Battery BTMS Using Peltier Cooler

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Abstract - *This paper proposes the use of a Peltier cooler for maintaining the temperature range of the battery system. As the battery pack is significantly important for electrically driven materials, the health of the battery must be taken care of. However, its performance will be affected by temperature changes, especially in the cast of Lithium based batteries. Therefore, the idea is to cool or heat the batteries using a Peltier based system. This method can solve the problem of BTMS (Battery Thermal Management System) in space applications where fan-based cooling systems can't be used. This paper highlights the important aspects that are to be considered in a Lithium based BTMS system along with the parameters necessary to be checked while we use Peltier devices in cooling it.)*

***Key Words*: BTMS -Battery Thermal Management System, Peltier, Li-Lithium, TEC-Thermoelectric Cooler**

1. INTRODUCTION

Over the years battery technologies have progressively improved with longer battery life, faster charging systems, ease of use, battery health prognostics system, etc…

One of the important characteristics of a lithium battery is its temperature, if the battery cells operate in a particular range of temperature the efficiency of the battery is seen to be way better. Even a difference of 3°C–5°C temperature in between two cells in parallel can lead to cell current variations of 25% to 40%, increasing cell imbalance and reducing battery cycle life [10]-[26].

Peltier cooler is an active device that creates a temperature difference by transferring heat from one side of the device to the other side, when powered by an electric source, depending on the polarity. The main application for a thermoelectric device such as Peltier is cooling but it can be used either for heating or for cooling. It can be used to control temperature that either cools or heats.

The size of a Peltier is small and compact, and it is a rigid device which makes it suitable for space application in CubeSats or nanosatellites, where volume and mass is a concern.

The thermoelectric (TE) effect encompasses three individual effects: Thomson effect, See beck effect, and Peltier effect. This imposes the transformation of electric energy to heat and vice versa [6]-[7]. The applications of TECs include (a)electricity generation from hot sources (b) heating and cooling effect. These systems have no mechanical parts or moving parts thus there is very less wear and tear and hence have good durability [6]-[7].

2. MODEL STRUCTURE

2.1 Heat Transfer in Peltier-effect

The combination of several junctions of two different semiconductors connected in series is known as the Thermoelectric (TE) module. The two semiconductors are of n and p type semiconductors material as shown in figure 1. These two dissimilar conductors lead to Peltier effect at the junction. When we pass the electricity through junctions of n and p semiconductors material, the heat pumps up and flows from one side to the other [24]. As shown in figure 1, QH denotes the heat released from the heat node and QL denotes the heat absorbed by the cold node. In a Peltier device, voltage is created when there is a difference in temperature on these two opposite plates. Conversely, there is a difference in temperature on each plate, when the voltage is applied. The beautiful part of the Peltier module is that it can flip the temperature characteristics when the polarities get reversed. [25] In simple words suppose Terminal A is used for heating the battery packet/ cell then the same terminal can be used to cool the surface of the particular battery packet/cell by reversing the polarity of voltage.

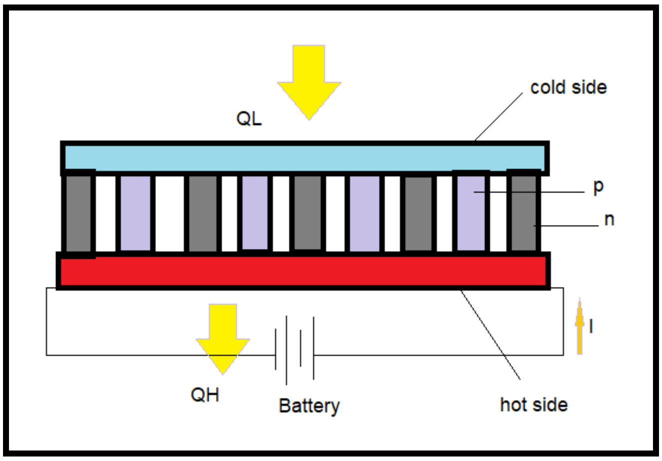

Fig-1: Transfer of Heat due to thermoelectric effect/Peltier Effect

The main characteristics of the Peltier chips is to release thermal energy at the one end and to absorb it to the other end [3]. Let us assume that the count of charge electrons at terminal A is greater than the count of charged electrons at terminal B. And the flow of the current is from A to B. We can notice that the temperature at terminal B is greater than the temperature at terminal A.

Let us make an assumption that temperature at the heat junction is T_{heat}. and the released heat outside is Q_{heat}. Similarly, the temperature at the cold junction is T_{cold}. And Q_L is the heat consumed from outside. Consider the current loop as I and the input power of the thermocouple is U. If all possible losses are neglected, from the first law of thermodynamics we can get:

$$Q_{heat}=Q_L+U \quad -(1)$$

Perle absorption heat:

$$Qc = pI \quad -(2)$$

The coefficient of Peltier here is p, which can be verified by the product of coefficient of beta(a) and the temperature at cold junction (T_{cold}).

$$p = aT_{cold} \quad -(3)$$

Joule heat:

$$Q_j = I^2R \quad -(4)$$

where R represents the resistance of the thermoelectric element.

R can be found if the length and resistivity is given as **L**, ρ1 and ρ2 respectively. and S1 and S2 are taken as cross section areas, then:

$$R = L(\rho1/S1+\rho2/S2) \; -(5)$$

In a semiconductor, conduction of heat occurs which leads to heat flow from the hot end to the cold end in a certain amount.

$$Q_k = k(T_{heat} - T_{cold}) \quad -(6)$$

where k represents the heat conduction of a thermoelectric component with a L as a length.

$$k = 1/L*(\lambda1*s1 + \lambda2*s2) \quad -(7)$$

Where λ1 and λ2 represent thermal conductivity coefficients of the two electric couple arms.

Lastly, to obtain the total heat absorbed by the cold junction from the outer environment.

$$Q_L= Qc - 0.5Qj - Qk \quad -(8)$$

$$Q_L = [\alpha*I*T_{cold} - 0.5*I^2*R - k*(T_{heat} - T_{cold})] \quad -(9)$$

Quantity of heat production:

$$Q1 = \alpha*IT_{heat} + 0.5I2*R - k*(T_{heat} - T_{cold}). \quad -(10)$$

To ensure the Peltier device functions smoothly the voltage applied equals pressure drop plus see beck voltage. The power P_o is

$$P_o = I*(\alpha*\Delta T + I*R) \quad -(11)$$

Coefficient of refrigeration:

$$ECOP = Q0/P_o \quad -(12)$$

Coefficient of merit

$$Z = \alpha^2 r/\lambda \quad -(13)$$

Here, r represents the electrical conductivity of the thermoelectric materials.

$$r = 1/\rho \quad -(14)$$

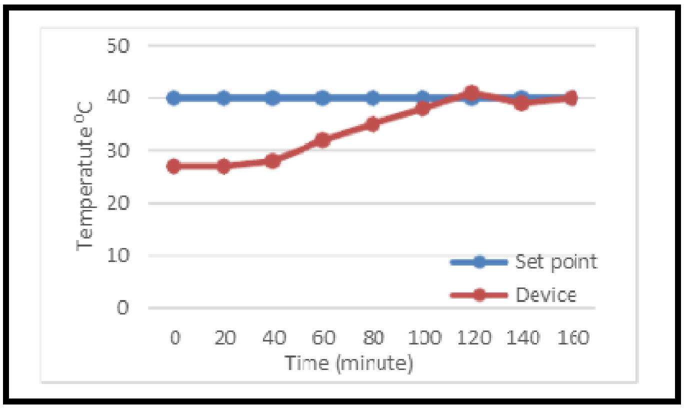

Fig-2(a): Heating process [25]

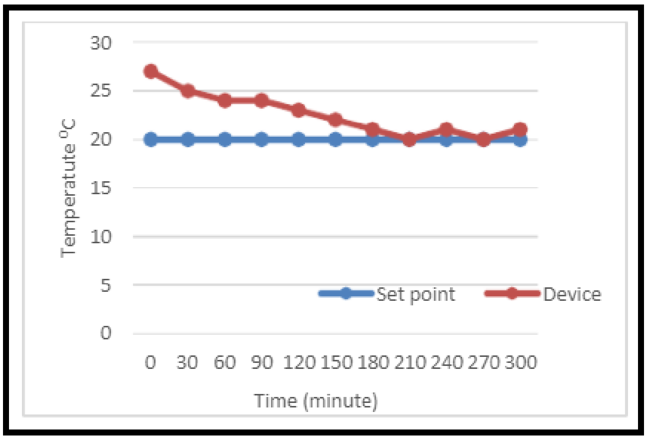

Fig-2(b): *Cooling Process [25]*

Figure 2 shows the graph of the Peltier module to attain the temperature set point at a certain time period. Time to attain these set points depends upon the different material used to make a temperature difference.

We all know that the Peltier is used to maintain the temperature of any material. So here, according to figure 2(a) we suppose that the set point is set as 40 °C. Then Peltier is being used to attain this set point temperature by heating one plate and to help maintain such temperature point.[10]

Similarly, figure 2(b) shows up the graph where temperature is to attain the set point by cooling process.

Here, suppose material has to maintain the temperature of 20 °C and it has the temperature of 26-27 ° C. Then Peltier is charged up to attain the temperature which is set by cooling down the plate.

2.2 Lithium-ion characteristics

When Lithium-ion batteries are exposed to extreme heat or high voltage they suffer from stress. Higher voltage limit and temperature limits would be 4.1 and 30°C respectively. The battery can't be used for a longer time at higher temperature as it may cross safe range of usage. Table1 below shows Capacity Loss vs Temperature.

Table -1: Approximate recoverable capacity after one year at various temperatures.

Temperature	Full charge
0°C	94%
25°C	80%
40°C	65%
60°C	60% (3 months)

These batteries have limited range of life and the loss of capacity in Lithium batteries is irreversible. Typically cells last up to 300-500 cycles, but if we use the battery in the SoC range of 20%-85% and maintain it in the temperature range, we can significantly improve the cycle life of the battery. From the above table we clearly conclude that the Lithium-ion cells operate with good recoverable capacity in the temperature range of 0°C-25°C.

3. EXAMPLE MODEL

Now when we have to use such setup let's check the possibility/ways to implement, Peltier coolers generate hot and cold temperatures from -40°C - 200°C, but there are constraints while using the device for a longer time that the heating side reduces the efficiency of the cooling side. So, for that very reason the efficiency of this device is reduced and cooling temperatures are reduced, but still it can be used up to a range of -10°C to -15°C with proper thermal management.[1]

Now another challenge is to trigger this device only when the battery pack system is overheated or getting too cold. A simple temperature sensor RTD can be used with the battery pack system to trigger the Peltier device whenever the temperatures are out of range (say in our case 0°C-25°C.). Hence, switching the polarity of the Peltier device based on the requirement either for Cooling or heating can generate respective thermal effects.

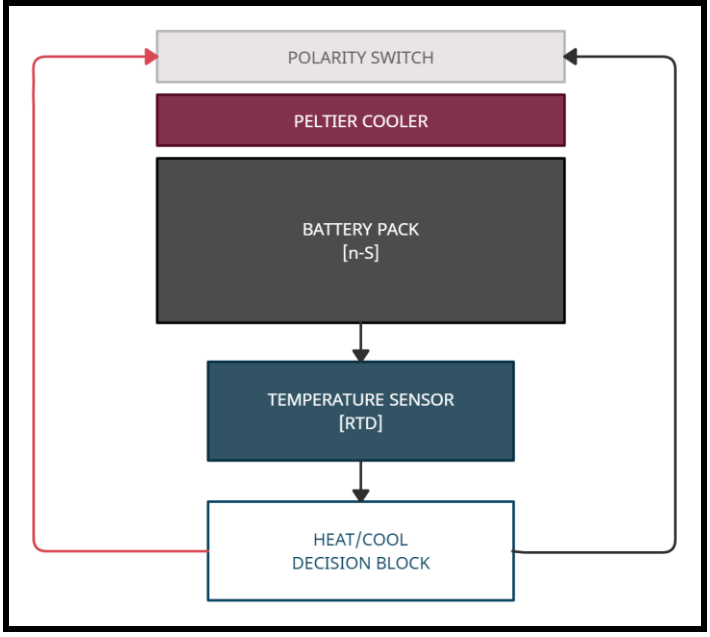

Fig-3: Flow diagram of the system

Figure 3 shows the flow of the system, the system can be monitored continuously and be controlled with such modelling. Figure 4 refers to the scenario where the battery pack is cool and the Peltier heats the system in order to increase the temperature. Whereas in figure 5 the battery pack is hot and the Peltier cools the system in order to decrease the temperature.

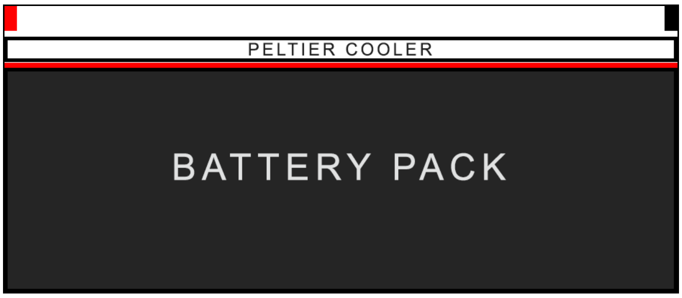

Fig-4: Peltier getting heated.

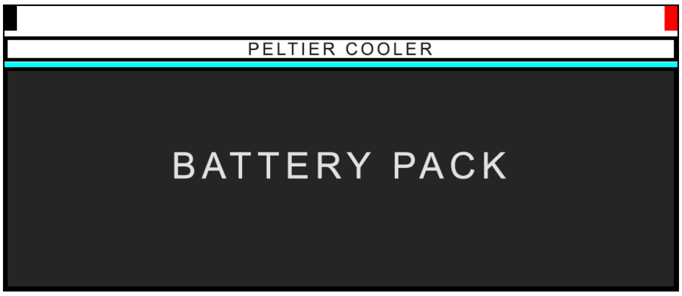

Fig-5: Peltier getting cooled on polarity reversal.

The polarity switch in Peltier devices can easily be implemented with the help of a MOSFET circuit or similar switching mechanism devices that triggers based on the sensing of RTD'S and switches to required condition.

There is one problem with using this system in such an arrangement that Peltier consumes more power and we need to ensure that we meet the power requirements of it else it's difficult for implementation. For that very reason it's quite useful in space applications as we can't use fan-based systems there. Also, the availability of energy in space is totally dependent on solar energy and if we can effectively provide energy to such a system by calculating the energy required in normal and eclipse situations then we can effectively use it. For example, in eclipse mode the system would be cooler thus we need to heat it versus in other situations where we have to cool it. Another noticeable challenge here is placing the battery pack in a conductive environment so that the conduction is carried out easily, for this we can fill thermal paste in the gaps of the battery pack cells and conduct it using a good thermal conducting metal. This leaves another topic of study for the project.

4. CONCLUSIONS

As this paper demonstrates, the use of thermoelectric cooler (TEC) Peltier to control and regulate the temperature in the given range for an efficient battery system. The health of a battery and its performance is affected by the change in temperature as discussed. Peltier is the right choice of thermoelectric cooler for small and compact battery systems and electronics in space applications such as CubeSats and nanosatellites.

The battery shows a recoverable capacity of 94% when kept at a constant temperature of 0℃ after a year and that of 60% when kept at a temperature of 60℃ for just 3 months. This shows the importance of thermal management for a battery to perform efficiently and prolong the life of a battery. But, it's an expensive trade for power consumption to run the Peltier to maintain 0℃ than to increase the capacity of a battery. It's suggested that the battery and the electronics be maintained at a temperature range of 0℃ - 25℃, which gives the recoverable battery capacity between 94% to 80% after a year.

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