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Augmented-Fin Air-Cooled Heat Sinks

Augmented-Fin Air-Cooled Heat Sinks Achieve Higher Performance without Significant Rise in Static Pressure Drop

New developments in segmented heat sinks use air flow as part of the design criteria, providing dramatic improvements in thermal performance while limiting the pressure drop to a few hundreds of an inch of water — an insignificant rise for most

In forced-air cooling, the heat transfer region or boundary layer thickness increases with fin length, in the direction of air flow. As shown in previous technical papers, the thickness of the boundary layer directly affects the amount of heat that can be removed from each square inch of exposed surface area. In fact, this boundary layer thickness is inversely proportional to the amount of heat that can be transferred from the surface.

By segmenting a single fin into shorter lengths, the effective boundary layer becomes thinner, improving heat transfer from the surface. Because the overall surface area is essentially unchanged, this heat transfer translates directly into improved thermal performance.

Enhanced Heat Transfer Surfaces

Pin-fins, cross-cut fins and augmented-fin are examples of the innovations produced by various manufacturers. They all have one thing in common: the improved heat removal surface has many shorter fin sections that produce thinner boundary layers than one long fin of the same overall length. The heat removed from many shorter fin sections is greater than heat removed from one fin section at a constant temperature rise, due to an increase in conductivity of the heat transfer boundary layer. Looking at it another way; augmented fins allow a lower temperature rise for an equal amount of heat load.

In each case, to dissipate the same amount of heat, whether you are using flat-fins, pin-fins, cross-cut fins, or augmented fins, the temperature rise of the discharge air is equal because the mass flow of air is the same. Whether the fins are flat or augmented, the air temperature rise is not affected, as long as the velocity (and subsequent volume) of the air is the same. This is due to a basic physics law of mass flow:
Air Temp. Rise = Watts Dissipated / (Air Density X Flow Volume X Specific Heat)

As seen from this formula, as the air flow volume and watts dissipated remain constant so does air temperature rise. This air temperature rise is just one of the components that result in an overall thermal resistance of a heat sink.

Pressure Drop

Pin-fin or rectangular cross-cut finned heat sinks have been used for years to improve the heat transfer coefficient on forced air heat sinks. As air flows through these fin configurations, the small openings constrict the flow, creating a pressure drop. The more effective the heat sink, i.e., the more shorter fins there are, the greater the pressure drop at the desired air flow volume. Because air flow velocity is directly proportional to air flow volume and proportional to the static pressure drop, these "pressure-hungry" heat sinks require a higher flow velocity pressure to move a given volume of air through a heat sink. To increase the velocity, an increase in fan power is necessary to maintain the same mass flow of air through the heat sink. This mass flow dictates not only velocity of the air but, as previously discussed, the thickness of the heat transfer boundary layer along every fin. To achieve the increased air moving power may require a larger fan or a different style of air mover.

Newer configurations, called augmented-fin heat sinks, take air flow into consideration and help to reduce this increased static pressure. In an augmented-fin design, the fins are staggered, placing the downstream leading edge of each fin section in the exact center of the air channel, maintaining a constant cross-sectional area for the air to move through the heat sink. This optimizes the effects of reduced boundary layer thickness (increased heat transfer) by reattachment (thinning) of the layer while taking advantage of the fastest air velocity and thinnest upstream boundary layer.

The pressure drop caused by a separated, augmented fin is slightly higher than that caused by a flat-fin of same overall length, but this drop is minimized due to the constant cross section of the air channel. Typical pressure drop in either a heat sink or parallel plate heat exchanger using flat fins exposed to the air stream consists of :

- Entrance loss (due to reduced air flow cross section)
- Static pressure loss (due to the drag of the air across the side of the fin)
- Exit loss (due to expansion of the air leaving the flow channels between fins)

When we compare heat sinks of the same size and fin density we can determine the static pressure drop of these parts based on the three loss parameters described above. In this case, all the heat sink dimensions are identical except for the shape of the fins in the air flow channels. Frontal density and exit density are the same, consequently there is no increase in static pressure due to those factors.

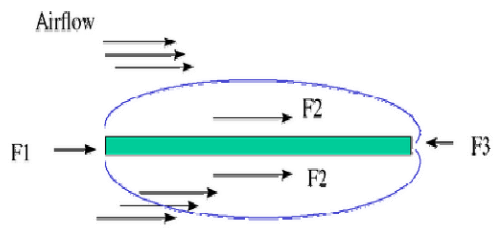

Figure 1. Forces on the leading and trailing edges of heat sink fin are nearly equal, canceling one another out.

The difference in the two styles of fin (flat versus broken) is in the additional leading and trailing edge losses associated with the reduction of boundary layer thickness and reattachment of the boundary layers to the fin surface. The friction factor or drag coefficient of the air as it passes a single fin consists of three separate elements:

1. The force on the leading edge:

   F(1) = A (P +1/2Cd x Density x Vel^2)
   Where:
   A = Frontal area of the fin
   P = Static force
   Cd = Drag coefficient - typically 0.9 for flat fins
   Density = Air density
   Vel = Air flow velocity

2. The drag of the air as it passes the side surface of the fin:

   F(2) = _ A x f x Density x Vel^2
   Where:
   f = Pressure drop characteristic based on channel geometry

   Typically, the "f" factor is found in various textbooks and references of heat sink and heat exchanger design. The numbers are based on the Reynolds number (Rey) of the cooling fluid and vary with the size and shape of the cooling channels. As an example the pressure drop for one model of heat sink is given as: f = 0.926 Rey -0.5.

3. The negative pressure drop (gain) based on the surface area at the trailing edge of the fin:

   F(3) = - A x P

   The components of the friction drop, F1, F2 and F3, combine to form the overall resistance to air flow.

   The drag due to the leading edge (F1) causes a pressure drop composed of: the static pressure drop , based on the surface area resisting the flow of air; and the dynamic pressure drop of the flow momentum, based on the frontal area exposed to the air stream.

   In the second component, (F2), the pressure drop is equal to the viscous properties of air resisting the flow of molecules past the surface. With a constant overall length of the heat sink, the friction of the air flow along the air length of the fin will be identical for one fin of full length or multiple fins equaling the same length. This is based on constant fin height and air travel length.

   The third component is the force, (F3), gained by the dynamic pressure of the air pushing against the trailing edge of the fin. This force is approximately equal to the same force exerted from the front edge of the fin. In actuality, the F1 and F3 forces cancel and have little or no net effect on the overall pressure drop of the air passing through the heat sink.

   Combining all of the individual formulas gives one overall equation giving the total force or pressure loss at each fin:

   F_n = _ A x f x Density x Vel^2
   This is F_n = F(1) + F(2) + F(3)

   The pressure loss of the total heat sink is the sum of the pressure losses at each fin. We can see that the pressure loss is dependent upon the frontal area of the fin, the channel geometry, and the total number of fins. Leading edge and trailing edge losses have canceled out. Assuming equivalent channel geometries, the additional pressure loss of the multiple-fin heat sink is not due to the friction of air as it flows past the fin surfaces, but only due to the dynamic force exerted on the multiple leading edges of the fin. The following lab tests support this conclusion.

Empirical Results

Laboratory tests were performed on a pair of identical bonded fin heat sinks. The only difference between the two parts was the style of cooling fin. One was a conventional flat-finned part, typical of parts available from a number of heat sink manufacturers. These parts are 12.00 inches air travel length, 10.78 wide with 45,0.05 thick fins at 4.50 inches in height. The other part was a broken, or augmented-fin, heat sink with fins that formed a series of individual heat transfer surfaces. Each of these surfaces had both entry and exit augmentations on each shorter fin section, to move the air stream at an angle to the bulk air-flow direction, promoting turbulence. The fin material itself, in both cases was an 1100 alloy aluminum.

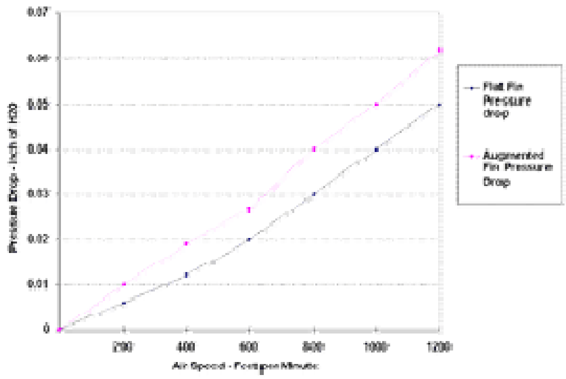

Figure 2. Pressure drop increase due to the segmented/augmented-fins.

Notice that the pressure drop using the augmented fin is only about 0.01 in. of water greater than that with the flat fin. This difference in pressure drop will increase with increased air velocity. However, in the range of air speeds used in most electronic cooling applications, this small pressure increase will have very little effect on the mass flow of the air. Increases in static pressure may become significant when air velocities are above 2000 feet per minute (10 m/sec).

Figure 3 shows the typical thermal performance gains achievable with the segmented/augmented fin heat sink.

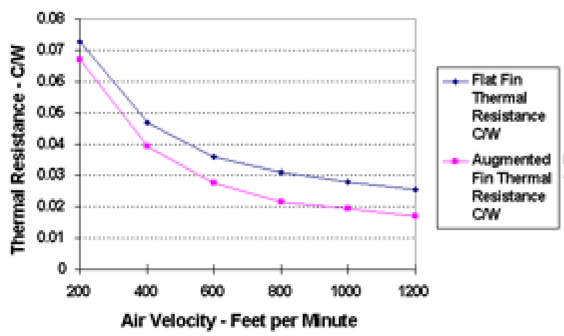

Figure 3. Typical thermal performance gains achievable with segmented/augmented-fin heat sinks.

The lower thermal resistance offered by the augmented-fin heat sink may enable an engineer to satisfactorily cool a sensitive device using standard air flow, where otherwise increased air flow, or other, more sophisticated cooling devices would be required.

The benefits in thermal performance offered by segmented- or augmented-fin surfaces far outweigh the reduction in air flow volume and the subsequent drop in air velocity due to the increased pressure drop.

References:

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