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Short communication

Investigations into a battery management for high power nickel metal hydride batteries

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Abstract

Bipolar nickel metal hydride batteries are of interest for intermediate power storage in hybrid electric vehicles. The special design allows to gain additional information on the state of charge (SOC). In order to keep a nickel metal hydride battery in a limited SOC range a battery management system is required. The influence of external conditions, like temperature, mode of operation and load profile to the quality of the operation of the quality of the battery management system are discussed.

Keywords: Alkaline battery; Nickel metal hydride; Hybrid battery; Battery management; Battery monitoring; Bipolar battery

1. Introduction

Nickel metal hydride batteries are considered to be a candidate for electric power storage in modern automotive hybrid conceptions. It has been shown that such batteries in a bipolar arrangement are able to provide high rate charging and discharge currents. As the negative electrode does not show any sufficient voltage raise at the end of charge the batteries must not be charged under constant voltage conditions. In addition the operation of such a battery in a hybrid electric vehicle requires methods for evaluating the state of charge (SOC). There are different approaches for determining the SOC of a battery in a hybrid vehicle. The implementation of a battery model into the battery management requires very detailed knowledge of the partial chemical processes occurring in the battery. In this paper we will present a different approach of controlling a battery for a hybrid vehicle application.

2. Bipolar NiMH stacks

Bipolar NiMH stacks have been under investigation for more than 10 years. They are based on the nickel fibre technology used at Hoppecke Batterie Systeme GmbH (HBS) for the production of alkaline industrial batteries (FNC®).

The electrochemical reactions are compiled in the following reaction scheme:

$$\underset{\text{negative electrode}}{} \mathrm{Me(H)} \underset{\text{charge}}{\overset{\text{disch.}}{\rightleftarrows}} \mathrm{Me} \quad \underset{}{\overset{\text{electrolyte}}{\overset{H^+}{\rightleftarrows}}} \quad \mathrm{NiO_2H} \underset{\text{charge}}{\overset{\text{disch.}}{\rightleftarrows}} \mathrm{NiO_2H_2} \quad (\text{positive electrode})$$

In addition to the electrochemical reactions an equilibrium state between the hydrogen dissolved in the storage alloy and in gaseous state is established.

$$\mathrm{Me(H)} \underset{\text{adsorbtion}}{\overset{\text{desorption}}{\rightleftarrows}} \mathrm{Me} + \tfrac{1}{2}\mathrm{H_2}$$

As the stack pressure is the same for all sub-cells of the bipolar stack (common vessel design, Fig. 1) the internal pressure can be used as a rough indicator of the state of charge (SOC). It has to be taken into account that the gas pressure is not strictly in an equilibrium state to the activity of hydrogen in the storage alloy. The deviations are caused by kinetic and transport hindrances. In addition the formation of oxygen at the end of charging and the over-dimensioning of the negative electrode limits the value of the information from pressure data for elucidating the SOC.

The properties of bipolar NiMH stacks have been described in earlier papers [1–4].

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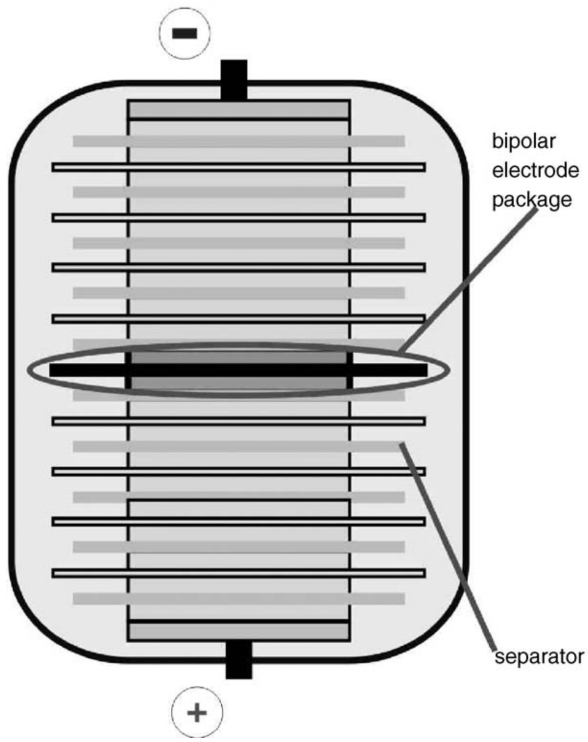

Fig. 1. Scheme of a bipolar battery in common vessel design.

3. Battery management conception

There are different approaches of determining the status of the battery in an electric vehicle or in a hybrid vehicle. Some of these designs are based on models of the electrochemical and physical processes in the battery. These physico-chemical models are based on the detailed knowledge of all processes in the battery. Such models are very helpful to design the batteries and to interpret their behaviour. Due to the complexity of the battery system the models are considerable large and require time for computing. As these processes are extremely complex there is a need to simplify the mathematical expressions of these models are in order to implement them directly as basis of the battery management. Further the accuracy becomes limited due to the variation of the actual battery parameters.

Another approach is the use of parametric models. These make use of experimentally obtained characteristics of typical batteries under simplified operation conditions. In order to gain information on the SOC the “master curves” have to be scaled-up and have to be compared to well-defined states. Under dynamic working conditions such a comparison becomes inaccurate. Long-term changes in the battery as well as variation between batteries require frequent re-calibration processes for the model.

In order to overcome these difficulties we have studied another approach for a battery management system. The dynamic battery control (DBC) approach is based on definitions of extreme conditions for the parameters of a working battery. The SOC is basically determined by integration of the current (raw data information). Due to the limited accuracy of measurements and long-term deviations such information cannot be expected to be correct for a longer period of time. Additional physical characteristics such as electric data (voltage, polarisation, etc.) and non-electric data (temperature of the battery and its surrounding as well as others like cell pressure) are measured. These measured data (like voltage, pressure and temperatures) and some pre-processed information (estimation of the internal battery resistance) are compared to boundary conditions. If a contradiction between the assumed SOC (from charge integration) and the physical observations becomes obvious the management system is reacting by adjusting the estimated SOC to the new conditions. The time constants and the technique of adjusting the SOC estimate is influencing the quality of the management system. In order to reduce the electronic requirements the battery management is communicating only the estimated SOC to the controlling device of the hybrid vehicle. Therefore additional information on the status of the battery has to be incorporated into that information. In opposite to conventional battery models the management system is based only on the knowledge of boundary conditions. This simplifies considerably the amount of information to be stored or computed in the course of evaluating the SOC. In this way the BMS-battery system is kept operational for long period of times without the need of resetting and delivers rather accurate SOC data. The mathematical functions of the BMS has to be set depending on the operation profile. This approach is of advantage for NiMH high power systems under dynamic load as the SOC of the battery cannot be directly computed from the battery voltage.

4. Experimental

Previously [4–6] it has been demonstrated that bipolar NiMH-battery systems can be operated under dynamic loads reaching a stable state of voltages and battery temperature. Therefore a balance of cooling and heat generation has to be established. In a first set of experiments the BMS is operating simply as a data logger unit (Fig. 2). The load profile is supplied from a battery testing machine (DIGATRON). The experiment is used to study the accuracy of current integration under dynamic conditions.

The result of the charge integration is compared to independent data measured independently and to the remaining charge after the experiment determined electrochemically.

In the second set of experiments the BMS estimates the SOC of the battery (Fig. 3). This estimation is based on both, the current integration as well as on the DBC-algorithm. The SOC is transferred as analogous information (0, . . ., 4 V) to the battery testing equipment DIGATRON via an auxiliary input channel (originally designed for single cell measurements). The software uses this information to modify the load profile in certain ways, e.g. for limiting the power output or continuing with the next profile step under certain conditions. The basic structure of the load profile is not changed by the modifications from the BMS information. The idea behind that is the assumption that in an application the power requirements is a result of the driving profile of the vehicle and the BMS can influence the energy flow from and to the battery only by limiting the electric currents.

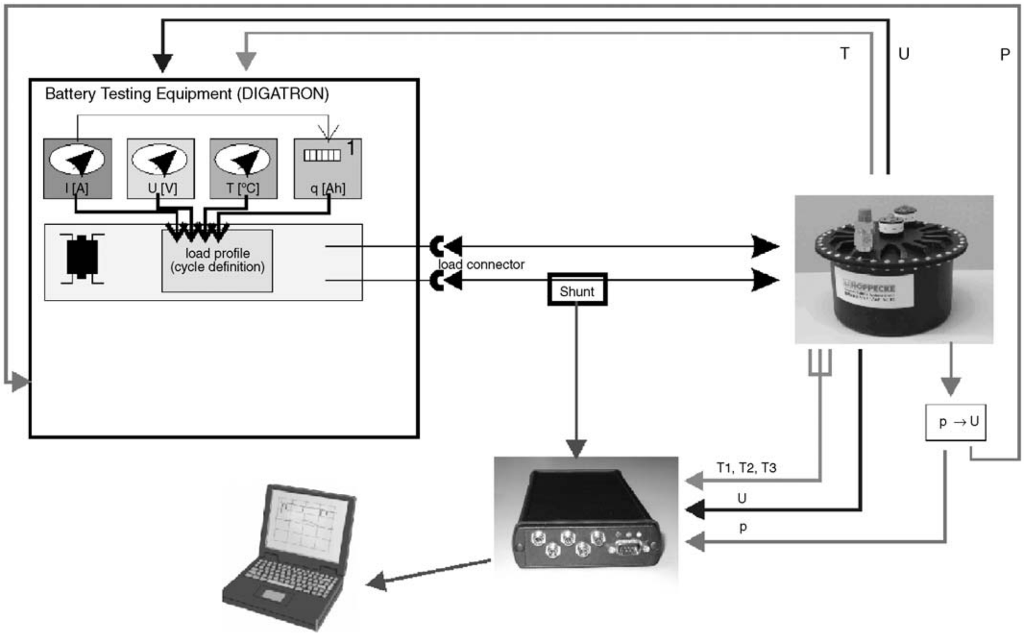

Fig. 2. Experimental set-up using the BMS as data-logging device only.

The current is integrated in the battery testing device and the BMS independently. These data are compared to the remaining capacity of the battery after the experiment had been finished.

For the various experiments different program sequences have been used. We assumed that almost any driving profile can be divided into a sequence of pulse steps as shown in Fig. 4. The difference between the cycle sequences "C" and "D" consist in the charge balance. These cycles differ in the total charge exchanged. The cycle E is composed of them and is neutral from the viewpoint of the total charge balance. In order to allow a long-term operation of a battery in a hybrid application the total charge balance must compensate self-discharge and other losses of energy. Thus we applied a special cycle in an experiment with additional temperature variation. This cycle was used to study the influence of daily temperature changes.

Additional cycling was performed according to a modified ECE 15 (simplified) testing profile.

5. Results

The results of the BMS operation are compiled in Table 1. The normal operation window of the bipolar Ni/MH stack was set to 30, . . ., 70% SOC.

The results of the last experiment are visualised in Fig. 5. It can be seen that the BMS is able to adjust the battery in the

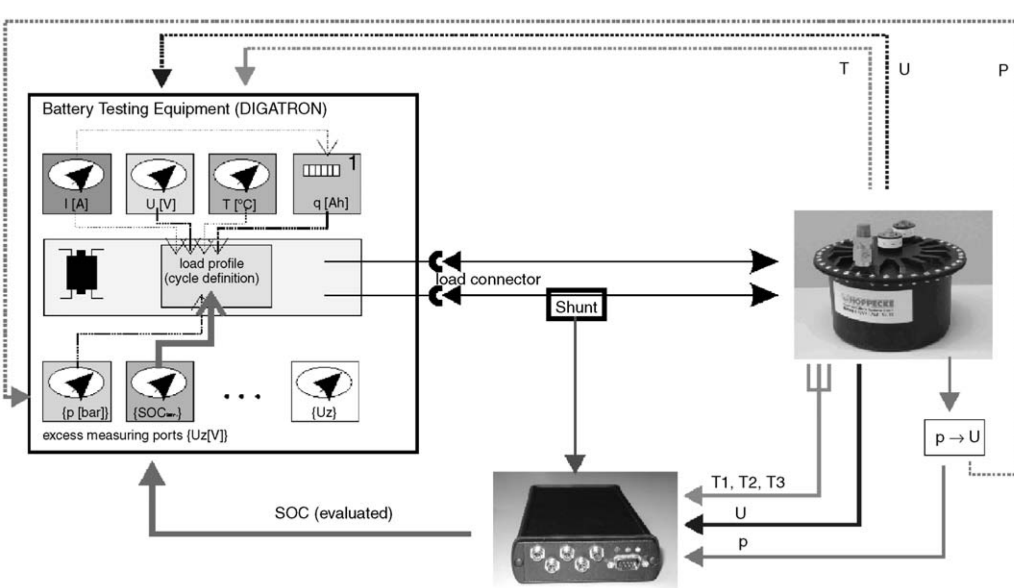

Fig. 3. Experimental set-up using the BMS as data-logging device only.

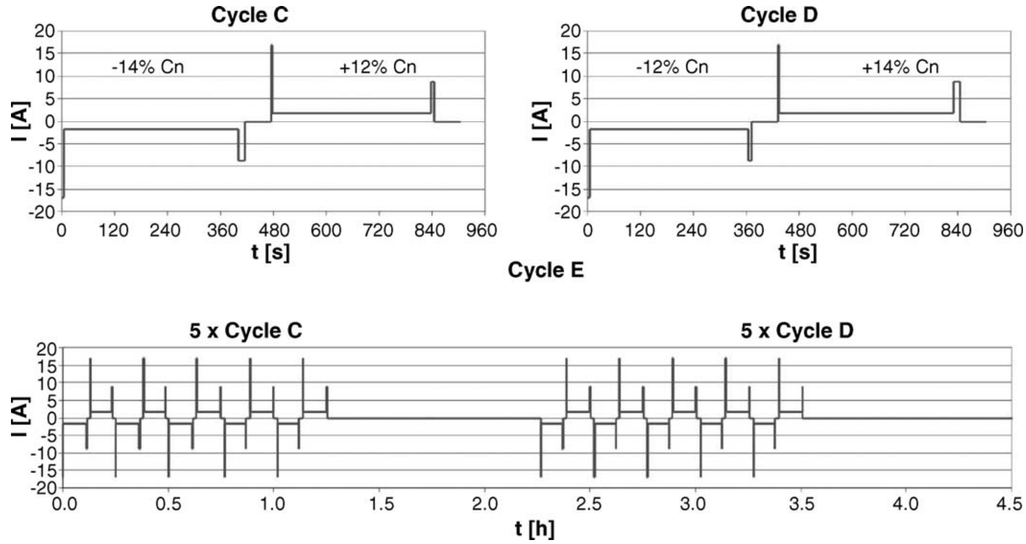

Fig. 4. Test profiles for the test of the BMS (cycle sequences “C”, “D” and “E”).

Table 1
Results of BMS controlled cycling (cycle sequences composed of sequences “C” and “D”)

Experiment	Experimental conditions				SOC after the experiment			
	Temperature (°C)	Starting SOC (%)	Duration of experiment (h)	Total charge exchanged (Ah)	BMS simple charge integration (%)	BMS interpreted SOC (DBS) (%)	Experimentally determined SOC (%)	Relative SOC deviation BMS: experiment (%)
6 × cycles E [5 × cycle C and 5 × cycle D]	25	50	27	26	71	52	54	−1.2
44 × cycles E [5 × cycle C and 5 × cycle D]	25	50	200	190	178	68	72	−3.8
9 × cycles F [5 × cycle C and 7 × cycle D]	0–35 variable	60	46.5	95	101	64	68	−5.0

operating window. The polarisation of the cell is influenced by the temperature.

The deviation between the SOC computed from the accumulated charge and the interpreted information from the BMS increase steadily. The results acquired by experimental determination of the remaining charge are in between a deviation of 5% from the information the BMS (DBS) is providing.

In the second series of experiments a modified ECE 15 cycle has been chosen as the driving profile for the battery testing program. The basic cycle was repeated several times and at different ambient temperatures. The projected SOC working window was adjusted to be 30, . . ., 80% SOC. The battery was adjusted before the experiment to a SOC of 70%. The results are compiled in Table 2.

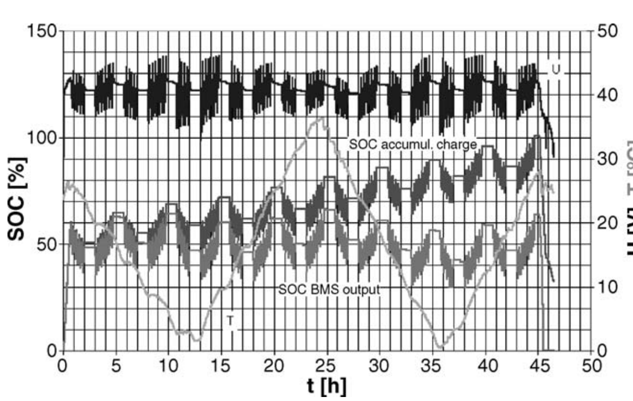

Fig. 5. Results from the third experiment (9 × cycles F [5 × cycle C and 7 × cycle D]) and daily temperature variation.

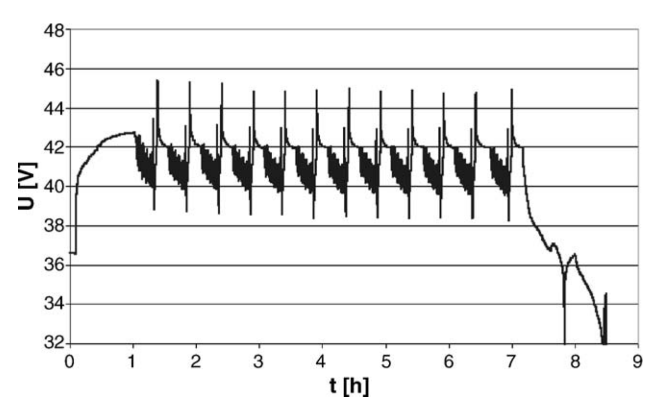

Fig. 6. Voltage of the bipolar stack during the experiment with ECE cycles at 25 °C (SOC shown in Fig. 7).

Table 2
Results of BMS controlled cycling (modified ECE sequence)

Experimental conditions			SOC after the experiment			Relative SOC deviation BMS: experiment (%)
Numbers of consecutive ECE cycles	Temperature (°C)	Duration of the experiment (h)	BMS simple charge integration (%)	BMS interpreted SOC (DBS) (%)	Experimentally determined SOC (%)	
12	25	6.5	86	79	76	3.0
12	35	6.5	94	79	77	2.9
7	−10	4	49	34	44	−10.6

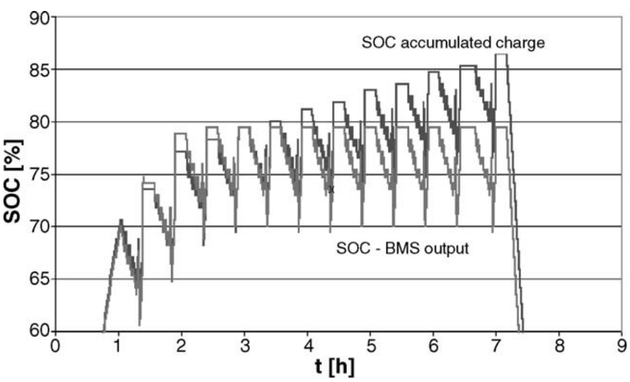

Fig. 7. SOC during the experiment with ECE cycles at 25 °C computed from the accumulated charge and as output of the BMS (DBS) system (voltage shown in Fig. 6).

In Fig. 6 the voltage of the battery during the experiment is plotted versus time. The initial charging step is followed by the cycling sequence. At the end of the cycling sequence the remaining capacity is determined. Fig. 7 visualises the resulting SOC curves for the experiment at 25 °C.

A more detailed part (cycle 8) of the cycling program is shown in Fig. 8. The deviation between the accumulated charge and the SOC determined by the BMS is clearly visible.

At the end of the experiment the deviation of the BMS/DBS SOC information compared to the experimentally determined remaining capacity is rather small (below 5%). Even at other temperatures and prolonged experimental times the BMS/DBS system is able to keep the battery in the defined SOC range of operation. There are stronger influences at low temperatures.

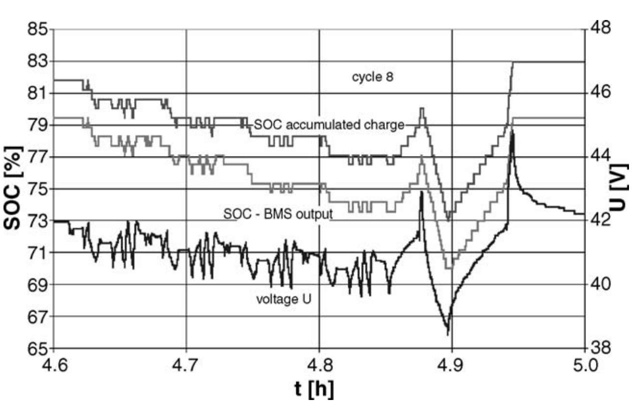

Fig. 8. Part of the cycling experiment with series of ECE cycles (sub-cycle 8).

These are contributed to the higher internal resistance of the nickel metal hydride system under these conditions. But even there the BMS system is able to protect the battery system from suffering any harm due to low charging states or overcharging.

In further experiments we were able to get information on the ageing effect of the battery from the data stored in the BMS. That requires to measure the dynamic behaviour with a time resolution tuned to the mode of operation. From these data the internal resistance and other characteristics can be computed. Additional information on the state of the battery can be obtained from the temperature changes of the cell and the cooling system. From precise measurements of the heat capacity of the battery we were able to correlate the heat production and the power losses of the battery.

6. Summary

The developed BMS/dynamic battery control system is able to compensate for errors of the integration of current in long experiments even at conditions of short peaks during the load profile. The BMS system will stabilise the battery in the designed working range. The DBC strategy enables to control the battery without the necessity of complete knowledge of the processes occurring under a given mode of operation. It will ensure that the battery remains in the given working SOC window and may give signals to the controlling device of the application system (e.g. a HEV). In addition the BMS records all important data and is able to perform even sophisticated mathematical operations to determine the state of charge.

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