Research methodology for lithium power supply characteristics in non-standard situations

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Abstract. The results of experimental study of structural integrity destruction of lithium-thionyl chloride batteries are provided in the article. The research methodology in non-standard situations was realized using the mechanical damage of the battery body integrity by impact of metal rod on the battery body. Battery charge impact assessment was held during the research process. Pressure change dependences in manometric bomb in the moment of explosion of lithium-thionyl chloride batteries are presented in the paper.

1. Introduction

The lithium-thionyl chloride (LT) batteries are widespread due to high content of energy in weight unit (volume) in comparison with usual chemical elements of power supply [1]. However, the same properties that allow concentrating the greatest possible stock of energy in limited volume increase potential danger in case of fast, uncontrollable energy output (depressurization or explosion of the battery). This process can lead to temperature increase and emission of harmful gaseous products. Destruction of integrity of the battery can lead to explosion and ignition of the contained components. Definition of the service conditions leading to explosion, as well as assessment of its power and thermal impact on surrounding subjects, allows organizing safe and proper use of batteries and minimizes risk of ignition or explosion.

2. Experimental study

One of the tests of LT batteries for explosion safety is mechanical damage of the battery body by piercing or punching by a sharp subject [2]. Thus, not only the battery body tightness is broken, but also there is internal short-circuit causing large discharge currents. This test determines only the possibility of explosion, not assessing its quantitative indices.

To assess the explosion energy, it is proposed to realize the LT battery explosion in a manometric bomb, which is widely applied to study burning of gunpowder and explosives [3]. On the value of pressure in manometric bomb at the explosion of LT battery, it is possible to calculate the trotyl equivalent of an explosion by comparing it with explosive substance. These results can be compared with the known trotyl equivalent of nitro powder [4] to determine the work on the compression of gas.
in a manometric bomb and the total amount of heat released during the subsequent combustion of the LT battery contents.

Assuming the process of battery explosion in a manometric bomb is adiabatic, then from the equation of state, using the value of the peak pressure, it is possible to calculate the mass of smokeless powder, which creates the same pressure when burning in a manometric bomb:

\[ m_n = \frac{p_{max} V}{f_n}, \]

where \( V \) is the volume of manometric bomb; and \( f_n \) is the nitro powder force.

The value of trotyl equivalent for nitro powder is equal \( k_n = 0.66 \), then the value of trotyl equivalent of explosion of LT battery is \( k_b = 0.66 m_n \).

When the content of the LT battery burns after explosion, pressure in the manometric bomb increases due to gas heating. According to the first law of thermodynamics, the change in the internal energy of the gas \( U \) is equal to the difference in the amount of heat \( Q \) supplied to the gas and work \( A \) made by the gas:

\[ dU = dQ - dA. \]

Neglecting change of internal energy of gas and heat losses, the equation (2) can be represented in the form:

\[ dQ = d(pV), \]

where \( d(pV) \) is the work on gas compression in a manometric bomb.

Integrating equation (3) from the beginning of the process until \( t_{max} \) of achievement of maximum pressure in the manometric bomb, for the amount of heat released during LT battery burning we obtain the equation:

\[ \Delta Q = V \int_{t_0}^{t_{max}} p(t) dt. \]

Thus, obtaining the dependence of the pressure change in a manometric bomb, it is possible to quantify the explosive and fire hazard of the LT battery.

Figure 1 shows the design scheme of the manometric bomb of fixed volume for determining characteristics of LT battery explosion. In the assessment of explosion energy of LT batteries the manometric bomb with inner diameter of 120 mm and with a volume of 2 liters was used. A sharpened metal rod with a diameter of 4.5 mm and a length of 40 mm was used as a punching device.

3. Results of research
The carried-out series of experimental studies allows estimating the influence of lithium-thionyl chloride batteries under the impact of a sharpened metal rod on the battery body. Experimental studies with the uncharged battery have shown that at additional charge from 0.15 g of smokeless gunpowder the rod punches the battery through. Thus, maximum pressure in manometric bomb does not exceed 0.01 MPa. When testing a charged LT battery, at the moment of breaking through the rod an internal short circuit occurs, which is accompanied by the ejection of electrolyte vapors (explosion) and a pressure peak from a few tenths to megapascals. Therefore, gas formation from combustion of additional charge gunpowder can be neglected.
Figure 1. The scheme of manometric bomb for determining the characteristics of explosion of LT battery: 1 – chamber; 2 – cover; 3 – ring nut; 4 – gasket; 5 – bolt with axial opening; 6 – adapter with electric igniter; 7 – stopper; 8 – the metal sharpened rod; 9 – igniter; 10 – additional charge of gunpowder; 11 – central electrode; 12 – insulator; 13 – pressure sensor; 14 – gas relief valve; 15 – spherical valve; 16 – LT battery; 17 – substrate; 18 – system of removal of gas.

Figure 2 presents dependences of pressure change in the manometric bomb at explosion of ER34615M LT batteries made by the «EVE ENERGY» (a) and made by the «FANSO» (b). The value of trotyl equivalent for ER34615M batteries is not great (0.0005 for LT battery made by the EVE ENERGY and 0.00033 for LT battery made by the FANSO). However, total heat release at the subsequent burning of contents of LT battery is considerable (3.9 kJ for LT battery EVE ENERGY and 4.6 kJ for LT battery FANSO).

Figure 3 presents dependences of pressure change in the manometric bomb at explosion of LT batteries EXIUM 130916-01H DD (a) and SCS93DD 3B63 (b).

The value of trotyl equivalent for batteries of DD type much exceeds the value for ER34615M batteries (0.0024 for LT battery EXIUM 130916-01H and 0.0072 for LT battery SCS93DD 3B63). Total heat release at the subsequent burning of contents of the LT battery is considerable (15.6 kJ for the LT battery EXIUM 130916-01H DD and 19.9 kJ for the LT battery of SCS93 DD 3B63).
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