Thermal Modelling of an Automotive Nickel Metall Hydrid Battery in Modelica using Dymola

Helmut Oberguggenberger   Dragan Simic
Arsenal Research
Giefinggasse 2, 1210 Vienna, Austria

Abstract

This paper deals with the thermal modelling of an automotive nickel metall hydrid battery. The thermal modelling will be done in two different approaches. The result of the distinct approaches will be the same, though.
The thermal models are implemented in *Modelica* simulation language and simulated using the *Dymola* simulation environment, [1].
Thermal and electrical measurements have been carried out to validate the simulation results of the thermal modelling and will be presented in this paper.

Keywords: simulation, modelling, nickel metall hydrid battery, validation

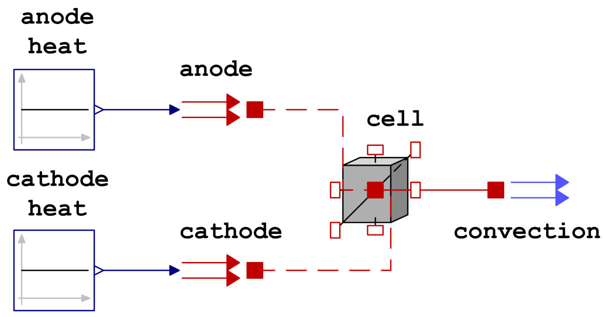

Figure 1: Thermal model of the cubical-shaped cell in *Modelica*

1 Simple thermal cell models

The first approach is the thermal modelling of a nickel metall hydrid battery package taking into account the geometry and temperature distribution during the operation of a single cell.
In this paper a thermal model of a cubical-shaped package of a battery will be modelled, simulated and evaluated. The thermal battery model comprises algebraic and ordinary differential equations. All components of the thermal battery model are taken from the *ModelicaStandardLibrary*, such as *Modelica.Thermal.HeatTransfer*.
The thermal model of the battery is modelled by means of discrete volume elements. In this model the coefficients of heat transfer for each discrete volume are calculated. The cell model, `cell` in figure 1, represents the thermal model with all inner thermal behaviors. The heat flow inside the cell in all three directions was implemented. The model was parametrized using geometrical and thermal measured data of the cell, such as length, width, thermal conductivity, density of the material etc. The heat losses of the anode and the cathode of the cell are implemented in the external models (`anode` and `cathode` in figure 1). The natural convection in this model is included. Each discrete volume, which is located on the surface of the modeled cell, contains heat transfer with the surrounding air. This heat transfer is identified as `convection`, figure 1.
Figure 2 shows the temperature distribution of a cubical-shaped cell in all three directions, `x-length`, `y-length` and `z-length`. The model considered 500 discrete volumes. Due to the origin of the losses in the area of anode and cathode the temperatures are higher in these discrete volumes.
The thermal model of the cell presented in this case simulates the thermal behavior of a cubical-shaped cell until the cell temperature reaches its stationary final value.
For the investigation of the thermal behaviour of the battery package which includes cylindrical cells, at first a detailed thermal model of one cell is implemented. This base model includes the same equations

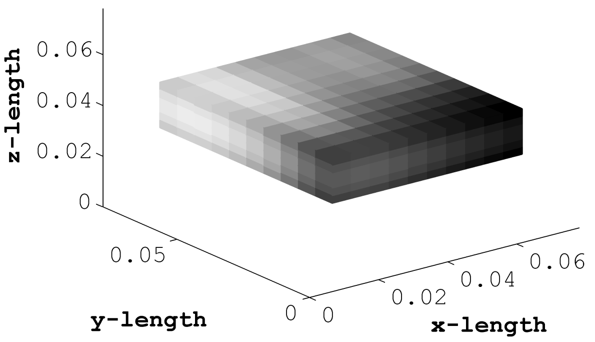

Figure 2: Simulation, temperature distribution in the cubical-shaped cell

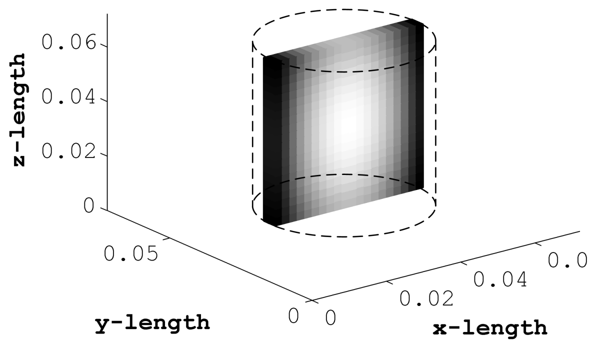

Figure 3: Simulation, temperature distribution in the cylindrical cell

and models as the cubical-shaped cell model. The anode and cathode of the cylindrical cell model are used in this case as spiral plates.

The heat losses distribution of the anode and cathode in this cell is implemented homogeneously. The heat flow in x and y direction, cross directions, has the same size and conductivity coeffcients . Therefore the model of the cell is reduced from a $3D$ to a $2D$ problem.

This reduced model of the cylindrical cell is used in this paper for implementation of a battery package which contains more alike cells. Figure 3 shows the temperature distribution of a cylindrical cell in all three directions, `x-length`, `y-length` and `z-length`. The model considered 400 discrete volumes. The discrete volumes in the centre area have a higher temperature due to the improved losses heat from anode and cathode, because the heat losses of each volume of this cell has the same size. As depicted in figure 3, the heat flow from the center in y direction is much higher than in z direction. That ocours, because the heat conduction coefficients in x and y direction are much higher than that in the z direction.

2 Thermal model of a nickel metall hydrid battery package

The simple thermal cell model was used for the implementation and validation of the nickel metal hydrid battery package. This package contains 153 cells, which were integrated in a steel housing. The cells have a cylindrical shape in this case. The housing box has the following geometrical sizes, length $468mm$, width $108mm$ and height $65mm$.

Each component of the battery package such as cells and housing needs a set of thermal and geometrical parameters which have to be determined prior to the simulation. They are used of base from cell and housing material specifications, according to [2], [3], [4] and [5]. For the parameterisation of the final simulation model the parameters have been adjusted and corrected through measurements results.

The natural convection coefficient in this model is $4.5W/m^2 \cdot K$ and the ambient temperature $20°C$. The size of this coefficent is used from quiet ambient air, according to [2]. The thermal conductivity coefficients of the battery package box housing in length, width and height direction are $254W/m \cdot K$, according to [3]. The thermal conductivity coefficients of the used cylindrical cells in cross direction are $40W/m \cdot K$ and in length direction $4W/m \cdot K$, according to [4].

The thermal losses of the entire battery package are determined through measured minimum and maximum temperatures of the entire battery surface. The battery package model was simulated until the simulated minimum and maximum temperatures were the same size as the measured temperatures. Then the heat loss of the entire battery package was determined to be $105.57W$. The heat losses of a cell determined using simulation is $0.69W$. The maximum simulated temperature of the battery package is $56°C$.

The first model of the battery package was simulated using more than 2800 discrete volumes. The problem of this discretization of the battery package was that each volume has more than 50 equations. The entire battery model has therefore more than 140000 equations and, hence, the simulation of this model was impossible. The size of the model was reduced remov-

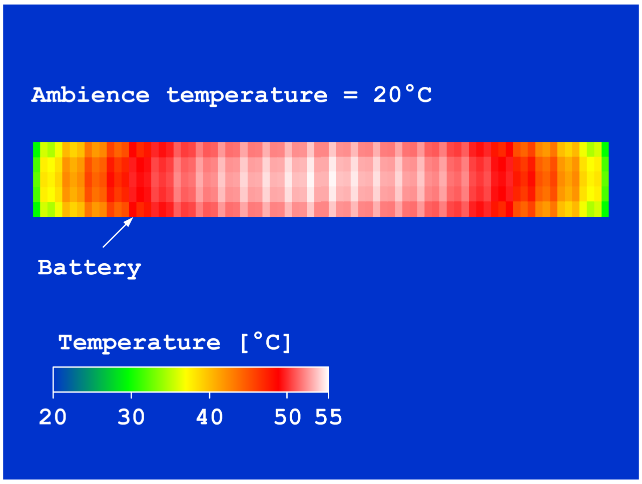

Figure 4: Simulation, temperature distribution in the battery package

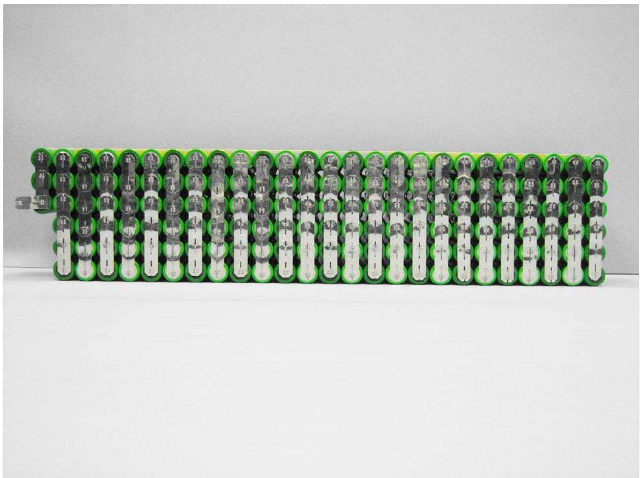

Figure 5: Assembly of the nickel metal hydrid battery package

ing surfaces where the heat flow rate was zero. With this optimization of the battery model the final model has less than 700 discrete volumes and therefore about 35000 equations.
Afterwards, simulation results were compared with measurement results of the real battery package. Figure 4 shows the temperature distribution of this simulated nickel metall hydrid battery package.

3 Test setup and testing of the nickel metal hydrid battery package

Thermal and electrical measurements have been carried out to validate the simulation results of both approaches of the thermal modelling. The nickel metal hydrid battery package consists of 153 single cells.

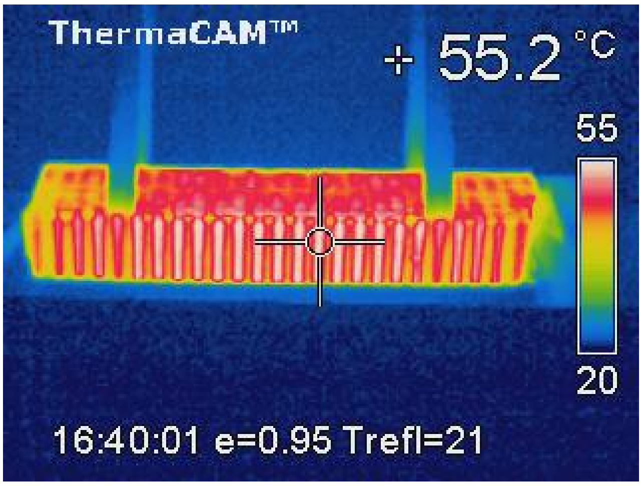

Figure 6: Thermographic picture of the nickel metal hydrid battery package

The cells are electrically connected in such a manner that the requirements for the given automotive application are fulfilled. In Figure 5 one can see the electrical and mechanical assembly of the nickel metal hydrid battery package.

The electrical internal resistance of a single cell depends on the state of charge of the cell, and the temperature of the cell.

The current profile for charging and discharging the the nickel metal hydrid battery package is a symmetrical current profile. Therefore the average state of charge of the cells stays constant. In this case the electrical internal resistance only depends on the cell temperature.

Several temperature sensors are applied in the battery package to control the temperature. The maximum temperature of a single cell must not exceed $60°C$. The nickel metall hydrid battery is charged and discharged until the exponential temperature course reaches its stationary final value. The amplitude of the charge and discharge current is $9.66A$. With this current profile the mean temperature of the battery package after reaching the stationary final value is $55°C$.

During the heating-up of the battery pack a thermocamera takes pictures of the pack to get the temperature distribution within the pack. Figure 6 shows a picture of the temperature distribution of the nickel metal hydrid battery package shortly before the mean temperature within the pack reaches its stationary final value of $55°C$.

4 Electrical and thermal modelling of the nickel metal hydrid battery package

The stationary final temperature value of the battery modelled with this second approach will be the same as the stationary final temperature value simulated with the first model approach descriped in chapter 2.
The second model approach takes into account thermal and electrical components. The nickel metal hydrid battery package is modelled in *Dymola/Modelica* as a lump thermal mass with an internal heat source.
The heat supply is caused by the ohmic loss of the internal resistance of the nickel metal hydrid battery package, the temperature distribution is assumed to be homogeneous.
The internal resistance model is temperature dependent, consequently the generated ohmic loss depends on the temperature. Heat will be taken away from the nickel metall hydrid battery package due to natural convection.
The solved heat equation for a lump thermal mass with an internal heat source and heat exchange to the ambience is

$$\vartheta = \vartheta_a + \frac{P}{\alpha \cdot A} \cdot \left(1 - e^{-B \cdot t}\right)$$

where
ϑ is the temperature of the nickel metal hydrid battery package,
ϑ_a is the ambient temperature,
α is the heattransfer coefficient,
A is the surface area of the package,
B is the heat up exponent and P is the heating power.
P is given as $P = R_i I^2$.
R_i is the temperature dependent internal resistance of the nickel metal hydrid battery package
and I is the terminal current of the battery package.
The temperature dependence of R_i is approximated with a cubical function as one can see in Figure 7.
The *Dymola/Modelica* model of the nickel metall hydrid battery pack is charged and discharged until the exponential temperature course reaches its stationary final value. The simulated temperature course is almost identical with the measured temperature course of the nickel metall hydrid battery pack.
Figure 8 depicts the simulated temperature course with a red line and the measured temperature course with a blue line.
The stationary final value of the battery pack is $56°C$ which is identical with the simulated results of the thermal model presented in chapter 2.

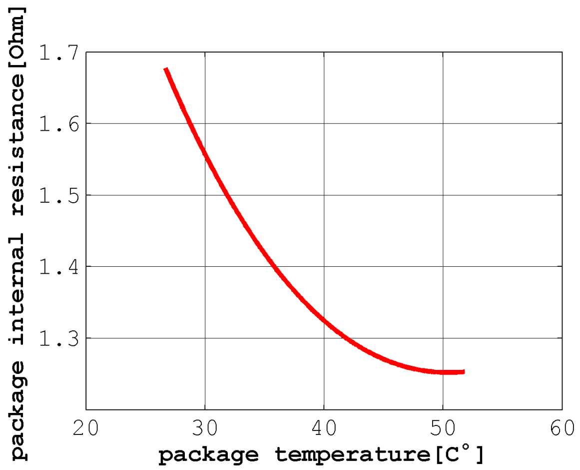

Figure 7: Temperature dependency of the internal package resistance, R_i

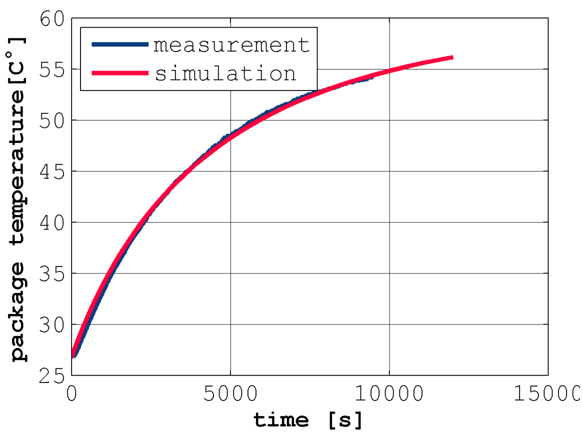

Figure 8: Simulated temperature course and measured temperature course of the nickel metall hydrid battery pack

5 Conclusions

In this contribution two thermal models of a nickel metall hydrid battery pack were presented. The results of the distinct approaches were the same, though.
The first model approach took into account the geometry and temperature distribution during the operation of the battery.
The second model approach took into account thermal and electrical components. Special emphasis was given to the temperature dependency of the electrical internal resistance of the battery pack.
Thermal and electrical measurements have been carried out to validate the simulation results of the thermal modelling and were presented.
The thermal models were implemented in *Modelica* simulation language and simulated using the *Dymola* simulation environment.

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