Design and Operation Verification of Integrated Battery Assembly Charger Using Cockcroft Walton Circuit

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Abstract
The new concept of charger for lithium ion battery assembly with several unit cells has been proposed and tested. The Cockcroft Walton (CW) circuit developed as a high voltage multiplier was applied for the battery charger of lithium ion battery assembly. The some capacitors in CW circuit were substituted with unit cells to design the charger circuit. This charger circuit worked well for the individual unit cell of integrated battery assembly. It is also considered that the wide application is feasible because of its simple circuit.

Keywords
Cockcroft Walton circuit, charger, integrated battery assembly

1. INTRODUCTION
Improper charge of the batteries may cause poor performance, heating, fire, explosion, damage, etc. It is important to design the appropriate charger for maintaining the good performance of secondary batteries especially in the integrated battery assemblies [Takehara, 1998]. The battery charger is specifically designed to produce the maximum performance and life for each battery. For this purpose, some protection circuits such as over voltage protection, over charge timer, temperature monitor, etc are combined in charger devices [Takamura, 1996].
The additional protection devices are, however, needed to prevent the over charge and imbalanced capacity of any unit cell for the charger of integrated battery assembly, and the switching circuit and voltage control IC for each cell monitor are added to the charger. Accordingly, many parts are needed for the design of charger, and the circuit becomes complex. In these situations, a simple charger is required for any battery especially for integrated battery assemblies [Takagi et al., 2005].

2. COCKCROFT WALTON CIRCUIT AND CHARGER OF INTEGRATED BATTERY ASSEMBLY
One of the cheapest and popular ways of generating high voltages at relatively low currents is the classic multi-stage diode/capacitor voltage multiplier, well-known as Cockcroft Walton (CW) multiplier [Cockcroft et al., 1932]. Figure 1 shows the CW circuit with capacitors (C_1, C_2, C_3, -C_n) and silicon diodes (D_1-D_n). The anode half cycle of alternating current (±V volt) as an example of input is applied to cause the charge of C_1 (V), and the next cathode half cycle causes the discharge of C_1 and charge of C_2 up to 2V. In the same manner, C_3, C_4 -C_n are charged up to 2V, and out put voltage gives 2nV.

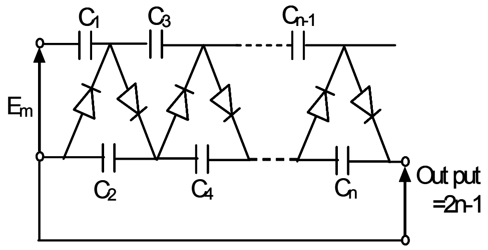

Fig. 1 Cockcroft Walton circuit

When C_2-C_n are substituted with the lithium ion cells with the operating voltage of 4 V ($Cell_1$ and $Cell_n$), it is considered that the charge of the cells proceeds up to 4V. The performance of unit cell in the battery assembly is usually different each other even for new batteries. If one of the unit cells gives lower voltage (V') in the integrated battery assembly, the charge of every unit cells proceeds up to V'. Accordingly, it is possible that this charge circuit prevent the damage by overcharge. Since the commercial battery chargers operate usually

as a charger of whole unit cells under same conditions, some unit cells are overcharged in certain cases.
The voltage response of capacitors in CW circuit varies in a linear fashion, but the characteristics of batteries are nonlinear. Accordingly, it is necessary to confirm the operation of charger using CW circuit. Another feature of the battery charger designed by CW circuit are that the circuit is simple to design it at low cost.
Usually every unit cells of battery assembly are charged under the same conditions. Since the unit cells varies each other in the value of capacity, this charge method are liable to cause the overcharge for the unit cell with the lowest capacity. In the charger proposed in the present paper, every unit cells are independently charged to avoid the overcharge. Furthermore, the output voltage of charger circuit may be used for other purposes during charging.

3. LITHIUM ION CELL TESTED AND CHARGER CIRCUIT

3.1 Lithium ion model cell

The lithium ion model cells used for analysis of charger operation were constructed as shown in Figure 2. Cathode mix of $LiMn_2O_4$ and acetylene black was dispersed in organic solution, and then applied on aluminum current collector. The amount of the active material was about 2mg, and corresponded to a capacity of 0.3mAh. Anode and reference electrode were lithium. Electrolyte was a 1 M $LiPF_6$ solution of EC-DEC (50:50 by volume %).

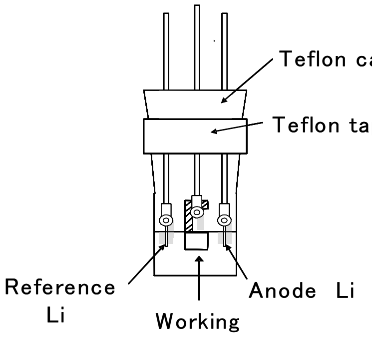

Fig. 2 Preparation of lithium ion model cell

3.2 Charger circuit and measurement of charge process

Figure 3 shows the charger circuit used for the charge of two model unit cells. The electrolytic capacitor C_1 (2200μF and 35V) and the silicon diodes (D_1-D_3) for rectifier were used. $Cell_1$ and $Cell_2$ were arranged in the charger circuit as shown in Figure 3. The positive current of 10μA (or 100μA) was applied to a-b terminal by a potentio/galvanostat (Hokuto Denko, HA-151). When the voltage of C_1 increased to 4.3V, the applied current was switched to -10μA. After the voltage of C_1 decreased to 2.8V, the applied current was again switched to 10μA. These manners were repeated to monitor the voltage of C_1, and $Cell_1$ and $Cell_2$. The charge voltage was regulated by the voltage of capacitor C_1, and the constant current was applied as shown in Figure 4.

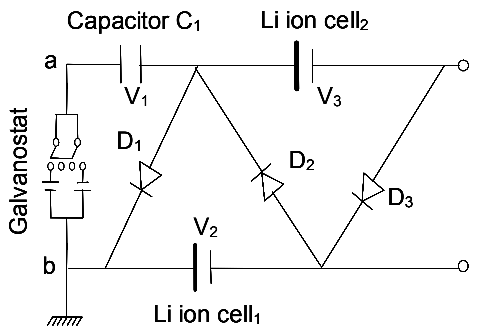

Fig. 3 Design of charger using Cockcroft Walton circuit

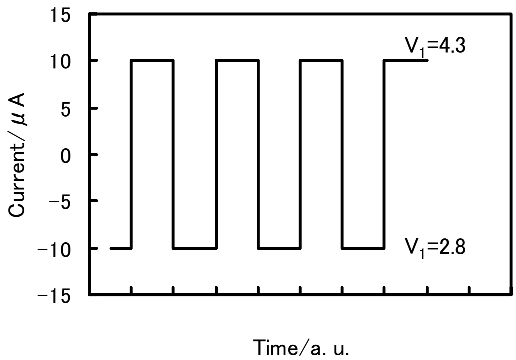

Fig. 4 Relationship of applied current and voltage V_1 of capacitor C_1 during charge

4. RESULTS AND DISCUSSION

Figure 5 shows the change in the voltages of C_1, $Cell_1$ and $Cell_2$ during the charge using the charger circuit of Figure 3. The initial cycles are shown as the enlarged

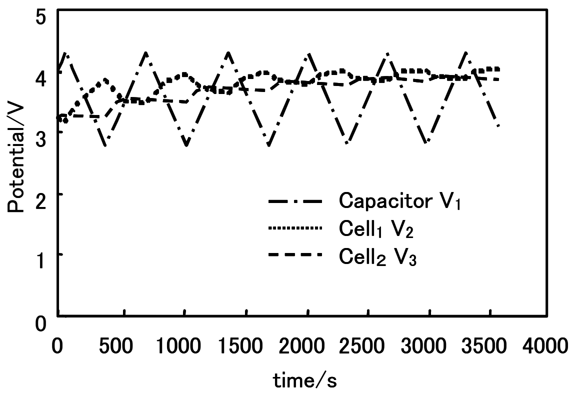

Fig. 5 The change in charge voltage of lithium ion cells at 10μA

figure. When the current of 10μA was first applied, the voltage (V_1) of C_1 increased linearly to 4.3V after 65s by charge of C_1. In this period no significant voltage change of $Cell_1$ (V_2) and $Cell_2$ (V_3) was observed.
The applied current was next switched to -10μA. The linear decrease in V_1 shows the discharge of C_1, and the voltage ($Cell_1$) of V_2 increases gradually by the progress of charge reaction. In this charge process of $Cell_1$, no charge or discharge of $Cell_2$ occurs, because the voltage remains constant.
Then, the current was again switched to 10μA after the voltage of C_1 reached to 2.8V. It is indicated from the change of voltage that the discharge of C_1 causes the discharge of $Cell_1$ and charge of $Cell_2$. The subsequent switching of applied current was repeated, and resulted in the charge of $Cell_1$ and $Cell_2$, the voltage of which increased gradually to 4.01and 3.88V after 3800s, respectively.
Figure 6 shows the charge process at the applied current of ±100μA. Since the applied current increased, the charge time decreased and the voltage of $Cell_1$ and $Cell_2$ became 4.10 and 4.13V after about 900s, respectively. Consequently, the charger using CW circuit worked well as the charger of unit cells in the integrated battery assembly. It is expected that this idea for the charger can be applied to other battery systems. Further studies are now being in progress for the development of a new charger system.

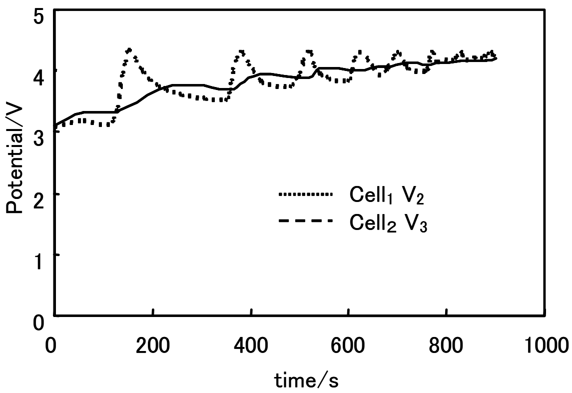

Fig. 6 The change in charge voltage of lithium ion cells at 100μA

CONCLUSION

The new concept of charger using CW circuit for lithium ion battery assembly has been proposed. The results obtained as follows.

(1) The designed charger worked well for unit cells of integrated battery assembly.
(2) The design is very simple to preparation of the charger circuit.
(3) It is considered that the charger is applicable to a wide variety of battery systems.

References

Takehara, Z., *High Power Secondary Lithium Batteries*, *Chapter 9*, Techno-system, 1998.

Takamura, T., *Battery Handbook*, p. 60, Asakura, 1996.

Takagi, S and T. Matsusima, Japanese Patent Kokai, No. 2005-20866.

Cockcroft J. D. and E. T .S. Walton, Experiments with High Velocity Positive Ions, *Proceedings of the Royal Society, Series A*, Vol. 136, 619-630, 1932.

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