UDC 541.135.5 DOI: 10.18698/1812-3368-2021-6-121-127

DIAGNOSTICS OF ADVANCED POWER INTENSIVE POWER SOURCES BASED ON THE ACOUSTIC SPECTROSCOPY METHOD

E.M. Petrenko lp-2002@mail.ru
V.A. Semenova valentann@yandex.ru

Joint Institute for High Temperatures, Russian Academy of Sciences, Moscow, Russian Federation

Abstract

Objective of this article is to develop a method for lithium chemical current sources diagnostics, which would ensure high reliability in assessing their technical state (primarily, the discharge degree) close to potentially achievable introduction of the acoustic spectroscopy method. Today, microcalorimetric studies and methods of impedance and noise spectroscopy make it possible to predict the lithium chemical current sources service life. However, implementation of the microcalorimetric studies result requires a lot of time accompanied by using stationary and large-size equipment, which is practically impossible in the autonomous conditions. Application of the impedance spectroscopy method provides satisfactory results only with high degrees of discharge. In the range of 0–30 %, it is very difficult to determine the discharge degree, since noticeable alteration in the correlate within its deviation from the mean value is missing. In this regard, it is proposed in order to provide diagnostics of the lithium chemical current sources in the region of initial degrees of discharge to introduce the noise diagnostics method. In order to increase reliability of the diagnostic estimates, it is advisable to use acoustic spectroscopy as a physically independent method in diagnosing the state of lithium chemical current sources. Results of the preliminary measurements analysis confirm the prospects of using the acoustic spectroscopy method in assessing the current state of primary lithium chemical current sources. Experimental studies of the lithium chemical current sources response to acoustic (mechanical) action made it possible to determine a set of parameters characterizing

Keywords

Chemical current source diagnostics, discharge degree, acoustic spectroscopy, lithium-thionyl chloride current sources

the proposed methodological approach. This provided a possibility to search for correlation dependences of the lithium chemical current sources spectral characteristics on the degree of their discharge. This makes it possible to use the method of acoustic spectroscopy in prompt and reliable diagnostics of the primary current sources in the region of low discharge degrees

Received 12.06.2020
Accepted 15.07.2020

Introduction. Lithium chemical current sources (LCCS) occupy an increasing place among the equipment power supply devices. In this regard, solving the problems of diagnosing their condition, including evaluation of the discharge degree, is very important. Several methods were developed for diagnostic assessment of the LCCS state based on impedance [1–5] and noise spectroscopy [6–10]. Nevertheless, improving reliability and efficiency of the LCCS diagnostics remains an important task.

Efficiency of the LCCS state assessment could be significantly increased by design and development of a fundamentally new method in acoustic spectroscopy of the electrochemical objects. It should be noted that this method was never previously used in studying the current sources. Its use is based on the fact that during the element discharge its internal structure is changing, masses and densities are redistributed. In this connection, responses to various acoustic influences should also change.

According to the curves in Fig. 1, the open circuit voltage (OCV) values of the lithium-thionyl chloride current sources being in different degrees of discharge practically do not differ from each other before exposure to acoustic impact (200 s). However, acoustic exposure results in registering characteristic changes in the OCV. Thus, the conducted OCV studies demon-

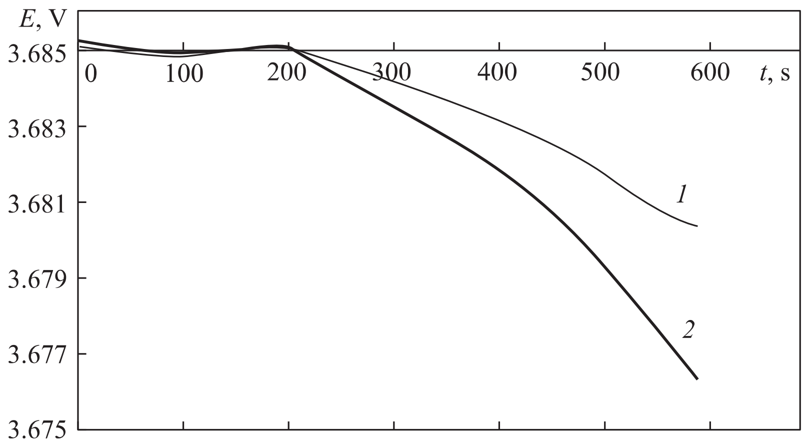


Fig. 1. OCV in LCCS at the discharge degree of 0 (*1*) and 100 % (*2*)

strated effectiveness of using the acoustic methods from the standpoint of obtaining informative responses.

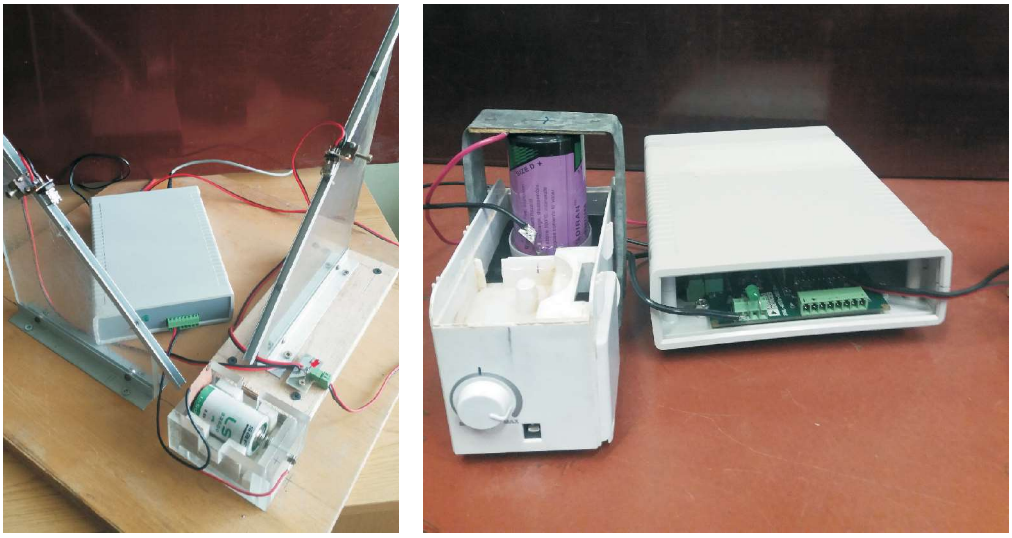
Under exposure to the radiating element monochromatic action, a stationary wave field is generated in the test sample at the radiation frequency. Nature of the registered amplitudes and phases distribution could be used to assess the current source internal state. Mechanical action could be applied in the form of a single pulse. In this case, the obtained response amplitude-frequency characteristics should be sensitive to any alterations in the diagnosed element internal structure.

Alterations in the object physicochemical structure, its mechanical and electrical parameters, mass transfer and redistribution of masses accompanying the LCCS discharge process could be identified by analyzing electrical and mechanical responses to acoustic impacts, as well as by detailed study of the internal structure using the ultrasonic defectoscopy methods. There is reason to believe that parameters of acoustic radiation are changing during the discharge process, and these parameters could be used after registration thereof to diagnose the current sources [11–13]. To identify the most informative parameters that could be effectively used as correlates of the LCCS current state, statistical characteristics of the OCV current sources long-term records characterized by various degrees of discharge were analyzed. Such recordings were obtained both without acoustic impacts, and in the mode of acoustic impacts of various types.

Consequently, possibility of using the acoustic spectroscopy method as an independent approach to assessing the LCCS state was considered.

Experimental technique. The studies were carried out on the equipment developed by the authors of this work, which provides noise studies in a wide dynamic range without using the additional compensating devices [14]. Such equipment makes it possible to measure signals against the background of amplitude units of volts, which minimum level is not exceeding a microvolt fraction.

To study responses to various acoustic impacts, special installations were developed making it possible to study pulsed mechanical (Fig. 2, *a*) and ultrasonic (Fig. 2, *b*) effects on the element and register response to these impacts.
Installations include devices for positioning LCCS, 24-bit ADC, units for generating standardized impulse and monochromatic acoustic (mechanical) impacts, as well as a laptop for data preliminary registration, processing and storage. Experiments are able to register data in a wide frequency range in three modes: 1) without acoustic impacts; 2) with impulse impacts; 3) with monochromatic impacts.



a *b*

Fig. 2. General view of experimental installations for studying acoustic (mechanical) impulse (*a*) and acoustic (ultrasonic) (*b*) impacts on LCCS

To solve the set tasks, a software-algorithmic system was developed, which makes it possible to identify parameters to establish correlation dependences between them and degree of the element discharge.

Mathematical processing of the results was performed using the software described in [15]. To study spectral characteristics obtained under acoustic impacts, a batch of the diagnosed LCCS was divided into groups, and each of them was subjected to one of the types of acoustic exposure.

Using the program of narrow-band filtering, energy distribution in the OCV random process, as well as response to the acoustic (mechanical) impact in a given set of the n frequency bands, was estimated. The program analyzed the OCV tracks after preliminary processing. These traces were filtered with a narrow-band filter, and energy of the narrow-band signal was calculated at the filter output.

Consequently, the n-dimensional vector of energy distribution was assigned to each experiment. The applied data processing procedures are able to significantly minimize the amount of analyzed data and reduce them to a limited number of parameters closely related to the LCCS state. To simplify classification, it is not the power spectra that are compared, but averaged data in the narrow spectral bands (≈ 1–2 Hz) or energy estimates at the outputs of the narrow-band frequency filters set. Thus, averaged multidimensional (up to 100) data vectors (including estimates of the process variance and of the narrow-band spectral components) were obtained suitable for the LCCS comparison and classification. When assessing the LCCS discharge degree, level of the multidimensional vectors' proximity was calculated and evaluated. It became possible to establish components of multidimensional vectors that were most sensitive (informative) to alterations in the discharge degree and those insensitive components that could be excluded from consideration, which also simplified the LCCS diagnostics.

Results and discussion. The studies were carried out on batches (80 pieces) of SL-2780 (*Tadiran*, Israel) and LS-33600 (*SAFT*, France) type elements. Experimental study results and their analysis demonstrated that in the LCCS diagnostics using acoustic spectroscopy it was most expedient to implement correlation dependence of the average noise energy in a given band of the most informative components of the calculated multidimensional vectors on the LCCS discharge degree. Best results were obtained under acoustic (impulse) exposure. For this type of exposure, such dependence was monotonic and had large steepness (modulus of the first derivative). In the range of LCCS discharge degree values of 0–50 %, the correlation parameter values were changing by 5 times. As an example, Fig. 3 shows dependence obtained for a batch of the SL-2780 type elements.

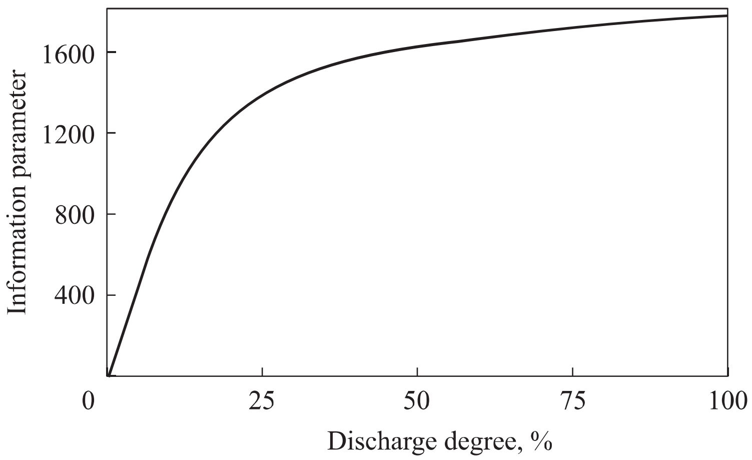


Fig. 3. Correlation dependence obtained as a result of acoustic influences from the LCCS residual capacity

Correlation dependence confirmed its monotony and significant steepness at the LCCS discharge degree of 0–50 %. This makes it possible to reliably diagnose an LCCS in the low discharge degree areas. It was established that using the acoustic spectroscopy allows evaluating the current LCCS state (first of all, its discharge degree) before using it in critical electronic equipment.

Conclusion. Possibility of using the acoustic spectroscopy method to assess residual capacity of the primary lithium-thionyl chloride chemical current sources is demonstrated in the region of low degree of their discharge.

It was established that acoustic spectroscopy allows diagnostics of the LCCS intended for use in critical electronic equipment.

The developed method makes it possible to construct a calibration curve for each type of the LCCS, which is a dependence of the informative parameter on the element residual capacity.

REFERENCES

[1] Lukovtsev V.P., Rotenberg Z.A., Dribinskii A.V., et al. Estimating depth of discharge of lithium-thionyl chloride batteries from their impedance characteristics. *Russ. J. Electrochem.*, 2005, vol. 41, no. 10, pp. 1097–1100.
DOI: https://doi.org/10.1007/s11175-005-0187-8

[2] Kanevskiy L.S., Nizhnikovskiy E.A., Bagotskiy V.S. Possibility of using an impedance meter to diagnose an elements state of lithium-thionyl chloride system. *Elektrokhimiya*, 1995, vol. 31, no. 4, pp. 376–382 (in Russ.).

[3] Petrenko E.M., Lukovtsev V.P., Dribinskiy A.V., et al. Methodical maintenance impedance spectroscopy for lithium chemical power sources. *Elektrokhimicheskaya energetika* [Electrochemical Energetics], 2010, vol. 10, no. 3, pp. 128–132 (in Russ.).

[4] Dribinskiy A.V., Lukovtsev V.P., Maksimov E.M., et al. Sposob opredeleniya ostatochnoy emkosti pervichnogo istochnika toka [Method for determining remaining capacity of primary current source]. Patent RU 2295139. Appl. 21.04.2005, publ. 10.03.2007 (in Russ.).

[5] Rahmoun A., Loske M., Rosin A. Determination of the impedance of lithium-ion batteries using methods of digital signal processing. *Energy Procedia*, 2014, vol. 46, pp. 204–213. DOI: https://doi.org/10.1016/j.egypro.2014.01.174

[6] Astafev E.A. Electrochemical noise measurement of a $Li/SOCl_2$ primary battery. *J. Solid State Electrochem.*, 2018, vol. 22, no. 11, pp. 3569–3577.
DOI: https://doi.org/10.1007/s10008-018-4067-z

[7] Astafev E.A. Wide frequency band electrochemical noise measurement and analysis of a $Li/SOCl_2$ primary battery. *J. Solid State Electrochem.*, 2019, vol. 23, no. 2, pp. 389–396. DOI: https://doi.org/10.1007/s10008-018-4151-4

[8] Astafev E.A. State-of-charge determination of $Li/SOCl_2$ primary battery by means of electrochemical noise measurement. *J. Solid State Electrochem.*, 2019, vol. 23, no. 5, pp. 1493–1504. DOI: https://doi.org/10.1007/s10008-019-04251-3

[9] Petrenko E.M., Lukovtsev V.P. Diagnosis of primary chemical power sources by noise spectroscopy with Fourier transforms. *Elektrokhimicheskaya energetika* [Electrochemical Energetics], 2018, vol. 18, no. 2, pp. 84–90 (in Russ.).
DOI: https://doi.org/10.18500/1608-4039-2018-18-2-84-90

[10] Petrenko E.M., Lukovtsev V.P., Petrenko M.S. Diagnosis of primary chemical power sources by noise spectroscopy with wavelet analysis. *Elektrokhimicheskaya energetika* [Electrochemical Energetics], 2018, vol. 18, no. 2, pp. 77–83 (in Russ.).
DOI: https://doi.org/10.18500/1608-4039-2018-18-2-77-83

[11] Vakar K.V. (ed.). Akusticheskaya emissiya i ee primenenie dlya nerazrushayushchego kontrolya v atomnoy energetike [Acoustic emission and its application for non-destructive testing in nuclear energetics]. Moscow, Atomizdat Publ., 1980.

[12] Stepanova L.N. (ed.). Akustiko-emissionnaya diagnostika konstruktsiy [Acoustic-emission diagnostics of structures]. Moscow, Radio i svyaz Publ., 2000.

[13] Sukhorukov V.V. (ed.). Nerazrushayushchiy kontrol'. Kn. 2. Akusticheskie metody kontrolya [Non-destructive testing. Vol. 2. Acoustic control methods]. Moscow, Vysshaya shkola Publ., 1991.

[14] Bobov K.N., Kubantsev I.S., Lukovtsev V.P., et al. Diagnostics of chemical current sources using noise spectroscopy. *Aktual'nye problemy gumanitarnykh i estestvennykh nauk*, 2016, no. 12-1, pp. 16–19 (in Russ.).

[15] Klyuev A.L., Grafov B.M., Davydov A.D., et al. Analysis of discrete spectra of electrochemical noise of lithium power sources. *J. Solid State Electrochem.*, 2019, vol. 23, no. 2, pp. 497–502. DOI: https://doi.org/10.1007/s10008-018-4156-z

Petrenko E.M. — Cand. Sc. (Eng.), Leading Researcher, Joint Institute for High Temperatures, Russian Academy of Sciences (Izhorskaya ul. 13, str. 2, Moscow, 125412 Russian Federation).

Semenova V.A. — Researcher, Joint Institute for High Temperatures, Russian Academy of Sciences (Izhorskaya ul. 13, str. 2, Moscow, 125412 Russian Federation).

Please cite this article as:

Petrenko E.M., Semenova V.A. Diagnostics of advanced power intensive power sources based on the acoustic spectroscopy method. *Herald of the Bauman Moscow State Technical University, Series Natural Sciences*, 2021, no. 6 (99), pp. 121–127.
DOI: https://doi.org/10.18698/1812-3368-2021-6-121-127