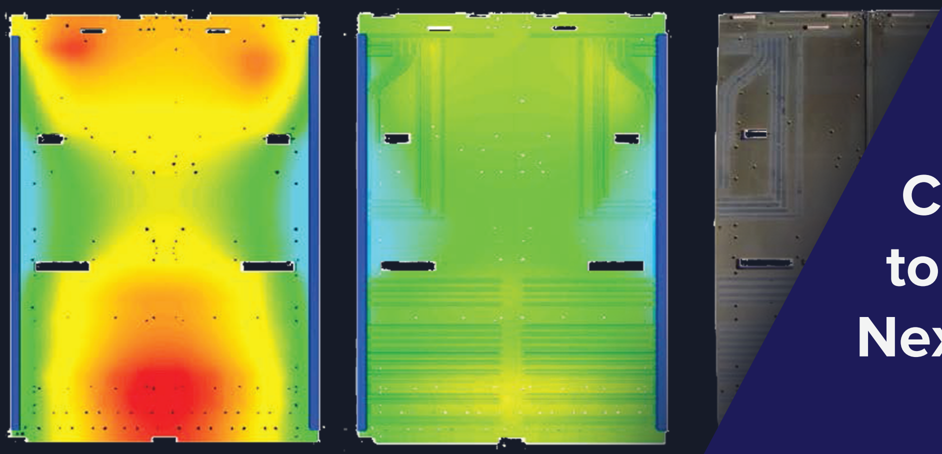


Medical Device Cooling Considerations to Know for Your Next Design Project

The term “Medical Device” covers an expansive range of applications from large MRI machines to hand-held surgical devices and diagnostic tools. These pieces of hardware can be orders of magnitude different in size and power output, so it stands to reason that there is no ‘one size fits all’ cooling solution that is suitable for all medical devices. With that said, there are certain unique constraints and challenges associated with designing a cooling system for the medical industry that must be appropriately addressed.

In this article, we will explore the various temperature, packaging, materials compatibility, and duty cycle considerations that often come up when designing a cooling solution for products that fall under the ‘medical device’ umbrella. We will make some suggestions about what types of cooling products work best under certain operating conditions, and maybe more importantly, we will outline what factors medical device engineers should consider when designing their products to allow for the best possible cooling solution.

Temperature Requirements

It may seem a bit obvious to have ‘temperature requirements’ on a list of items to be considered when designing a product intended to modulate temperature, but the considerations here are a little more nuanced and worth discussing. First, let’s start with the obvious and primary function of a cooling system: to maintain a specific component and/or surface within a specified range of acceptable temperatures. This is a straightforward requirement for almost all electronic devices and one that most system designers are used to accommodating. Electronics manufacturers have requirements for what the maximum operating temperature of their components must be to retain full functionality from the hardware.

> **Key Takeaway:**
> When packaging components in their system, medical device designers should think about the proximity to a cooling source when placing higher-powered components.

When designing a cooling system for a relatively large, non-contact medical device the strategy is very similar to that of a more standard electrical system. Power electronics and standard computing components can usually be cooled through traditional means by utilizing air cooling or even liquid cooling if necessary. Most of the challenges specific to medical applications revolve around packaging considerations. Often the components that generate the most heat are buried deep within the system and are difficult to access with traditional cooling products When packaging components in their system, medical device designers should think about the proximity to a cooling source when placing higher-powered components. The cheapest and most straightforward cooling systems are the ones with the most access to a cooling medium. The more difficult the hot component is to access, the more 'exotic' (and potentially complex) the cooling solution becomes.

Another challenge for larger diagnostic equipment systems is the need for multiple operating temperature ranges. For example, the magnets in an MRI machine like to operate at cryogenic temperatures (-270°C) while the supporting electronics can operate up to 80°C. This introduces the challenge of trying to isolate the heat being generated (and dissipated) from the power electronics to minimize the heat leak that must be supported by the cryocooler. Again, clever packaging of the components inside of the assembly can reduce the level of effort required to maintain all relevant hardware within its desired operating range.

A challenge specific to handheld or human contact devices is the balance between maintaining appropriate electronics temperatures while minimizing exposed surface temperatures that may cause injury to the operator or the patient. Most electronic components can tolerate temperatures up to 70-80°C during operation, but the human body can only tolerate temperatures up to about 44°C before experiencing some pain or discomfort . This presents a unique scenario for the designer of a cooling system in which you either need to over-cool the component to well below its maximum temperature to avoid excessive surface temperatures or you intentionally incur a large temperature difference between the component and the surface (i.e. insulate the device) to maintain an appropriate exterior temperature. Neither option is particularly optimal from a thermodynamics perspective and can be counterintuitive to engineers not used to operating within these constraints.

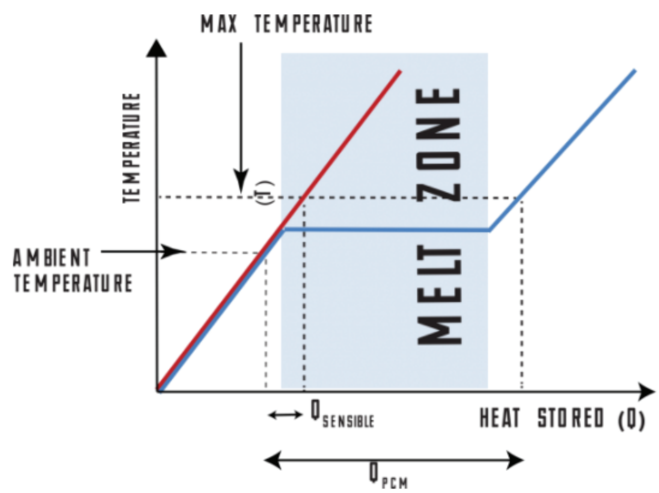
The heat generated in smaller devices is usually concentrated in a small area and surrounded by surfaces that cannot be heated. In these cases, one solution is to use a product like a heat pipe to move and spread the heat from the electrical component to a larger surface area far from the immediate contact surfaces. Heat pipes are essentially superconductors of heat along a path defined by the geometry of the pipe. If we imagine a surgical device with a very localized heating zone at the tip and a relatively long handle with no heating, it is apparent that without heat spreading, the tip of the device and the surrounding area will become very hot relative to the rest of the device. A solution for this application would be to add a heat pipe to the design to transfer a portion of the energy generated at the tip of the device and spread it evenly throughout the handle to maintain a stable, safe, and uniform temperature profile across the whole device.

As a final note about temperature requirements, it is worth discussing applications that require precise temperature control. These applications often involve lasers or sensitive electronics that operate best within a relatively small temperature window. Precise temperature control can be achieved in several ways, so to select the most efficient method, it's important to consider the operating nature of the components and the environment in which it will be operated. Most laser devices operate below 30°C and are used in environments that are between 20-25°C. With only a slight temperature difference between the cooling medium (air in the room) and the component, a refrigeration system is often required to achieve cooling temperatures below the ambient temperature in the room. Lower-powered applications can utilize thermoelectric devices (a.k.a. TECs or Peltier Coolers) to achieve precise temperature control and high reliability. The challenge with TEC devices is that they tend to be inefficient and incapable of handling large power dissipation requirements (>100W). Alternatively, temperature control can be achieved using a liquid cooling system and a vapor compression-based chiller to achieve colder than ambient temperatures.

When a Duty Cycle is Present

Often when discussing the power dissipation of a component, engineers will talk in terms of steady-state performance. This is appropriate for the majority of thermal management applications where operation is continuous or the device must be "on" for a significant period of time. However, there are a significant number of applications that require a more transient approach to the problem. Consider a medical device that operates at full power for 1 minute and then sits idle for the next 10 minutes as its standard operating cycle. If an engineer were to treat the heat dissipation from this device as a steady-state condition, the cooling system would wind up being sized for 10 times more power than is likely needed.

Alternatively, pulsed loads like this example can be treated as temporary conditions that just need to be absorbed during periods of high load and slowly dissipated during idle periods to reduce the load on the cooling system. Thermal energy storage can be achieved using either sensible or latent energy storage. Sensible energy storage involves utilizing the thermal mass of an object to absorb energy and then reject it back to the environment. This method of energy storage results in a significant temperature increase in the material as it absorbs energy and it tends to be less effective than latent energy storage. Latent energy storage involves the phase change of a material from either solid to liquid (i.e. melting) or liquid to vapor (i.e. boiling). This change in the thermodynamic state of the material is far more efficient than sensible energy storage and therefore requires less material to absorb the same amount of energy. Latent energy storage also occurs at a constant temperature as the material changes phase which allows the system to operate at cooler overall temperatures.



A common implementation of energy storage in medical devices is for pulsed laser or LED applications where the duty cycle can be on the order of 5-10%. For these applications, latent energy storage in the form of phase change material (PCM) is often used. Typical materials are paraffin waxes or glucose-based materials that are solid at room temperature. When the laser or LED is on, the PCM is melted absorbing the energy from the device and keeping it cool. During the off period the energy in the PCM is rejected to the environment, usually by natural convection or fan-assisted air cooling, and the PCM is refrozen to prepare for the next pulse of energy. This process can be repeated thousands of times if the solution is designed properly.

Materials Compatibility

The materials of construction are important in any engineered system but particularly critical in medical applications. For surgical devices, there is a list of certified plastics, rubbers, and metals that are available for the construction of these devices. The challenge from a thermal management perspective is that most of these materials are either thermally insulating (e.g. plastics and rubbers) or poor thermal conductors (e.g stainless steel, titanium). In some applications, it is possible to enhance the thermal performance of certified materials by embedding a higher performance (possibly not certified) material within the envelope. This is a great application for heat pipes where the thermal conductivity of a plastic or stainless-steel component can be significantly improved by fully encapsulating a heat pipe within its structure. The exterior of the device then retains its compliance with medical standards and the thermal performance of the materials can be increased up to the levels of more traditional heat transfer materials.

Another consideration regarding the materials of construction is related to high-temperature stability and survivability. Some medical devices are required to be cleaned and sanitized in an autoclave before use which exposes the component to a humid environment up to 120°C. This kind of environment can be damaging to some thermal management materials and must be considered when designing a solution for a particular application.

Bringing it all Home

If you are a medical device designer and you've made it this far, you're probably wondering if, and how, to apply these considerations. Thermal management may not be your department or usually on your radar when you are designing a new product. Like most products, medical devices benefit from a more collaborative design process where sub-systems are co-designed to maximize the potential of the complete system. Being armed with the knowledge of how thermal management systems are affected by the different challenges of medical applications can help your team avoid unexpected thermal problems. You don't have to be a thermal expert to design a product with good thermal performance, but it helps to understand early on when your potential problems are serious enough to warrant one!

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