Temperature Management of Li-ion Battery Pack for Stop & Start System *

Takao SUENAGA   Takahiro JO

The automotive industry is placing high importance on technologies that can reduce CO_2, even in a highly fuel-efficient compact car. One major technology is Stop & Start (S&S) System, with a combined energy regeneration system. A key component of the system is a power supply storage device that has high-charge acceptance, light weight, and compact size. We believe a Lithium-ion (Li-ion) battery completely meets these requirements. For the battery, there are three key points: 1. Battery cell specification, 2. State Of Charge (SOC) detection method, 3. Temperature management for Li-ion battery.

We are going to introduce "Temperature Management" this time. If the temperature of a Li-ion battery operates over 60 degrees Celsius, the battery could be severely damaged. Therefore, temperature management of the battery is very important. Conventionally, the temperature is managed by several thermistors and a cooling fan. However, this method is difficult to install in a compact car where cost and space are limited. We have developed our battery pack with the flexibility that allows it to be put in a compact car. The pack has two features:

1. One thermistor measures the temperature of one of the cells, and then the temperature of all the cells is calculated using a secondary temperature off of the control board.

2. The temperature of the battery is controlled by natural cooling.

We succeeded to install this system in a compact car through our new temperature management.

Key words :

Battery Pack, Lithium-ion, Temprature management, Stop & Start

1. INTRODUCTION

Fig. 1 shows an anticipated increase of CO_2 emissions. This red line shows the present energy consumption. In 2030, CO_2 emissions will become 1.4 times the present rate and the average temperature of the Earth will increase 6 deg C. Therefore, the "CO_2 concentration scenario of 450 ppm in the atmosphere" is proposed.

Fig. 2 is an example of vehicle's powertrain energy flow analysis. The technology of CO_2 reduction is classified into three points: "Load reduction", "Energy regeneration", and "Engine efficiency". Stop & Start (S&S) System with combined energy regeneration is an effective technology to reduce CO_2 emissions.

A Stop & Start (S&S) system which stops the engine while waiting at stoplights is an effective way to reduce fuel consumption. We propose improving S&S system. First technology is an engine stop during deceleration. Conventional S&S system stops the engine after the vehicle stops. Our system stops during deceleration to cut down fuel consumption.

Second technology is increasing regeneration. While

braking, conventional vehicles waste kinetic energy as thermal energy. Regeneration is converting to electric energy for battery charging. We consider adopting a Li battery of high charge acceptance to utilize more regeneration energy.

Large current regeneration triggers an increasing temperature of Li battery. The temperature of a Li-ion battery must be managed appropriately. This paper reports on the temperature management of Li-ion battery.
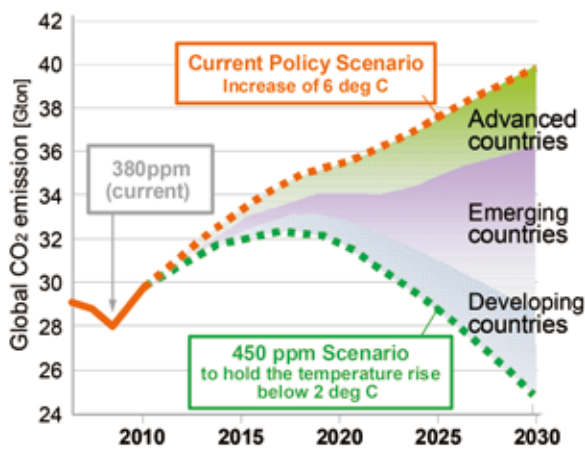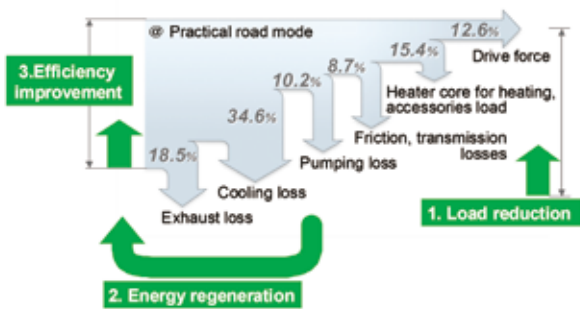

Fig. 1　World Energy Outlook 2010, IEA[1]

Fig. 2　Powertrain Energy Flow

2. TEMPERATURE CHARACTERISTIC OF LI-ION BATTERY

The battery produces heat by large current regeneration when a car slows down. As the temperature of the battery increases, the battery performance decreases and also the size of the battery increases. The battery produces elution of manganese and the resolution of the electrolyte when they exceed approximately 60 degrees Celsius, and performance degradation and gasification accelerates. Therefore, temperature management of a battery is important for safe use.

3. TEMPERATURE MANAGEMENT

We examined the means of temperature management; those three ways are shown in **Fig. 3**. First, forced air cooling means cool the battery cell with a cooling fan. However, the user feels unpleasantness from the noise by the fan. Because the battery pack is placed under the passenger seat. Second, Gable Vent means to knock a gable vent in the outer package and increase size to promote heat dissipation by convection. Unfortunately this solution does not prevent water intrusion. Third, current control and natural cooling means will radiate the battery temperature through an outer package, and regulate the heat generation of the battery by regulating regenerative current when temperature of the battery increases. This method does not have limitations because of position. Vehicle chassis have high radiation performance, and need accurate temperature monitoring for regulate regenerative current. We set a target that an error of the temperature monitoring is less than 5 degrees Celsius and avoids rise temperature in 15 degrees when driving by JC08 (Japanese Emission test cycle) for providing regenerative performance and safety.

Fig. 3　Temperature Measurement

空調・熱マネ

156

3.1 In Conventional Temperature Measurement

Fig. 4 shows a temperature measurement method of Li-ion battery pack of Hybrid vehicle (HV). Battery cells are arranged in one direction and the temperature is typically measured in three positions: the center cell, and at both ends. The center cell of Li-ion battery has the highest temperature, and cells at both ends have the lowest temperature. The maximum temperature and the minimum temperature can easily measure by using several thermistors. However, this method has a problem when it is adapted to a S&S system. There is little flexibility for the shape of the battery pack because the direction of the batteries must be the same. There is a cost issue of using several thermistors, but it is difficult to install it in a compact car where cost and space are limited. Our thought is to make the battery pack smaller to adopt into the compact car.
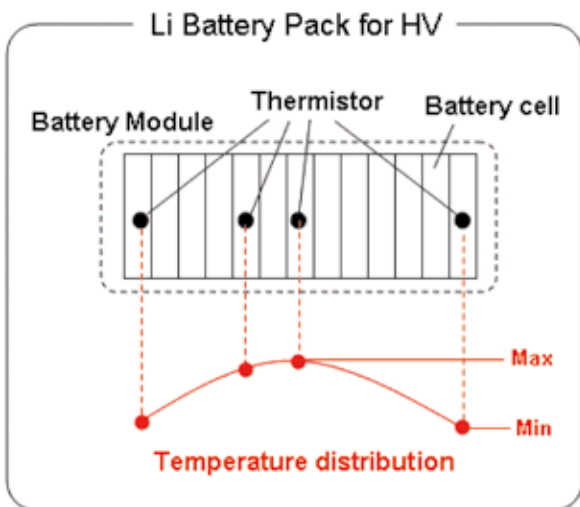

Fig. 4   Temperature measurement of HV battery pack

3.2 Developed Temperature Measurement

Fig. 5 shows a structure of the battery module. Battery cells are transverse-mounted and a thermistor for measuring battery temperature is above the battery module and the control board for compact and lower cost. Our idea is to estimate the temperature of all cells by minimum number of thermistor. Three of following are necessary to realize this:

1. Simple thermal radiation course
2. Location and number of thermistor appropriately
3. Calculate heat increase of cells

About thermal radiation course, radiate heat of battery to control board through a bus-bar. Thermistor is mounted onto cell 5 that nearest + side of battery module and onto control board. Two thermistors are on the thermal radiation course and estimate cells temperature by thermal gradient between two temperatures of thermistors.
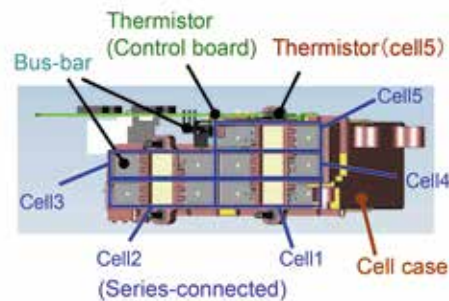

Fig. 5   Battery Module

Fig. 6 shows the thermal network of the battery module. We estimate the temperature of battery with it, but it has a problem. It is hard to understand the heat transfer between cells. (R5-R9). We thought to reduce it by increasing thermal resistance between cells.

We designed materials and shapes of battery cell case for increase thermal resistance between cells. Battery cell case is required electrical insulation, holding force for cells and strength. We selected a material of cell case Polypropylene (PP), structure which cells is covered with resin case (Fig. 7).

We examined heat transfer whether ignorable or not. We compared temperature increase of cells when heat generation of cells is equal or one of cells heat generation is higher than other. Fig. 8 is the result. The battery which heat generation is high in has higher temperature 7 to 8 degrees than the other batteries. But, as for other cells, a temperature increase is low with less

than 0.4 degrees. Therefore, it was examined that the heat transfer between the cells can be ignored.
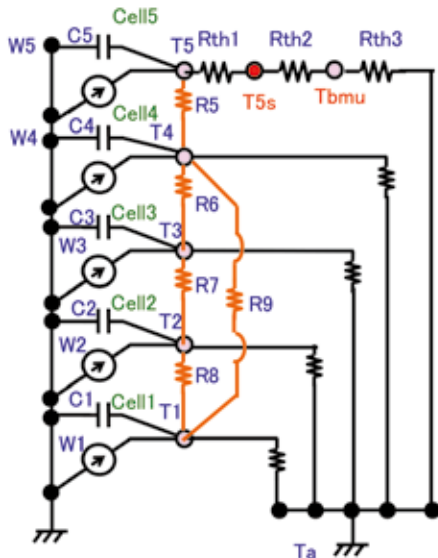

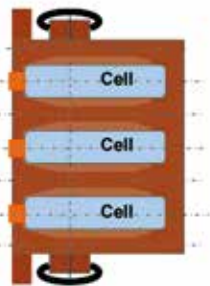Fig. 6   Thermal Network of Battery Module

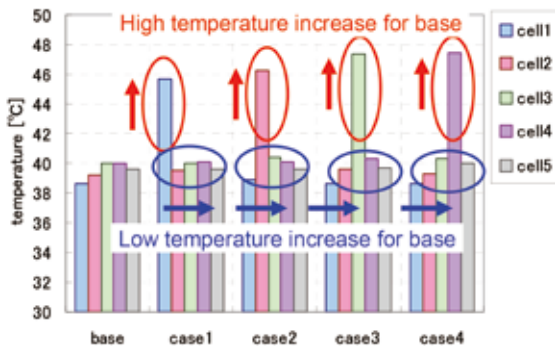Fig. 7   Structure of Battery Cell Case

Fig. 8   Temperature of cells by heat generation of cells

Base: all the heat value of the battery cells is same
Case1: the heat value of cell1 is higher than other cells
Case2: the heat value of cell2 is higher than other cells
Case3: the heat value of cell3 is higher than other cells
Case4: the heat value of cell4 is higher than other cells

Fig. 9 shows simplified thermal network. Fig. 10 is thermal network that points to cell 5.

T5, W5 and Ta are calculated by T5s and Tbmu. Temperatures of cell 1 to cell 4 are calculated by specific internal resistance and W5.

$$T5 = Rth1/Rth2 \times (T5s - Tbmu) + T5s \qquad (1)$$

$$W5 = 1/Rth2 \times (T5s - Tbmu) \qquad (2)$$

$$Ta = -Rth3/Rth2 \times (T5s - Tbmu) + Tbmu \qquad (3)$$

$$Wn = K[n] \times W5 \qquad (4)$$

$$Tn = Wn \times R[n] + Ta \qquad (5)$$

$K[n]$: specific internal resistance of cell[n] versus cell5

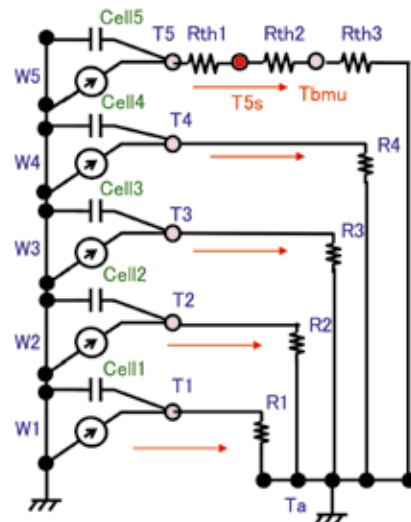$R[n]$: thermal resistance between cell[n] and ambient temperature

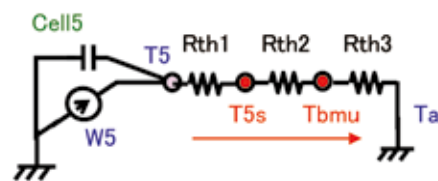Fig. 9   Simplified Thermal Network of Battery Module

Fig. 10   Thermal Network of Battery Cell 5

Fig. 11 is the waveform of cell during regeneration. One Can calculate specific internal resistance by voltage waveform of the cell.

$$Re[n] = (Ve[n] - Vs[n]) / (Ie[n] - Is[n]) \qquad (6)$$

$$K[n] = R[n]/R[5] = (Ve[n] - Vs[n]) / (Ve[5] - Vs[5]) \qquad (7)$$

Therefore, specific internal resistance is calculated by voltage of cells, before charge and after charge.

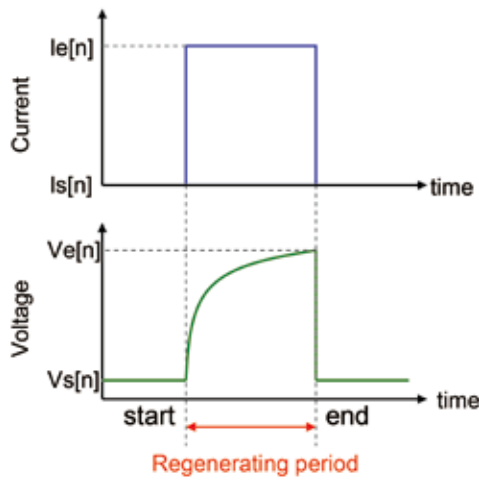

Fig. 11   Voltage and Current at Regeneration

3.3 Logic Construction

Fig. 12 shows control block diagram for temperature estimate. The temperature of all cells can be calculated by temperature of thermistor, temperature of control board and voltage of cells. Therefore, we can calculate maximum temperature of cells.
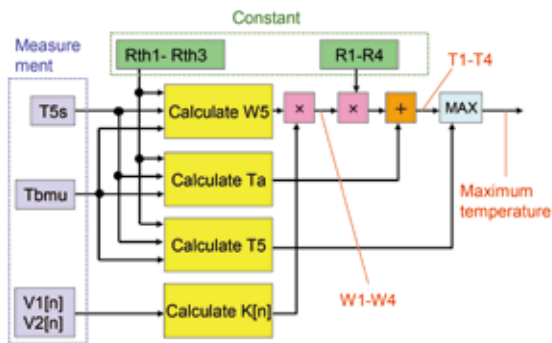

Fig. 12   Temperature Estimate Logic

3.4 Radiation of battery pack

It is necessary for battery radiation, while keep route of radiation. But, there is not the heat transfer between the cells. We thought that radiation the battery cell for outer package through a bus bar which connects cells. Formula (8) shows relations of battery temperature increase and thermal conductivity of battery pack. We decide Q so that dT meets the target less than 15

degrees Celsius when driving by JC08.

$$Q = k \times Fa \times dT \tag{8}$$

> Q: radiation amount of battery pack
> k: thermal conductivity
> Fa: volume of battery module
> dT: temperature increase of battery

Fig. 13 shows Thermal analysis of battery module when driving by JC08. This model shows a bus bar is needed to remove the heat trapped inside the battery pack insulation case.
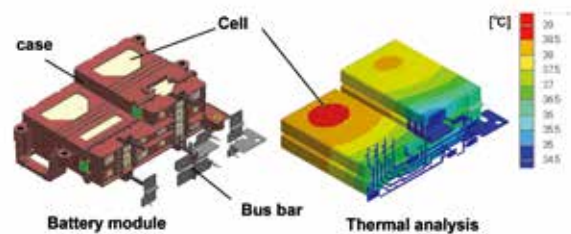

Fig. 13   Thermal simulation of battery module

3.5 Evaluation Result

Fig. 14 shows the evaluation result. This graph expresses battery cell 4 temperature (maximum temperature) at the time of driving by JC08 repetition. The horizontal axis of this graph indicates time, and the vertical axis indicates temperature. The red line shows real value. The blue line is thermistor output. If battery temperature is measured by thermistor without the temperature estimate logic, we have about 10 degrees Celsius of maximum error for real value. The green line is the temperature estimate logic output. The temperature estimate logic is effective managing error. The error value is less than 5 degree Celsius.

Fig. 15 shows the battery cell temperature at the time of driving by JC08. The horizontal axis of this graph indicates time, and the vertical axis indicates temperature. Ambient temperature is 25 degree C, and maximum cell temperature is 34 degree C. Therefore, temperature increase of the battery is less than 15 degree Celsius.
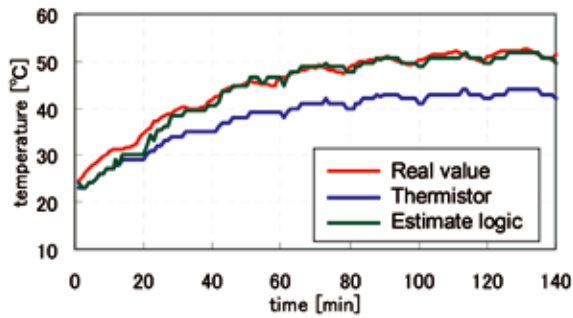
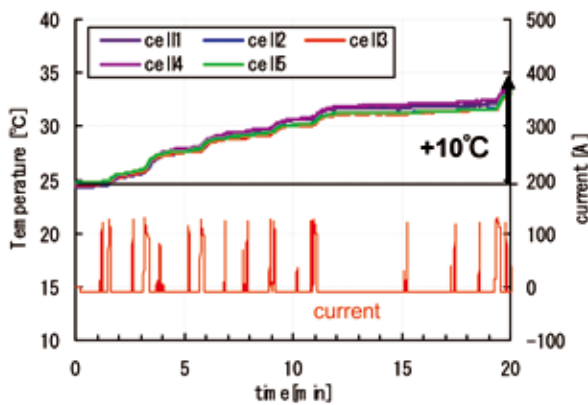Fig. 14　Maximum Temperature of Cell by Driving JC08

Fig. 15　Temperature of Cell by Driving JC08

4. CONCLUSION

We developed battery temperature estimation logic that estimates all cell's temperature by using only two thermistors, on the battery module and control board.

Additionally, It is equal to the decrease of some cells because this logic can calculate specific internal resistance of cells.

We succeeded to install this system in a compact car through our new temperature management. We developed the Lithium-ion battery pack with a small size and good mounting characteristics by using temperature estimating logic and structure of the battery pack.

REFERENCES

1) International Energy Agency
   http://www.iea.org/
2) Lithium-Ion Battery Pack for Stop and Start System
   #.2013-01-1538
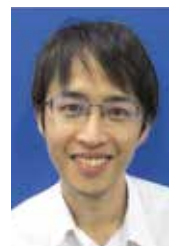   Published:2013-04-08
   2013 SAE International

著者

末永 貴郎
すえなが たかお

エレフィ機器技術２部　第４技術室
12V リチウムイオン電池パックの開発に
従事

城 貴洋
じょう たかひろ

エレフィ機器技術２部　第４技術室
12V リチウムイオン電池パックの開発に
従事