AUTOMATED CONTROL AND DATA ACQUISITION SYSTEM FOR LITHIUM-ION ACCUMULATORS TEST BENCH

E A Mizrah, R V Balakirev, N V Shtabel

Siberian State Aerospace University Named after Academician M.F. Reshetnev
31, Krasnoyarskiy Rabochiy Ave., Krasnoyarsk, 660037, Russia.

E-mail: shtabnik@gmail.com

Abstract. In the article authors describe architecture of an automated data acquisition system for lithium ion accumulators lifetime test bench. The system is based on high performance data acquisition modules and allows acquisition of data in the process of simultaneous testing of 12 accumulators, including current, voltage and temperature of each accumulator. LabView based software is used to control testing, registration of data and loading of test program into system modules.

1. Introduction

The lifetime testing of lithium-ion accumulators (LIA) is done during terrestrial accumulator development. In this way, it protects technology of LIA and its production. In the process of flight LIA production, electrical parameters of accumulator verified with acceptance testing. World market leaders use dynamic stress test (DST) to diagnostics of lifetime characteristics. This method based on sample accumulator selection from each flight production batch, and with high probability can measure lifetime characteristics and degradation of real accumulator. In addition to charge and discharge cycles test include temperature cycling which is done with heat chamber.

Accumulators test bench developed in SibSAU (Krasnoyarsk, Russia) [1, 2] is able to carry simultaneous testing of up to 12 LIA with continuous testing time up to 3 months.

The main tasks of data acquisition system are:

- test control in accordance with given program;
- measurement of accumulator parameters (current, voltage, temperature);
- heat chamber control;

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2. Test bench control system
Control system should provide continuous long-time testing of accumulators including current and voltage protections and emergency stop in case of energy breakdown.

Structure of control and data acquisition system is shown on figure 1. On figure 1 shown: TS – temperature sensors, CDM – charge-discharge modules, accumulators, National Instruments (NI) PXIe-8115 – control computer, NI PXI-6225, PXIe-4300 – data acquisition modules, NI PXI-8433/2 – RS-485 communication interface.

All CDM modules and control computer connected into one half-duplex RS-485 network. RS-485 protocol was selected because of its good noise protection and reliability. If necessary network can be expanded up to 32 devices (due to RS-485 protocol limitations) [3].

Main requirement for control system is continuous communication with each of 12 CDM’s to obtain state information and provide fast response to accumulator state change. According to technical requirements data from all modules should be obtained each 250 ms.

Half-duplex network implies limitation of one master device in network which can send messages, all slave devices can only send response to master messages. In case of long-time testing it can be critical because during test there can be connection problems or computer software freezes. Even in this cases test should be completed or paused with respect to situation. Moreover, two CDM can work together with one accumulator, which means it should synchronize time of critical events such as charge to discharge and back transition.

Network with computer acting as master and CDM acting as slaves became fault-tolerant, because in case of computer problems system looses control.

To deal with this problems two methods was chosen: time-division multiplexing and autonomous CDM architecture.

Time-division multiplexing (TDM) is well-known technology of channel multiplexing where one communication channel can be divided into several subchannels with dedicated time slot (frame) [4]. Frames number can be fixed in case of static TDM or variable in case of dynamic TDM.

In case of computer communication with CDM to eliminate mandatory requirement of one master each device in network (every CDM and computer) has dedicated 16 ms time interval in which it allowed to send data. Each fixed time interval of 250 ms transmit cycle is repeated. One communication cycle time diagram is shown on figure 2.
Figure 2. 250 ms communication cycle with TDM.

To synchronize devices with each other each device waits for packet start byte from device with previous address for time interval called “silence time” of 5 ms. If during this time it’s not received, it means that device is not present in network and data can be sent.

This method allows to work without master device, but comes to new challenge: each device should react fast enough to previous device packet not to lose it’s time frame. It’s easy to obtain in CDM control devices which are based on microcontrollers and allow to get sub-millisecond reaction, but in case of computer it’s not true.

In our case computer works on non-real-time operating system, which means that communication task can’t guarantee response time [5]. In case of Windows operating system it means that even if task is working with highest priority and it send data to communication port driver in required time, it can’t guarantee that driver will process data quick enough [6].

During test it was shown that time needed to process data from driver buffer to port output can easily grow with increase processor load even in case of highest task priority. In test with 10% processor load maximum response time was 30 ms which is sufficient for wider time frame of 58 ms dedicated for the computer. But in case of 80% and more processor load maximum response time grown to more than 100 ms. It is unacceptable because it leads to transmit overlap over devices resulting in communication error. Example of delayed frame shown on figure 3.

Figure 3. Communication cycle with delayed computer frame.

Problem of real-time response has several solutions, one of them is using real-time operating system on computer, but in National Instruments configuration it requires one more additional computer – one for communication task with real-time operating system and one for user interface and control with general purpose operating system. System became
complicated in this case, communication and user interface layers should communicate between each other and has to be fully separated modules.

More straightforward solution is to use dedicated microcontroller pairing device (MPD) between computer and CDM to buffer packets and transmit them only in allowed time frames. It means that for computer system remains transparent, it can send packets at any time, because packets will remain in MPD buffer before next allowed data frame. Responses to computer transmitted directly without delay, because in given solution communication interface between computer and MPD is full-duplex with separated receive and transmit lines. Example of data communication frame with MPD shown on figure 4.

**Figure 4.** Communication cycle with microcontroller pairing device.

During test operator inputs test program via user interface, which contains sequence of LIA charge-discharge cycles and test steps. Each step includes information about required LIA voltage, current, charge or discharge method (with constant current, changing current, constant power), duration and repetition count of each step. Test program read from text file, written in special algorithmic language, which is converted to machine form to load program into CDM. Currently next features are supported:

- Charge and discharge with constant or linear changing current
- Loops (up to 65535 repetitions)
- Simple conditions based on loop counter
- Dynamically changing current and voltage protection
- Delay
- Special commands to measure accumulator capacitance

Text to binary format converter and communication protocol with CDM done in native LabView language.

Autonomous CDM architecture means that full test program including all steps stored inside CDM, and even in case of communication failure with computer it will continue to work and will be able to correctly shut down.
3. Test bench data acquisition system

Data acquisition system consists of two types of modules:

- NI PXIe-4300 modules with 8 isolated analogue input channels
- NI PXI-6225 module with 80 non-isolated analogue channels

Isolated analogue input channels used to measure current and voltage of accumulator with high accuracy. Non-isolated analogue input channels used to measure accumulator temperature.

One of the main requirements to test bench is accuracy, which can be obtained by using precise sensors and measurement devices. Accumulator voltage range is -5 to 5 V and can be measured directly by PXIe-4300. Voltage measurement error should be lower than 5 mV. Current measurement is more complicated because of high current range up to 160 Amperes and accuracy requirements:

- 30 mA in range 0-5 A
- 50 mA in range 5-50 A
- 200 mA in range 50-160 A

To match these requirements LEM Ultrastab IT200-S current sensor was chosen, it has measurement accuracy of 0.1% [7].

Filtering of current and voltage signals is necessary because of high-frequency noise coming from two convertors inside CDM which are working on frequencies of 100 kHz and 10 kHz. Two filters are used for filtering: 10 kHz 2-nd order digital Butterworth low-pass filter and additional 1 kHz analogue first-order Butterworth low-pass filter. It allows to efficiently reduce noise on analogue inputs. In addition to filtering averaging is used, with 100 averages on 1 kHz sample rate [8]. Results of current measurement analysis for 14 modules shown on figure 5. Voltage measurement analysis for 14 modules shown on figure 6.

![Figure 5. Current measurement error for currents of 1A, 30A, 80A, 160A.](image)
From measurements on figure 5 and figure 6 we can see that measurement error in all ranges is lower than allowable.

To store data TDMS file format was chosen [9], because of its high portability, ability to store metadata together with values, ready program modules in LabView to directly stream collected data to file.

Programmatically data acquisition done in two loops, one for data collection into buffer and one for data writes to disk, it allow continuous data collection every 100 ms without interruption and eliminates dependence on disk drive performance.

4. Conclusion
Presented architecture of modular accumulator test bench allows to build scalable system for near any type of known accumulators besides lithium-ion. Time division multiplexing used in communication system is expandable and can be used for more than 20 modules depending on communication baud rate. Data acquisition system can be also extended to match requirements. Accumulators test bench presented in the article supposed to use in accumulators production quality control.

References
[1] Mizrah E A, Kopylov E A and Balakirev R V 2012 Accumulator cell testing device Russia Utility model patent 123530
[2] Volochaev M N and Mizrah E A 2013 Charge characteristics simulator for spacecraft power system testing Proceed. of XVII International Science conference in memory of M.F.Reshetnev (Krasnoyarsk: SibSAU) I 196
[3] Axelson J 1998 Serial port complete: programming and circuits for RS-232 and RS-485 links and networks (Madison, WI: Lakeview Research)
[4] Hanrahan H E 2005 Integrated Digital Communications (Johannesburg: University of the Witwatersrand).
[5] Tanenbaum A S 2008 Modern operating systems (Upper Saddle River, N.J.: Pearson
Prentice Hall)

[6] Orwick P and Smith G 2007 Developing drivers with the Windows driver foundation (Redmond, Wash.: Microsoft Press)

[7] 2014 LEM Ultrastab IT-200 datasheet (http://www.lem.com/docs/products/it_200-s_ultrastab.pdf)

[8] Williams A B and Taylor F J 2006 Electronic filter design handbook (New York: McGraw-Hill)

[9] 2015 The NI TDMS File Format (http://www.ni.com/white-paper/3727/en/)