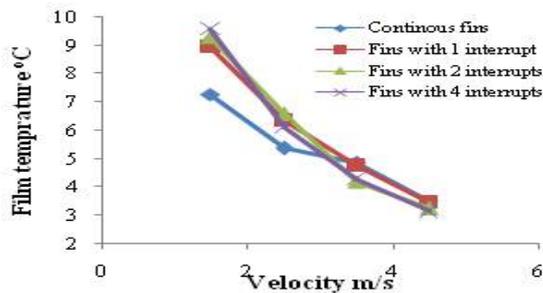


Fig 4 Effect of velocity on film temperature

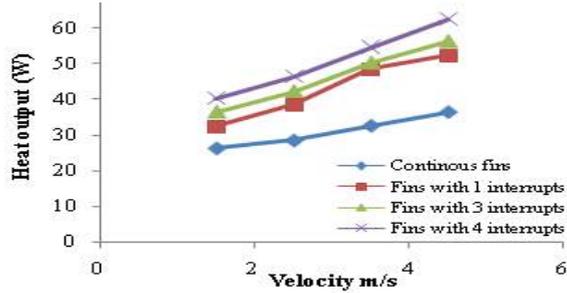


Fig 5 Effect of velocity on heat out put

Fig 4 and 5 shows the effect of velocity on film temperature and heat output by the fins. The film temperature of fins will decrease with increase in air velocity and heat output to atmosphere will increase. This is due to the turbulent flow of air through the fins, so that heat transfers to the air will increase. The continuous fins have less obstruction to the flowing air due to which heat dissipation from base plate to the atmosphere will reduce, hence film temperature from the fin surface to ambient air measured will be high. The fin with interruptions has more obstruction and wakes are formed at the interruption, due to which high turbulence is generated. This causes higher heat transfer rate to the air from the fin surface which leads to lower film temperature and increases the heat output. The fin with 4 interruptions has less film temperature and higher heat output compared to other fin patterns.

5.2.2 Effect of Reynolds number on Nusselt number and heat transfer

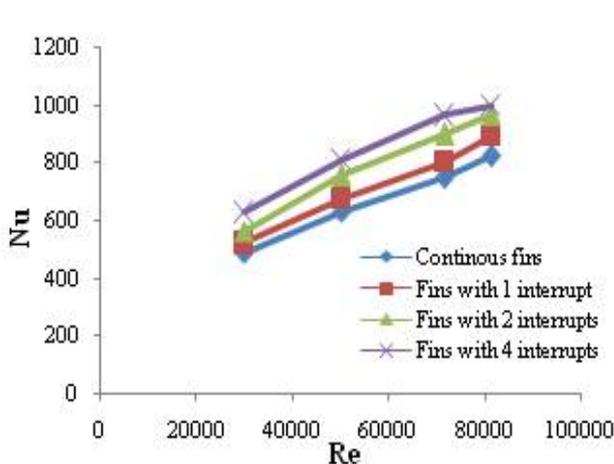


Fig 6 Effect of Reynolds number on Nusselt number

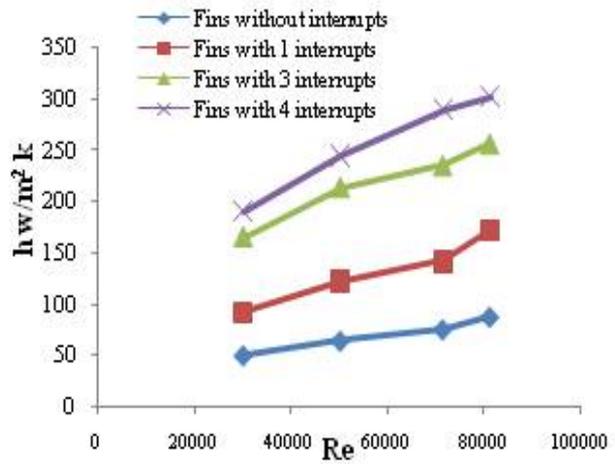


Fig 7 Effect of Reynolds number on heat transfer co- efficient

From the experimental data a comparative relations of heat transfer coefficient and Nusselt number for different fin patterns corresponding to different Reynolds number are shown in Fig 6 and Fig 7. It was found that for all cases interrupted fins have higher Nusselt number and heat transfer coefficient compared to continuous fin. Because of interrupts both hydraulic and thermal boundary layers will be discontinuous and this will reduce the thermal resistance and increase the heat dissipation to the surrounding. It was found that there is a significant increase in heat transfer coefficient values between fins with 4 interrupts compared to that with 1, 3 interrupted fins and continuous fin at

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maximum velocity. It also worth mentioning that as increase in interrupts the weight of heat sink decreases, which place an important role for the applications in which weight was considered has an important matter.

5.2.3 Effect of Reynolds number on Efficiency and Effectiveness

Fig 8 and Fig 9 symbolize the comparative results of rectangular fins with continuous, one interrupts, three interrupts and four interrupts. The results show that the efficiency and effectiveness of fins increase with increasing the number of interrupts and also increase with Reynolds number. The fin with 4 interrupts has higher effectiveness when compared to other fin patterns. Since fin with 4 interrupt has more heat transfer area and higher impediment compare to other fins, hence the efficiency and effectiveness of fin will enhance with increase in velocity i.e. Reynolds number.

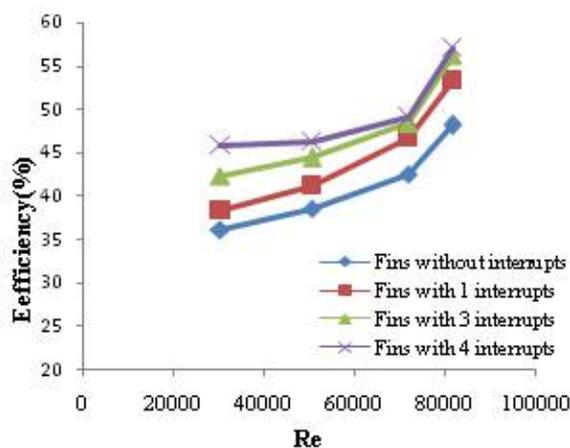


Fig 8 Effect of Reynolds number on efficiency of fins

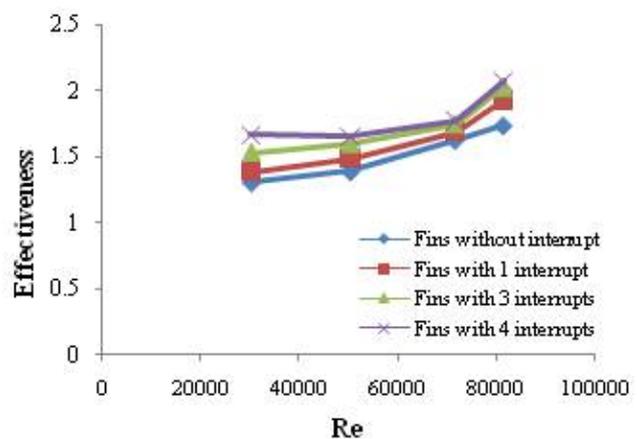


Fig 9 Effect of Reynolds numbers on effectiveness of fins

VI. CONCLUSION

In the present analysis experiments was conducted for different aluminium fin patterns, such as continuous and with interrupted fins. Fin dimensions and interrupt length was kept constant ($G=20$ mm) and number of interrupts was varied from 1, 3 and 4. The thermal performance characteristics, efficiency and effectiveness are compared with varying Reynolds number and for constant heat input of 80 W for both natural and forced convection.

- In natural convection experimental result shows that fins with 4 interrupts has a higher heat transfer coefficient compared to the other fin patterns.
- The experimental results shows that the fin with 4 interrupts at maximum velocity has lower film temperature and has a higher heat output when compared to other fin patterns.
- The obtained results shows that the convective heat transfer coefficient and Nusselt number increases with increasing Reynolds number for all fin patterns. But for fins with 4 interrupts shows higher heat transfer coefficient compared to other fin patterns.
- The experimental result shows that at maximum velocity there was an increase of 10% efficiency and 30% effectiveness when 4 interrupted fins used instead of continuous fins at same heat input.
- It also importance to mentioning that as increase in interrupts the weight of heat sink decreases, which place an important role for the applications in which weight was considered has an essential matter.

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