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TELEMETRY DEVICE FOR CONTROL OF TECHNICAL STATE OF CHEMICAL CURRENT SOURCES

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The article describes the device for telemetry and control of the technical state of chemical current sources. The controlled parameters are the residual capacity, voltage, discharge current, temperature of current sources. The article presents a functional scheme of the device, its feature being galvanic isolation of the current source circuit and the monitoring device. To provide galvanic isolation, the authors propose a circuit solution for non-contact current measurement in order to reduce the error in measuring currents of various magnitudes. An asynchronous parallel-serial data transfer interface is used for the exchange with the upper-level system. The article describes the algorithm of telemetry device operation, which is implemented for the 1887VE4U microcontroller. When developing the device, the main difficulty was the need to ensure the minimum weight and dimensions and use only domestic-made electronic components to comply with the import substitution strategy in the Russian economy.

Keywords: telemetry, noncontact measurement, discharging current, current sensor, capacity, voltage, chemical current source.

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УСТРОЙСТВО ТЕЛЕМЕТРИИ И КОНТРОЛЯ ТЕХНИЧЕСКОГО СОСТОЯНИЯ ХИМИЧЕСКИХ ИСТОЧНИКОВ ТОКА

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Описано устройство телеметрии и контроля технического состояния химических источников тока. Контролируемыми параметрами являются остаточная ёмкость, напряжение, разрядный ток, температура источников тока. Приведена функциональная схема устройства, особенностью которой является обеспечение гальванической развязки цепи источника тока и устройства контроля. Для обеспечения гальванической развязки предложено использовать схемотехническое решение для бесконтактного измерения тока с целью снижения погрешности при измерении токов различной величины. Для обмена с системой верхнего уровня использован асинхронный параллельно-последовательный интерфейс передачи данных. Описан алгоритм работы устройства телеметрии, который реализован для микроконтроллера 1887ВЕ4У. При разработке устройства основная трудность заключалась в необходимости обеспечить минимальные массогабаритные параметры и использовать электронные компоненты только отечественного производства в рамках реализации стратегии импортозамещения в экономике России.

Ключевые слова: телеметрия, бесконтактное измерение, разрядный ток, датчик тока, ёмкость, напряжение, химический источник тока.

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Introduction

Chemical current sources (CCS) are widely used in everyday human life (uninterruptible power supplies, cars, household appliances, etc.) and in various industries (for autonomous power supply of civilian, military, space and other specialized equipment).

When supplying power to industrial facilities, two types of CCS are used: primary batteries and secondary batteries. The most common batteries are saline, alkaline, lithium. Lithium cells and batteries from the listed are the most energy-intensive and capable of delivering powerful current pulses.

The problem of diagnosing the state of CCS and the possibility of predicting their performance is one of the central problems of the production and operation of current sources [1]. According to the requirements for the operation of lithium CCS for long-term and high-quality operation, as well as their timely replacement, it is necessary to ensure control of the main parameters – residual capacity, voltage and discharge current.

There is a term “smart” CCS [2]. It is a current source, which contains a parameter monitoring device and sends information about the current state of the battery, discharge current, voltage, capacity and temperature of the battery to the monitoring system in real time. Such control devices must have minimum weight and dimensions.

Reducing the influence of the human factor, labor intensity of maintenance and the need for remote diagnostics during battery operation is an important task and requires introducing monitoring and diagnostics devices into the electric power facilities [3–10]. In addition, one of the problems arising during the operation of lithium batteries is the absence or insufficient number of effective methods and devices for non-destructive and continuous monitoring of parameters in all operating modes, including during operation [11].

There are many methods for determining capacity. These can be methods based on measurements of the open circuit voltage [12], discharge voltage [13–19], internal resistance of a CCS [20–23], as well as density, optical refractive index, dielectric constant of the electrolyte, intensity of infrared radiation emitted by the outer surface of the CCS [24, 25].

For lithium power sources, the number of successfully tested methods is limited due to the peculiarities of such power sources. These methods include: impedance measurement, fluctuation of the discharge voltage, assessment of the discharge current at constant and pulse current, microcalorimetry [1].

The method of potentiostatic diagnostics of the capacity of an active electrode of a nickel-cadmium battery, which is based on the relationship between the current arising during potentiostatic polarization of a nickel oxide electrode, and the residual capacity is given in [26]. However, this method for determining capacity is only intended for a nickel-cadmium battery.

Devices for monitoring the state of CCS are proposed in [27–32]. A device for measuring direct current with galvanic isolation was proposed in [33]. The disadvantage of these devices is that they do not simultaneously measure the voltage, discharge current, residual capacity and temperature of the CCS. In addition, the overall dimensions of the devices are not indicated.

A computer system for monitoring the parameters of power supplies consisting of CCS is proposed in [34]. The monitored parameters include voltage, current and discharge time. However, the system does not take into account the residual capacity of the CCS, and also has large weight and size characteristics.

The known devices for monitoring the parameters of the CCS do not meet all the necessary requirements for the quantity and quality of the monitored parameters, permissible weight and dimensions, and the possibility of information communication with upper-level systems.

The authors have developed a device that allows continuous monitoring of the CCS parameters. The introduction of a telemetry and parameter control device into the CCS makes it possible to create a "smart" battery and to simplify obtaining objective information about the current state of the battery. The information obtained will make it possible to analyze the operation of batteries in order to increase their reliability, determine ways to improve equipment and establish the causes of its failures.

Within the framework of the implementation of the import substitution strategy in the Russian economy, only domestic-made electronic components were used in the development of the device.

Functional scheme of the device

The developed device consists of the following functional units: non-contact current measurement unit, voltage measurement unit, temperature measurement unit, microcontroller (MC), power supply.

The functional scheme of the current measurement unit is shown in Fig. 1.

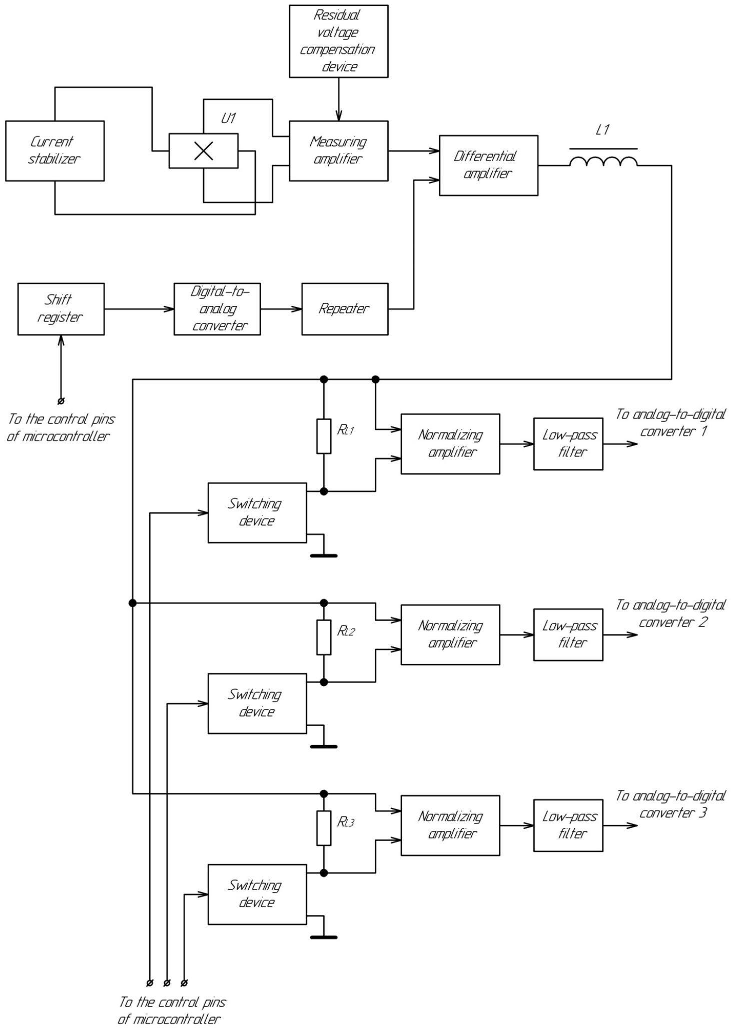

Fig. 1. Functional scheme of the current measurement unit

The non-contact current measurement unit implements the circuit design developed by the authors for the contactless current measurement, in which three current measurement subranges are used in order to reduce the error. Contactless measurement is implemented using a compensation current sensor of our own production, since the existing current sensors either cannot be used in terms of design, weight or dimensions, or are not produced in the Russian Federation (for example, manufactured by LEM [35]).

The current sensor consists of a toroidal ferromagnetic core, a compensation coil $L1$, consisting of 10,000 turns, and a Hall sensor $U1$ PKHE61A1 [36], which is installed in the gap of the core with a wound compensation winding.

The proposed circuitry principles of non-contact current measurement make it possible to galvanically isolate the battery circuits and control circuits in order to prevent the destruction of the controlled battery in the event of the control device malfunction.

The amplified voltage from the Hall sensor is used in the compensation type sensors to generate a compensation current I_c in the secondary winding. As a result, a magnetic flux is created, which compensates for the magnetic flux created by the primary current I_d. If the magnetic flux is fully compensated (equal to zero), then the magnetic potential of the two windings is identical [37].

The Hall sensor is powered by a current stabilizer. One of the parameters of the Hall sensor is the residual voltage, so the device is included in the circuit to compensate for the residual voltage.

The measured current creates a magnetic flux in the magnetic circuit, which induces an electromotive force (EMF) in the Hall sensor, proportional to the discharge current. The EMF signal from the terminals of the converter is amplified by the measuring amplifier (MA) and fed to one of the inputs of the differential amplifier.

A signal from a digital-to-analog converter (DAC) is fed to the second input of the differential amplifier through a repeater. The digital-to-analog converter is controlled through a shift register to save discrete pins of the microcontroller.

This is necessary to compensate for the offset voltage at the output of the instrumentation amplifier and the possible uncompensated residual voltage of the Hall sensor at the input of the measuring amplifier.

The signal goes to the compensation winding $L1$ from the output of the measuring amplifier and, then, goes to the load resistors (shunts) R_{L1}, R_{L2} or R_{L3}, which are earthed by means of switching devices controlled by the MC. The current flowing through the winding and one of the load resistors creates a magnetic flux in the opposite direction in the magnetic circuit.

Thus, a negative feedback magnetic system is created. In this case, the following equality must be satisfied

$$I_d \cdot W_d = I_c \cdot W_c,$$

where I_d is a discharge current; W_d is the number of conductors through which current flows I_d ($W_d = 1$); I_c is a compensation current flowing through the coil; W_c is the number of turns of the compensation coil.

The sensor operates at almost zero magnetic flux, which eliminates the temperature drift of the sensor's conversion factor. Thus, the resulting compensation current I_c flowing through the coil accurately represents the discharge current I_d to be measured. A voltage proportional to the primary current I_d can be obtained by a series connection with the secondary winding of the load resistor-shunt.

The use of three different size load resistors-shunts allows changing the range of current measurement and allows you to reduce the error when measuring currents of different magnitude. The voltage drop across resistors R_{L1}, R_{L2} or R_{L3}, created by the compensation current, is converted by the normalizing amplifiers into a normalized signal, which passes through a low-pass filter (LPF) and then is transmitted to the input of an analog-to-digital converter (ADC) built into the microcontroller.

The voltage measuring unit must be galvanically isolated from the rest of the circuit of the parameter monitoring device in order to exclude the failure of the developed device in the event of a malfunction of the controlled object. In this regard, a *DC*/*DC* converter is used to power the voltage measuring unit, which is controlled from the MC through a galvanic isolation and a switching device. In addition, the controlled voltage of the CCS is also supplied through the switching device not to constantly load and discharge the battery.

Since the value of the monitored voltage can reach +40 V, there is a voltage divider at the input helping to adjust the input resistance of the voltage measuring unit and reduce the voltage to be applied to the input of the measuring amplifier. The MA amplifies the voltage and transmits it to the input of the low-pass filter, from the output of which, through the repeater, the voltage signal is fed to the input of the ADC unit with a built-in Serial Peripheral Interface (SPI). The ADC unit is exchanged through galvanic isolation with the microcontroller and digitally transmits the measured voltage value using the SPI interface.

The temperature measuring unit contains a resistive temperature sensor built into one of the arms of the bridge measuring circuit. The bridge is powered by a voltage stabilizer connected to one of the diagonals of the measuring bridge. The voltage signal from the other diagonal of the bridge is fed to the input of the measuring amplifier, amplified and fed to the input of the low-pass filter and transmitted to the ADC built into the microcontroller.

The microcontroller is one of the central blocks of the device. It is designed to collect and process information about the magnitude of current, voltage, solve computational problems, including the problem of calculating the residual capacity of the battery, communication and data exchange with the upper-level system and the control panel.

The data on the discharge current, capacity of the monitored battery and voltage will be transmitted via the asynchronous parallel-serial data interface. The array returned by the device will consist of 48 bits and 6 eight-bit words (8 digits for markers of discharge current, voltage and temperature, and 16 digits for capacity). The first word is a marker for the beginning of the information transfer. The second word contains information about the current of discharge. The third and fourth words contain information about the capacity of the monitored battery. The fifth word contains voltage information. The sixth word contains information about the temperature of the battery.

Algorithm

The operation algorithm of the telemetry device and control of the technical state of chemical current sources is shown in Fig. 2.

At the first stage, the MC modules are initialized (interrupt controller, analog-to-digital converter, watchdog timer, input-output ports, interfaces and others). After that, the device proceeds to the cyclic measurement of the monitored parameters: discharge current I_d, voltage and residual capacity of the CCS.

The discharge current measurement subroutine is responsible for current measurement (Fig. 3), the voltage measurement subroutine is responsible for voltage measurement.

If the value of the discharge current I_d is in the range from 40 to 120 A then the discharge current I_{d1} is assumed equal to I_d and the subroutine ends.

In the opposite case, a more accurate determination of the current is required. For this, the load R_{L1} is disconnected and it is determined whether the measured value of the discharge current I_d belongs to the range from 5 to 40 A. If it does, then the R_{L2} load is switched with the control signal from the MC and the voltage is measured at the ADC2 input. After that, the value of the discharge current I_{d2} is determined and the subroutine ends. The magnitude of the current corresponds to the voltage signal fed to the ADC2.

If the measured value of the discharge current I_d does not belong to the range from 5 to 40 A then the readings are in the range from 0 to 5 A. Similar to the previous steps: the load R_{L3} is switched, the voltage is measured at the input of ADC3 and the value of the discharge current I_{d3} is determined, which corresponds to the voltage signal received by the ADC3. Then the subroutine ends.

The residual capacity of the CCS is calculated at the next stage by the measured value of the discharge current as the difference between the nominal value of the capacity Q_{nom} and the capacity of the discharge Q_d.

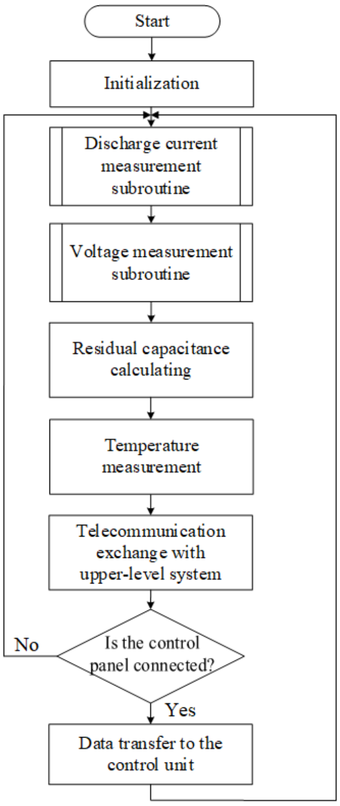

Fig. 2. Algorithm of the telemetry device and control of the technical state of chemical current sources

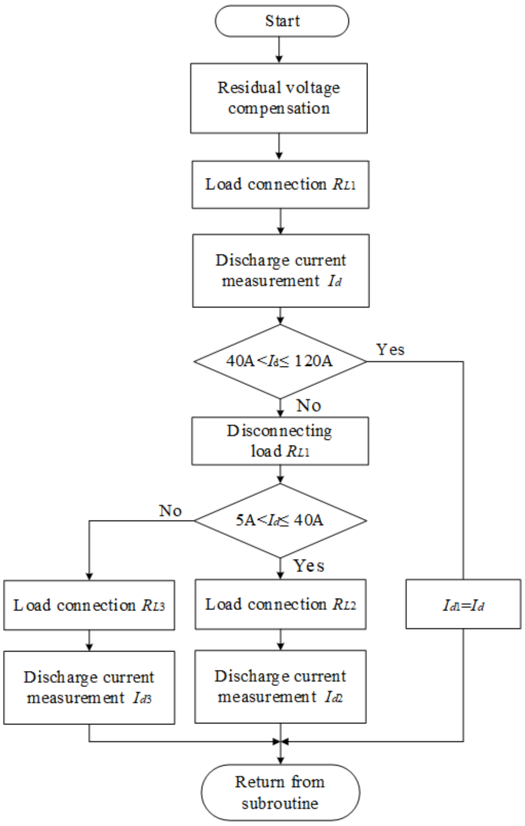

Fig. 3. Algorithm of the current discharge measurement subroutine

$$Q_{SC} = Q_{nom} - Q_d = Q_{nom} - \int_0^t I_d dt = Q_{nom} - \sum_{i=1}^{n} I_d \Delta t_i,$$

where Q_{nom} is the nominal value of the controlled CCS capacity (technical datasheet value); Q_d is the value of the capacity for which the CCS was discharged; I_c is the current value of discharge current; Δt_i is the time elapsed since the last measurement of the discharge current.

The device exchanges data (discharge current I_d, voltage, residual capacity and temperature of the CCS) with the upper-level system by means of telemetry after each measurement cycle. When a control panel is connected, the measured values are transmitted to it. It can be used to configure the device.

The algorithm is implemented in software using the 1887VE4U microcontroller [38]. The program is written in a high-level language C (ISO/IEC 9899:1999) in a software development environment Keil µVision. It consists of a head module and subroutines [39].

Conclusion

The device for telemetry and control of the technical state of chemical current sources developed by the authors allows analyzing the operation of both batteries and autonomous devices in order to increase their reliability, determine ways to improve equipment and establish the causes of its failures.

A three-dimensional model of the developed device for telemetry and control of the technical state of chemical current sources is shown in Fig. 4.

Device characteristics: voltage measurement range from 0 to +40 V, current from 0 to 120 A, capacity from 0 to 511 A/h and temperatures from 0 to +100 ºC.

The error in measuring current and capacity does not exceed 5 %, in voltage and temperature is not more than 1 %. The values of the discharge current, voltage and capacity are transmitted to the upper-level system via an asynchronous parallel-serial interface; it is possible to connect a control panel. Operating temperature range varies from 0 to +50 ºC, relative humidity 60 % at a temperature of +25 ºC.

It should be noted that in connection with the state policy of import substitution and the development of the production of a domestic electronic component base, the device includes domestic components only.

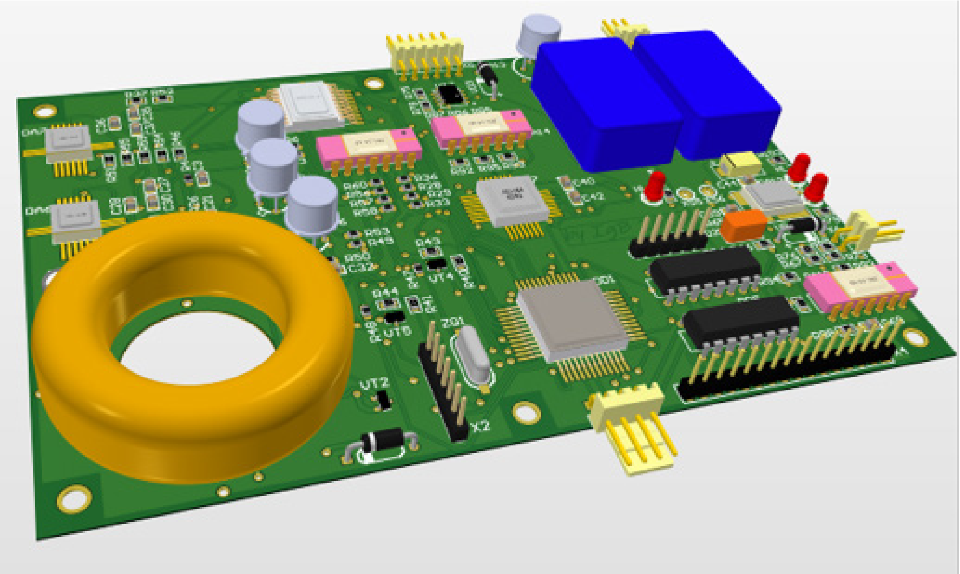

Fig. 4. Three-dimensional model of the device for telemetry and control of the technical state of chemical current sources

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