

Designing for heat

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A few things to consider when designing for a harsh environment



I want to start off with a look at the four methods of cooling: conduction, convection, radiation, and pumping. What? They don't teach the four methods of cooling in physics class? Only the first three? The fourth method is a combination of the first three with the addition of pumps.

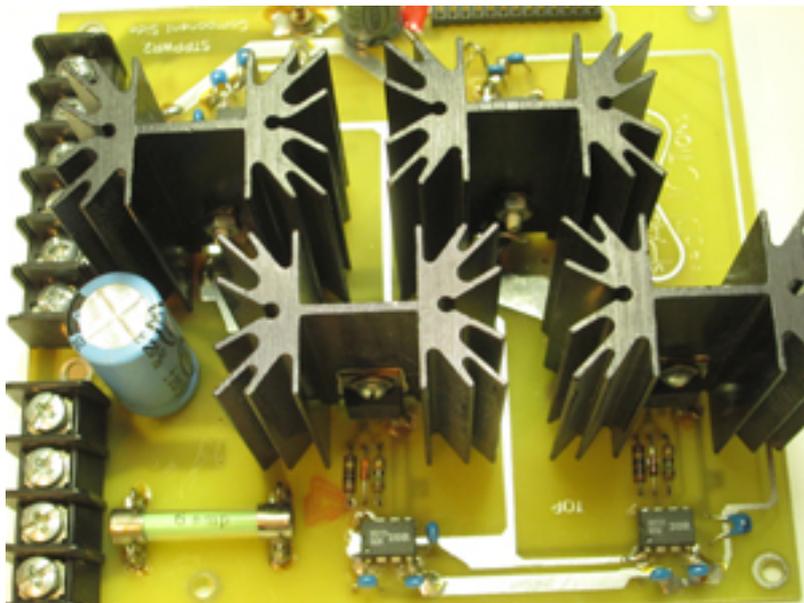
The pumping method is essential for the operation of steam plants. It is also a method used for cooling electronics. Sometimes the pumping is explicit as in the use of actual pumps to move fluid. Sometimes the pumping is implicit like using heat pipes where wicking/capillary action is used as a liquid pump.

Sizing heat sinks

Obviously, cooling electronics is not as straight forward as it once was because options have been added since the days of convection cooling or fan cooling heat sinks. One of the things I learned early on was if you have the PC board space more heat sinks are better. For example, suppose you have four transistors all dissipating equal power and if you heat sink them individually four heat sinks rated at 4°C per watt will do.

Now suppose you want to cool them with one heat sink. That would require a heat sink rated at 1°C per watt. You will find that the heat sink rated at 1°C per watt weighs more and takes up as much or more room than the four individual heat sinks. In any case a heat sink per device is always an option worth looking into if the frequencies you are operating at allow the extra lead length on the PCB.

Also keep in mind that the density of the final heat sink makes a difference in cooling. This is not too important if the sink is water or some solid material but can be critical in air cooled designs that have to operate at varying altitudes.



Fan cooling

Fan cooling is always an option for reducing the size of the heat sinks required for a given level of cooling. However there are, as usual in engineering, tradeoffs. First, power requirements will increase. Secondly, reliability will be going down (possibly by a lot.)

There are ways to increase the reliability of fan cooling. You can upgrade from a lower cost sleeve bearing fan motor to a more expensive ball bearing fan motor. Alternatively, measure the temperature of the object being cooled and only run the fan as long and as hard as required to keep the temperature below the desired level. This adds complexity in that it may require a variable speed fan plus attendant control electronics. That's what's done in most PCs and all laptops these days.

Fan types

There are other types of fans besides those with blades. They are called squirrel cage fans or, more technically, axial fans. These fans produce high flows at low pressures, but are generally bulkier than bladed fans. This is an important consideration in applications where you need to keep the bulk down like in laptops. However, by putting the right kind of shroud on a bladed fan you can convert a high pressure - low flow fan into a low pressure - high flow fan.

Fan noise

Cooling fan noise can be an issue in some cases. Generally the squirrel cage fans are lower noise because of their lower pressure. However, there are low noise bladed fans made especially for desktop PCs and laptops. If you have enough room noise can be further reduced by the correct application of shrouding.

DC motor types

If you are running a fan on DC you have a choice of two types of motors: motors with brushes and brushless motors. There are a several problems with brushed motors. One is limited brush life. A second is the residue from brush wear which is conductive and can play havoc with electronics if it escapes the fan housing. The antidote to both of those problems is a brushless DC motor. They cost more, but have a longer life which can compensate for the higher cost.

Piezoelectric fan motors

Piezoelectric fans are the new kid on the block. They are very low weight, don't take up much space and can be operated directly from line voltage, if available. They consist of a piezoelectric bender and a cantilever sometimes called a blade or a wing. The blade is used to multiply the motion of the bender to increase the mass flow. The whole unit is tuned to the supply frequency to increase the efficiency and the mass flow.

Since the mass and viscosity of the air being moved is part of the frequency operation these types of fans are best used where the density of the air won't vary much. For DC operation an oscillator is used to generate the fan frequency. The oscillators are generally in the 50Hz to 500Hz range. They can be designed so that the piezoelectric fan system itself is the tuned element which will tend to optimize electrical efficiency and cooling rate with variations in air density and oscillator components.

Space allocation - heat pipes

Heat pipes are used for applications with limited space where the heat generated is moved a different place with more space for the cooling components - either by natural convection or a fan. In a heat pipe where the gas and liquid flows are controlled by gravity, proper orientation in the gravitational field is essential (obviously a gravitational field is also essential.) If you don't have a gravity field or can't maintain a given orientation, fluid pumping by wicking/capillary action is required. When operating a wicked heat pipe in a gravity field the heat transfer rate will vary some according to the orientation. Be sure to take that into account in your design.

Space allocation - pumped cooling

Pumped liquids are another way of moving the heat from where it is generated to where it is finally dissipated. Be sure the liquid you choose for cooling is compatible with the electronics it comes in contact with and will remain in the system for the life of the system.

Sometimes pure water will work (if it has suitable corrosion inhibitors), but sometimes you will need more exotic liquids. Make sure everything that comes in contact with the fluid is compatible. This goes for surfaces as well as pump impellers. You also need to make sure that the system pressure at the pump input is sufficient to prevent pumping cavitation. Cavitation can drastically reduce the life of the pump.

Thermoelectric cooling

A thermoelectric cooler moves heat from its hot face to its cold face using electricity. Under most circumstances you would not use them for general cooling. They are expensive and use a lot of power for the heat moved. Where they do come into their own is if your electronics - such as a sensor - needs to be cooled below ambient. They are rated by maximum heat flow and maximum temperature differential.

Designing for heat

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The rating system gives maximum heat flow at zero temperature difference between the two cooling plate faces and maximum temperature difference with zero heat flow between the two cooling plate faces. You cannot get both maximum heat flow and maximum temperature difference at the same time. Thermoelectric coolers can both heat and cool a given face by reversing the polarity of the current supplied.

This could be useful if you want to keep a device or system at a given temperature near ambient if the ambient temperature is varying some. In addition to the cooler and its associated heat sink a fan may be required to dissipate or supply the heat pumped.

System simulation

One way to tie all these elements together is with a fluid flow or multi-physics simulator. Keep in mind a simulator is not a perfect representation of a physical system, but it can be very handy in telling you which way to go to make things better or worse (depending on what you are optimizing.) In the end though you will need to build a prototype and take measurements or build into your system enough margin to cover for errors in design and mistakes in assembly.

Cooling system design

When designing a cooling system that is close to optimum, you need to start with a series of budgets. These include a space available budget, a temperature rise budget, a cooling system lifetime budget, and electronic system lifetime budget, a power budget, and a cost budget that includes not only parts costs, but also manufacturing and assembly costs. Many of the items are interrelated. For instance system lifetime determines to some extent the temperature rise budget. You get longer power electronics component (such as power transistors) lifetimes if the temperature rise can be reduced. There are a lot of factors that go into a good design. Do your best to take them all into account while also meeting your engineering budgets of manpower, dollars, and time.

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