Thermal Challenges

in Automotive High Density Lithium-Ion Battery Packs

We may not want to think about it, but eventually we are going to run out of cost effective fossil fuels. When this happens, what will be our means of personal transportation for our daily business? We're still trying to develop the ultimate power system, one that is clean and uses sustainable energy sources. In the meantime, we have hybrid-electric vehicles (HEV) which are cleaner, more fuel efficient and more practical than most other options. These vehicles use a battery and motor to generate mechanical energy when an idling combustion engine is not needed.

The batteries used in automobiles are large, heavy and designed to pack energy into as small a space as possible. Most currently produced vehicles use nickel metal hydride (NiMH) battery technologies. These allow energy to be packed within a lightweight and modular package as compared to using stacks of lead acid battery cells. As seen in Figure 1, the battery pack for today's Toyota Highlander Hybrid is stowed underneath the rear passenger seats. Note the individual modules for easy installation and access, along with the three individual blowers to the right that draw cooling ambient airflow through the battery compartment.

Figure 1. Location and Orientation of the Toyota Highlander Hybrid Battery Pack [1].

The automotive market will eventually switch to more efficient and powerful lithium-ion batteries. They commonly allow double the energy density per unit volume than NiMH batteries, while occupying a lighter package due to the relatively low density of lithium metal. Commonly seen in cell phone and notebook consumer markets, we have already witnessed the possibility of thermal failure within these batteries as evidenced by the recent battery recalls of Apple and Dell.

There are two main types of lithium-ion cell chemistries – cobalt and manganese (spinel) [2]. The cobalt variety is common in cell phones and notebook applications and, while allowing denser energy packing than manganese spinel chemistries, it is also more temperature dependent and costly. Spinel variants are slightly cheaper and are more stable than cobalt chemistries.

Like most other batteries, lithium-ion variants can mechanically and chemically break down and lose their ability to store and deliver charge at high temperatures. The polymer- or fiber-based cell dividers become inherently weaker at higher temperatures, which can induce failure at the cell wall. At high temperatures, irreversible chemical reactions may occur which reduce the ability of a battery to hold a charge.

Noxious or flammable gasses may be produced by these reactions which can present a public safety hazard. Unlike the NiMH batteries, lithium batteries can also suffer from thermal runaway – a condition whereby the battery becomes unstable and chemical reactions create rapid and strong heat generation which can cause an explosion or meltdown.

Discharge capacity is also lowered during cold temperatures, as shown in Figure 2 below. The discharge capacity is lowered because, at colder temperatures, the electrolytic solution has a higher impedance [2].

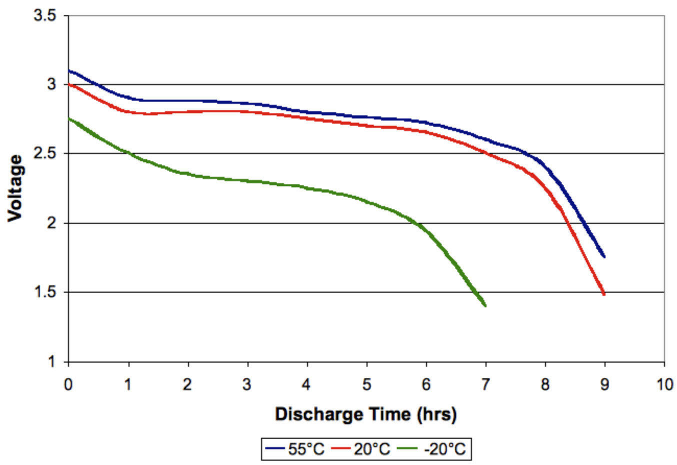

Figure 2. Discharging Performance of a Sample Lithium-Ion Battery Pack as a Function of Temperature [3].

For these reasons, while the lithium-ion battery may be the best energy carrier, the need arises for thermal management of the battery pack to avoid the issues of freezing and, particularly, of overheating. The battery designer must be aware of the effects of cooling and heating on the battery and all the other packaging issues when placing a large battery system within a consumer-oriented vehicle.

The battery must operate intermittently, which creates cycles of charge when braking, discharge when accelerating, and latency when not in use. The thermal mass of the battery pack therefore becomes important because of the transient nature of the battery. To slow the thermal response of the battery pack to stop function-like heat loads, increasing the thermal mass of the system can dampen the effects of sudden heat generation. Increasing inter-cell conductivity can also insure cell temperature uniformity, and this is important to reducing potential hot spots within the battery pack. The proposed use of a phase change material may also interest a thermal designer as the material will absorb and store the transient heat loads, so long as there is still material which can change phase. Some developments, such as using graphite-impregnated paraffin waxes as filler material within the unused spaces between cells or structures, can lead to better response under sudden heat loads [3].

On a more macroscopic system level, heat needs to be extracted in some way from the battery pack to the ambient. The battery compartment can be treated similarly to how thermal designers often treat electronics enclosures. Natural convection cooling or even conduction cooling may be an effective mode of heat transfer if the heat density is low enough and there is adequate space to feature such a design. The benefit of high reliability due to the lack of moving parts can be attractive from the consumer's point of view. Conduction cooling is a possibility that could be particularly effective for aluminum chassis vehicles. Aluminum has excellent thermal conductivity to spread the heat generated from the battery pack throughout the entire vehicle.

Where heat loads cannot allow natural convection or conduction cooling, the use of forced air may be an attractive option when the surface area of the battery pack is increased with fins or other geometries. Packaging issues become apparent when designing the channels to allow the system to adequately breathe because of the reduced volume that can be used. Filtration of the cooling airflow may be a necessity given the extreme and variable conditions a vehicle may operate in. This includes dust storms or snowy conditions, where ice and sand can be lodged in intake systems.

Liquid cooling is another option for cooling these battery packs. The batteries can be cooled by using a jacket or cold plate which features a mixture of ethylene glycol and water, similar to the convectional means of cooling combustion engine blocks. A recent development from Dana Corporation circulates the battery electrolyte through a heat exchanger which heats a glycolbased fluid used in climate control systems in the passenger cabin [4]. Recent developments in aluminum brazing make this possible by ensuring good wall strength to separate the two fluids in the heat exchanger.

Complex electronics used for monitoring cell temperatures are important for recognizing failure or delivering fan power when it is needed. The ability to recognize and shut down the cells before a situation occurs -- such as thermal runaway -- is quite important. These systems may monitor the entire battery pack as a system, or monitor the individual battery modules so that the controller has the option of shutting down a particular battery module instead of the entire system. This can allow the vehicle to go into a “limp home” mode where it can still operate, although erratically or sluggishly, to a nearest repair shop. Shutting down a module at the site of local failure is also important in preventing further damage to other battery modules.

The engineers who will design the next hybrid vehicle battery packs will need to be cognizant of the growing need for thermal management, especially when the use of lithium-ion battery packs becomes more prevalent. The increased need for thermal protection, due to safety considerations; the reduced thermal capacity, due to lesser mass; and the reduced workable volume are among the challenges to be faced. The hybrid vehicle we may soon drive must have reliable and intelligent cooling systems to cool down their high-density battery packs.

References:

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