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Automated test system for special-purpose batteries verification

Abstract

The paper describes the automated test system, designed for a special-purpose batteries examination, along with some exemplary test results. It presents requirements from energy supply sources for mobile devices working in coal mines spaces and its most crucial parameters, justifies the need for deploying a proposed solution, presents its hardware and software architecture and finishes with the batteries test outputs and some observations made.

Keywords: batteries examination, automated test, ATEX.

1. Introduction

Today's mobile devices require increasingly efficient power supplies. Commercially available modern Li-Ion, LiPo and NiMH technology batteries seem to be the attractive options.

Despite the availability of data sheets and the vendor support, for the reliable battery selection it becomes necessary to carry out series of examinations and supplementary tests. They are targeted at checking the cells safety, verifying the technical specifications given by the manufacturer and also measuring parameters not reported in official data sheets.

2. Aim of the study

The aim of this study was the selection of energy supply sources for mobile devices working in coal mines spaces with special emphasis put on methane and coal dust explosions danger. In particular application it became necessary to select a new power supply source for the radio remote controller of the mining machine. It has been assumed, that a single cell or the cells stack will be applied to allow direct supply of the radio remote control electronics, without the circuitry for converting the voltage.

During the preparation of functional and technical specifications of the radio remote controller a number of requirements relating directly to the power supply source have been pointed out:

- minimum continuous operation time,
- maximum battery charging time,
- the whole device permissible maximum dimensions and weight,
- expected temperature range during the device operation and during the battery charging,
- expected time-of-life of the battery – to guarantee assumed operation time for the radio remote controller during the entire warranty period despite cells aging.

Demanded radio remote controller operating parameters, like - among others - the possibility of 24-hour uninterrupted machine operation and the necessity to increase the unit ergonomics have forced designers to reach for new types of energy sources that have not been widely used yet in the mine underground environment [1]. Therefore, it was crucial to nominate commercially available secondary cells (repeatedly rechargeable) taking into account:

- cell capacity and energy density fulfilling the radio remote controller weight limitation,
- rapid charging possibility,
- cells degradation for the intended product life,
- possibility of operation within the entire range of required temperature, during cells charge and discharge cycles.

Authors' gathered experience in designing, construction and maintaining battery powered portable devices prove that the technical data set provided by the cell manufacturers is very often insufficient to guarantee safe and reliable operation of these elements in a demanding environment of mining excavations. It becomes necessary in this case to perform an additional assessment of such a cell for safety issues, carried out by analyzing the requirements of the relevant norms, harmonized with the ATEX Directive (94/9/EC). This allows for fulfilling the essential ATEX requirements defined for equipment intended for use in potentially explosive areas.

In addition to safety issues, in order to confirm the functional properties it is also necessary to perform practical verification of the data declared by the manufacturer and to check the cell parameters not reported (like service life) [2][3]. It is also very important to verify cells within conditions similar to actual operating conditions (like for example extreme ambient temperatures), for which there are no reliable data.

It was assumed that in addition to safety assessment for each of the selected cells the following tests will be carried out to verify functional parameters:

- checking the cell real capacity,
- checking the temperature effect on the cell operation during charging and discharging (for extremely adverse temperature conditions),
- checking the cell aging during subsequent charging/ discharging cycles.

Study objects

As a result of the survey of the current market offer 6 different cells types have been selected, meeting preliminary technical criteria with confirmed long term commercial availability. These cells were then tested for the safety usage in a potentially explosive environment. The study verified, among others, the thermal cell stability during the electric circuit shortage and the possibility of the case unsealing and potential leakage. Research and evaluation in this area were carried out in a notified body specializing in the assessment of devices dedicated for use in potentially explosive atmospheres in accordance with ATEX Directive (94/9/EC). Four different types of cells passed successfully this examination stage (Table 1). These cells were then subjected to the functional examination as described in this paper.

Tab. 1. Cells under test

Cell ID	Cell's technology	Manufacturer declared capacity, mAh
Cell 1	Li-Ion	3350
Cell 2	Li-Ion	4800
Cell 3	Li-Ion	6800
Cell 4	NiMH	3800

3. System architecture

For the analysis of the scope of required tests it was assumed that the measuring system setup should meet following general assumptions:

- support for the following cell kinds: Lithium-Ion (Li-Ion), Lithium-Polymer (LiPo) and nickel-metal hydride (NiMH) batteries. In particular, it should be possible to charge the cell

according to the recommended algorithm and discharge with fixed current down to the defined cell voltage level [4],
- measuring and recording the basic parameters: cell voltage, charge and discharge current and cell temperature [5],
- measuring the ambient temperature,
- current tester's status visualization like cells detaching, excessive heat and other errors handling,
- independent multichannel architecture,
- flexible user interface with the ability to easily define and perform different profile cells tests,
- automatic reports generation,
- stability allowing for trouble-free, multi-day running tests.

A big number of parameters to be controlled and checked during the test, a repeatable manner of the performed tests and the requirement to test several cells concurrently, all this made the task an ideal target of measurement automation.

Test platform

At the beginning of the work a review of the ready to use hardware platforms for battery measurement and control has been performed. Appropriate solutions are offered (among others) by companies like National Instruments (eg. PXI-4130 SMU) or Keysight (Agilent) (eg. N6783A). It should be noted, however, that the available modules have several hardware limitations (like insufficient current range or no temperature measurement) and there is the necessity to purchase a large set of modules and/or usually the extra host module. Ready to use charge/discharge modules come also with dedicated software which should work within factory defined limitations and with the customer accepted price. Lack of flexibility and high prices of commercially available solutions inspired authors to build their own system.

It was assumed that system will be able to control independently six Li-Ion/LiPo cells or five Li-Ion/LiPo and one NiMH cell.

Hardware

As the hardware interface responsible for cell voltage measurements, bi-directional (charging and discharging) cell current measurements and temperature measurements, the Keysight (Agilent) NIU 34972 data logger/recorder has been selected. The unit is equipped with additional expansion cards (34901 & 34907 modules) which enable the multichannel measurement of voltage, current and temperature, along with reading digital inputs and controlling digital outputs. Such instruments are widely recognized measurement solutions used in industry and laboratory applications. This allows for accurate and reliable measurements results of the most important physical parameters describing the cell state (voltage, current, temperature). As a standard such devices offer remote control mode, very often with National Instruments LabVIEW environment support.

Charging and discharging process

To implement the charging process in each of the tester's six channels a specialized type of integrated charge controller BQ24105 from Texas Instruments has been selected. This controller is a pulse charging device and supports Lithium-Ion (Li-Ion) and lithium polymer (LiPo) cells. The tester has also a single channel for nickel - metal hydride (NiMH) cells based on the DS2715 chip from Maxim Integrated. The usage of specialized integrated circuits greatly simplified the design of the hardware and provided the precise control of the charging process without implementation of standard charging algorithms. The charging controllers also provide information about the status of the charging process and errors that occurred during the cell charging (like exceeding the designated charging time, detaching cells during charging, etc.).

To implement the discharging process the dedicated current source with fixed voltage cut-off has been designed. When cut-off voltage is reached, the circuitry is disconnected from the cell. This enables fixing the discharge completion condition in the repeatable manner, thus it allows to simulate the real electronic system in reaching of a minimum safe operating voltage.

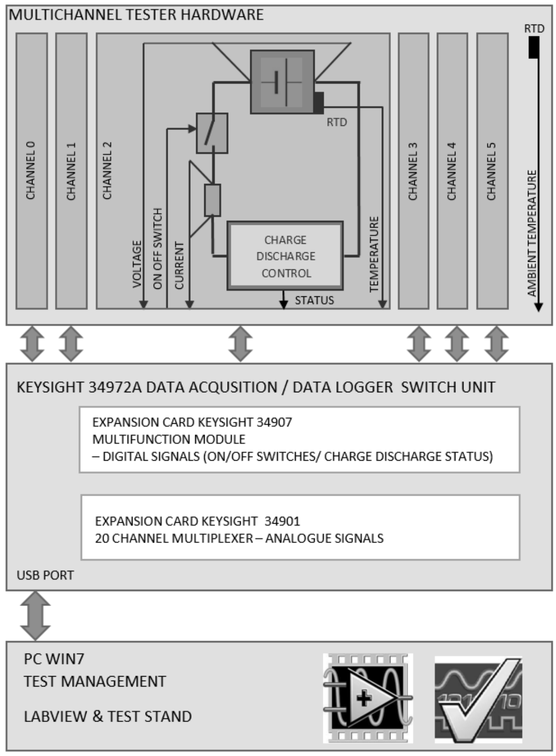

Fig. 1. System block diagram

Software platform

After analyzing the scope of the required tests, authors decided to use one of the most generally recognized standards in this class of applications - National Instruments LabVIEW and TestStand environment [6]. Such an environment offers enormous flexibility as well as the possibility of adaptation to possible changes both in the hardware layer (especially in multichannel system development) and in the software layer (like graphical user interface functionality and fulfilling requirements for reports generated). LabVIEW environment has been used to develop the user interface and drivers for hardware layer - while software running in TestStand performs the cyclic test procedures management – mainly controlling the charge and discharge circuits.

Software architecture

For the accomplishment of allocated tasks the following assumptions have been made for the system software:
- controlling the charge and discharge executive circuitry with digital output lines of the Keysight 34907 expansion card,
- continuous readout of the circuit state (current values of voltage, charge/discharge current and temperature) with Keysight NIU 34972 data logger/recorder,
- checking the status of the charging and discharging hardware using digital input lines of the Keysight 34907 expansion card,
- visualization of each channel actual operating status,
- generating measurement reports ,
- application reliability and stability to enable long term tests.

The application is configured using profiles, which allows the independent selection of the following configuration parameters for each active channel:

- current measurement factor for calculating charge/discharge current,
- number of preset charge/discharge cycles,
- pause time after reaching the charged/discharged state before continuing the next test step,
- the ability to stop the test sequence after full charging of the cell,
- an optional ambient temperature sensor logging,
- interrupt test conditions temperature values:
  - exceeding the ambient temperature,
  - exceeding the cell temperature during charge step,
  - exceeding the cell temperature during discharge step,
- name and folder for measurement results.

Software architecture presented in Fig.2 uses TestStand and LabVIEW modules. TestStand environment is responsible for the test management and working channels profiles. LabVIEW functions are responsible for I/O drivers and GUI controls.

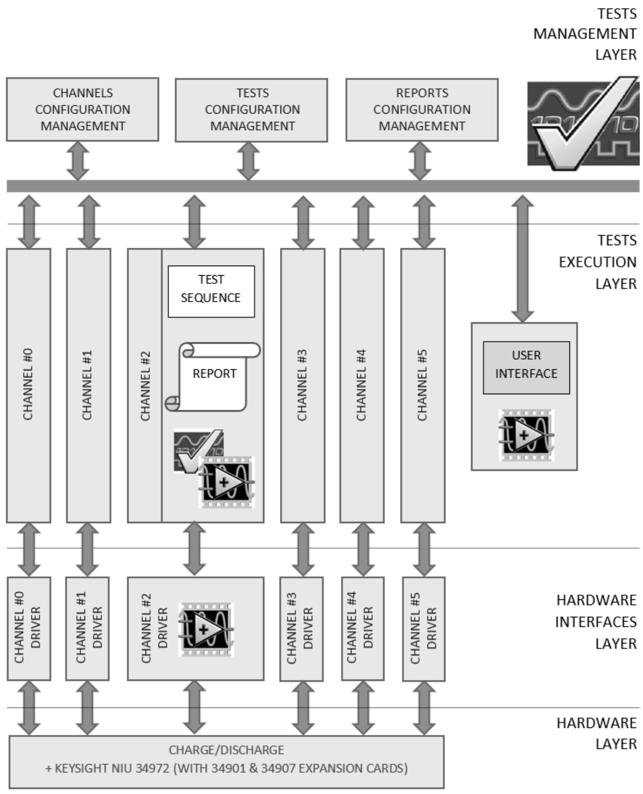

Fig. 2. Software architecture diagram

4. Results

Additionally, outside the LabVIEW/TestStand environments several macros have been written in Microsoft Excel to make ease the data report processing for the cell under test.

Obtaining reliable results required a large amount of preparatory work, then the auxiliary and principle tests. Table 2 presents partly the scope of activities carried out within the framework of the tasks described.

Tab. 2. Monthly tests summary

Cell ID	The full aging charge/discharge tests number	The full capacity charge/discharge tests number	The full temperature charge/ discharge tests number
Cell 1	149	49	5
Cell 2	98	39	5
Cell 3	74	27	5

Table 3 and 4 present the results of the manufacturer's data verification and selected results of thermal and aging examinations.

Tab. 3. Cell capacity verification

Cell ID	Manufacturer declared capacity, mAh	Verified capacity. mAh
Cell 1	3350	2840
Cell 2	4800	4480
Cell 3	6800	6440
Cell 4	3800	3885

Tab. 4. Cell capacity verification at extreme temperatures charge/discharge

Cell ID	Capacity, mAh Tch = 25°C Tdis = 25°C	Capacity, mAh Tch = 40°C Tdis = –20°C
Cell 1	2840	no data *
Cell 2	4480	2880
Cell 3	6440	5230

* premature cut-off

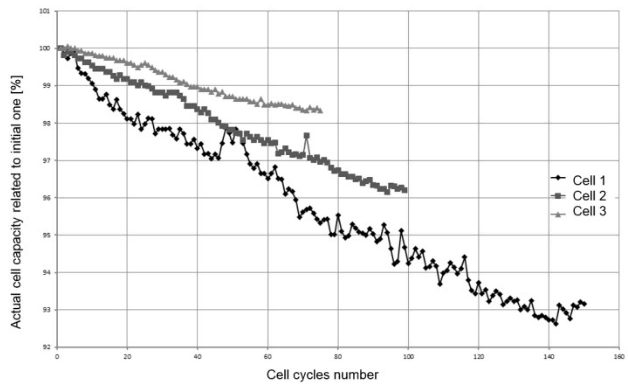

Fig. 3. Cell capacity aging as a function charge/discharge cycles

5. Summary

The performed tests have provided data allowing for the cells selection, that satisfied assumptions raised in radio remote control design technical specifications. Within the preselected six different cell types, only two types are suitable for the envisaged application. The main reason of other types rejection was high deviation of measured results in extreme temperatures related to rated parameters defined by manufacturers.

In addition to verification of the technical data provided by a manufacturer, studies allowed for drawing conclusions about the practical application of Li-Ion cells. Particular attention should be paid to the cells behaviour in extreme temperatures. Some of the cells tested exhibited a noticeably longer charging time at 40° C than at 25° C. This is important due to the fact that cells charging integrated controllers typically use maximum charge time timers, (often as the external hardware, with an additional capacitor). Charging at the high ambient temperature may cause the need to increase the time charging allowed. Another interesting phenomenon is the sudden cell voltage drop during the discharge with high current at low temperatures. Typically, cell is secured with the voltage detection circuit that prevents too deep discharge level [7]. When the cutoff level is set too high, the discharge of the cells at low temperatures may not be possible.

Knowledge about the cells obtained during the tests performed fully justified the construction and deployment of the described test system. It gave an invaluable service during the test period, enabling the repeated tests of several cells at once along with multi-parameter data logging and some on-line analysis and immediate control of test procedures execution. The test system also proved its high reliability during the long term tests performed in room conditions, as well as in climate chamber.

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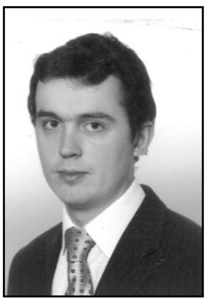

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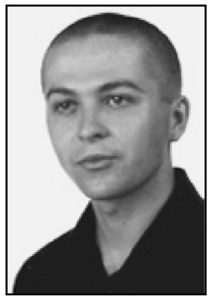

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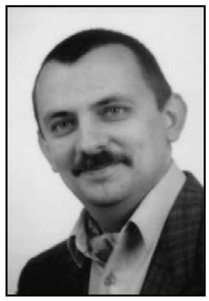

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