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DESIGN OF LI-ION BATTERIES FOR PORTABLE ELECTRIC TRANSPORT

Abstract. During the work, the designs of traction batteries for portable electric transport were considered and analyzed. Serious flaws have been revealed that battery manufacturers carefully hide. The inability of balancing BMS boards to prevent long-term effects of overcurrent on elements has been theoretically proven. The next task of our research was the design and manufacture of the first Li-ion battery, which in its design was similar to factory analogues. During the operation of the battery, the inability of the BMS board to regulate the charge current was practically observed. After analyzing the shortcomings of the first Li-ion battery prototype, they concluded that it was hopeless. The production of the second Li-ion battery, taking into account the shortcomings of the previous prototype, and its operation did not meet the expectations of the authors. And she also pointed out her hopelessness.

Keywords: Li-ion batteries, balancing BMS boards, overcurrents, service life.

The rapid development of society and progressive population growth in the 20th and 21st centuries have led to significant environmental problems. Internal combustion engines (ICEs) and industrial facilities, which are the cause of greenhouse gas emissions, pose a considerable danger to the environment. Mankind is making a lot of efforts to solve the issue of global warming. One of the main achievements of civilization in the 21st century is the beginning of the process of replacing internal combustion engines with engines with zero greenhouse gas emissions, such as electric ones. Electrification of transport is one of the important measures to overcome the climate crisis.

In parallel with the conversion of traditional transport (cars, buses, cars, trucks) to electric traction, there is a rapid development of portable electric transport, such as: scooters, bicycles, quad bikes, maps, scooters, motorcycles, gyroboards, gyroscooters, unicycles, etc. Previously, the problems faced by consumers when using portable electric vehicles were analyzed [1].

As you know, the main unit of electric transport is a battery (AB), which has a limited number of cycles. ABs gradually lose their capacity, degrade, fail and as a result require partial or complete replacement. The most popular now are batteries with Li-ion cells of standardized sizes. The variety of modern lithium-ion batteries for electric bicycles is due to a wide range of technical characteristics. They differ in nominal voltage, capacity, current output, the presence of a hard case, and standard sizes. But there is one thing that connects all lithium-ion batteries regardless of their technical characteristics. This is a design flaw that leads to rapid degradation of elements and a noticeable loss of battery capacity. The fact is that the set of lithium-ion batteries that form the battery is located in the case, and each element is welded to another with the help of a metal tape. It is clear that it is extremely difficult to disassemble such a structure, and it is completely impossible to diagnose each element after the battery has been used. The manufacturers assure that the balancing BMS board installed on the battery prevents deep discharge and fully controls its charge, each battery is charged to 100% and does not suffer from excessive overheating. Earlier [1] we theoretically described the helplessness of the BMS board in balancing AB assemblies, and now we will tell about our own experience of using a Li-ion battery together with a BMS board and its consequences.

Battery № 1. The idea to build our own Li-ion battery came to us while browsing the range of electric bike kits. We were impressed by the price/capacity ratio and the significant amount of negative customer feedback. It was decided to manufacture its own Li-ion battery for 21 A*h with a nominal voltage of 36V, using Li-ion cells "18650". The purchase of elements with a declared capacity of 3.3 A*h was made on the AliExpress trading platform. The design of the battery included 10 serially connected assemblies of 7 cells each. Thus, the battery consisted of 70 Li-ion cells. To protect and "balance" the elements in discharge and charge modes, a 10S36V BMS board [2] was connected according to the diagram in (fig. 2). Balancing wires of the BMS board in (fig. 1) in red insulation.

Figure 1. The first 21 Ah, 36 V Li-ion battery with BMS board

Design features:

- "18650" cell holders in the form of honeycombs, which were purchased on AliExpress, were used;
- honeycomb holders were additionally equipped with bronze threaded bushings (glued with epoxy glue);

- branches from the elements are made with a flexible wire PV3 1*0.75 with the help of soldering to the element and pressing with a copper, tinned tip towards the assembly;
- each element could be disconnected from the assembly for the purpose of diagnosis and recharging, for which a screw connection on the assemblies was used;
- the hams of the assemblies were made of strip bronze, had an open design for the possibility of voltage measurement and separate recharging of the assemblies;
- prompt replacement of defective or "sick" elements was not foreseen.

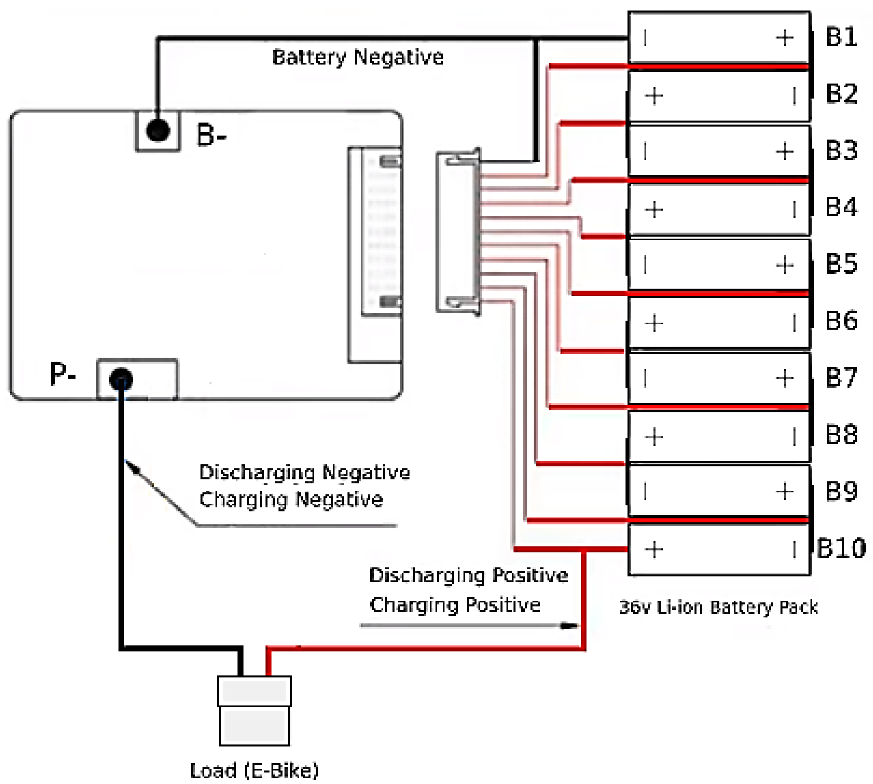

Figure 2. Battery connection diagram to the BMS board 10S36V

Operating experience.

1. After the first ten cycles, a rapid decrease in the battery voltage during discharge and, as a result, a reduction in mileage due to the operation of the deep discharge protection in the bicycle controller became noticeable. The measurements showed that one of the assemblies discharges more than the others. During charging, the voltage on it did not even approach 3.8 V (approximately 20% charge), while the voltage on other assemblies was at the level of 4.25 V. The balancing function in the BMS of the board worked, the charger stopped the charge mode, because the total voltage of the battery reached the maximum 42 V. After the charging cycle was stopped, the "healthy assemblies were recharged to 4.22–4.23 V, while the "sick" assembly remained at the level of 3.8–3.9 V. It became obvious that the BMS board is not able to equalize the resistances of the assemblies to acceptable values at a charge current of more than 1 A. Observation of the "sick" assembly also indicated its significant self-discharge, somewhere at the level of 0 .01V per hour. Compensation

for this defect required individual recharging of the assembly immediately before the trip, which in turn increased the number of manipulations and time and caused certain inconveniences. So, the BMS board with a nominal balancing current of 30 mA turned out to be absolutely helpless at charge currents of 1 A and above.

2. The mass and dimensions of the battery turned out to be too large for its placement on the bicycle trunk.

3. The battery capacity turned out to be excessive for a motor-wheel with a power of 350 W and for a cyclist weighing 70 kg. The battery was discharged to 10…15% of the remaining capacity only after 2–3 long trips.

It is clear that the reason for the deviation of the parameters of the "sick" assembly is the degradation of one or more elements of this assembly. The equalizing charge of the assembly is not a panacea, since the distribution of the charge current between the parallel elements is predicted to be uneven. That is why the processes of undercharge and overcharge of elements in the assembly remained and caused their rapid degradation. In the design of the battery under consideration, there was a possibility of separating individual elements for diagnosis and recharging, but it was used only a few times. A significant number of operations to control the condition of the elements, the difficulty of replacing faulty elements, the potential danger of creating a short circuit during maintenance, and the huge labor cost of manufacturing became decisive in recognizing such a design as a failure.

Battery № 2. The goal of creating a new Li-ion battery design was the desire to obtain an AB with the possibility of rapid analysis to the level of a single cell. This would make it possible to apply a combined charging cycle, which means a preliminary charge of the entire battery assembly to the level of 50%, quick disassembly of the battery and subsequent recharging of each element in the charging station. This method of charging was supposed to make it impossible to overcharge the elements and provide the possibility of operational control of the parameters of each element according to the indicators of the charging station.

This time we decided to design a battery for 15 A*h, 36 V. The battery consisted of 10 serially connected assemblies of 5 elements each. Thus, the AB consisted of 50 elements of the "18650" type.


Figure 3 – Second Li-ion battery for 15 A*h, 36 V assembled and top view

For individual charging of 50 cells on the AliExpress trading platform, they purchased 3 universal charging devices (hereinafter ZP) "MIBOXER C8" [3] (Fig. 4) for 8 cells each. Functionality:

1. LCD screen, which displays the parameters of each element (charge level in percentage, voltage, charge current, charge time, internal resistance and capacity transferred to the element).

2. The presence of a combined charge algorithm (stage 1 – maintenance of the specified charge current, stage 2 – stabilization of the voltage upon reaching the upper level on the element).

3. Availability of 8 independent channels.

4. Automatic determination of the type of batteries, disconnection of the slot in the event of a short circuit, signaling of a malfunction of the element and installation of the element in the slot with reverse polarity.

5. Manual adjustment of the charge current of a separate cell in the range of 0.1 ... 1.5 A, which allows you to charge small capacity elements.

6. Charging deeply discharged batteries with ultra-low current followed by switching to a combined cycle.

Figure 4. Charger (ZP) "MIBOXER C8"

Three ZPs were mounted on a box-type plywood frame and received a rather compact charging station for 24 cells (Fig. 5) with the possibility of expansion to 32 cells. In the middle of the frame, 220 V sockets and power supply units of the ZP were placed.

Figure 5. Charging station based on "MIBOXER C8" for 24 elements

Let's go back to the battery. Design features (Fig. 6):

1. Already known honeycomb holders are used.

2. Copper strips and foiled fiberglass are used as assembly bars.

3. We used elastic elements purchased on AliExpress (steel springs on a steel holder), which were soldered to the conductive bronze layer of fiberglass.

4. The electric circuit of each element should be formed as a result of contact with the material

of the bars of the upper and lower bases of the cassette.

Already the first cycles of operation of the battery revealed a number of shortcomings.

1. Unstable capacity return.

2. The difficulty of assembling the battery, namely, putting the upper base on the upper edges of the 50 elements installed in the lower base. They had to get into their cells at the same time. Pulling the upper and lower bases through the threaded pins required their compression with a force of at least 20 kg, which had to be done on the floor, "riding" the battery.

Figure 6. Upper and lower bases of the AB cassette

3. Unsatisfactory aesthetic appearance and the presence of rather sharp protruding parts.

4. The need to remove the battery from the bicycle every time.

If 2–4 defects could be explained and attributed to the pilotability of the design, then the first one had signs of an engineering error.

An excessive number of contact connections are used in the design of the current-carrying parts of the battery. Each element was in contact with the current-conducting parts of the bases, which included: steel springs, rolled in steel, nickel-plated holders, soldered to a bronze layer of foiled fiberglass; copper plates with tin solders, connected to each other with copper wires by the soldering method, etc.

The second mistake was the use of cell holders. The spread of the honeycomb cell caused a fairly tight insertion of the element. The holes in the honeycomb holders of the upper base were drilled to a larger size and conical shape for self-centering of all elements and to achieve acceptable values of the compressive force of the bases (according to the criterion of their rigidity) and reliability of contact at the poles of the elements. However, it was not possible to achieve satisfactory results in improving the reliability of the electrical contact, especially in the lower base of the cassette. Too much variation in the values of transient resistances in the circuits of individual elements and, even, the complete "non-connection" of an element affected the participation of each element in feeding the load and led to the constant failure of the elements due to current overloads in the discharge cycle.

Another problem arose later. After each trip, all elements were charged. However, after storing them for several days and re-installing them in chargers, a tendency to increase the number of cells with a high level of self-discharge was recorded. Inspection of such elements revealed a change in the color of the film insulation around the positive pole (Fig. 7). The dissection of the film insulation in the places of color change indicated the depressurization of the elements, the release of electrolyte along the rolling, which caused a short circuit between the poles of the elements.

Cleaning and restoration of insulation gaps made it possible to “bring back to life” most of the damaged elements (those that could continue to be used as part of the traction battery based on the value of the residual capacity). The elements that were connected to the assemblies through small transition resistances ended up in the mode of long-term current overload. This caused them to overheat, increase internal pressure and leak electrolyte or fail completely.

Figure 7. An element with a high level of self-discharge through a layer of dried electrolyte

Having analyzed the main problems of the second AB prototype:

- low reliability and lack of protection against ingress of moisture;
- danger of short-circuit of the entire assembly of elements due to leakage of electrolyte from at least one element to the lower base of the cassette, which threatens to catch fire;
- time-consuming process of filling the battery with elements, etc.

Thus, after analyzing the shortcomings of the first Li-ion battery prototype, they concluded that it was hopeless. The production of the second Li-ion battery, taking into account the shortcomings of the previous prototype, and its operation did not meet the expectations of the authors. And also pointed out its futility, that is, they came to a conclusion about the futility of further modernization of such a structure. Therefore, we came to the conclusion about the need to create our own Li-ion battery design, which will be the goal of further research.

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