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Battery Management for the Electric Hydraulic Pump System of a Lifting Trolley

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Abstract: This study proposed a battery management approach for the electric hydraulic pump system of a lifting trolley. The pump system was powered by two 12-V lead-acid batteries in series. Because direct measurement of the actual battery state of charge is unlikely, it has mostly been determined through estimation based on the measured open-circuit voltage. A discharge current will result in a voltage drop and hence a lower voltage during discharge; however, the battery voltage will return to the original open-circuit voltage once the discharge stops. The operating current of the electric hydraulic pump system employed in this study was associated with three factors: the lifting height, lifting load, and battery state of charge. The operating current remained constant during the first half of the lifting phase and increased gradually with the lifting height in the second half. The operating current peaked when the lifting height reached the maximum. The power management approach for the electric hydraulic pump system featured the following basic functions: overcharge protection, overdischarge protection, short-circuit protection, overload protection, and an operating timer established in accordance with the system's operating current variation. According to the manufacturer-defined maximum lifting load and lifting height of the lifting trolley, this study conducted experiments to obtain the maximum required operating time. An operating time greater than the maximum required operating time indicates the occurrence of an unexpected event, discharge should be stopped until the fault is resolved.

Key words: Battery management, lead-acid battery, electric hydraulic pump system.

1. Introduction

This study proposed a battery management approach for the electric hydraulic pump system of a lifting trolley. Two 12-V lead-acid batteries in series powered the pump system. The lifting trolley had a maximum lifting load of 300 kg and a maximum lifting height of 600 mm.

A lead-acid battery cell exhibits an electric potential difference of 2.1 V; therefore, the most common 12 V lead-acid batteries on the market are actually composed of six cells in series [1]. Fig. 1 presents the relationship between the open-circuit voltage and state of charge of a battery. Because direct measurement of the actual battery state of charge is unlikely, it has mostly been determined through estimation based on the measured open-circuit voltage. Generally, the voltage of a fully charged lead-acid battery is 14.4 V, and it decreases gradually as the discharge time increases. An excessively low level of charge is indicated when the voltage falls below 10.8 V, which is the generally recommended latest time point when the discharge should stop.

The voltage of a lead-acid battery is related to its discharge current and internal resistance, as shown in Eq. (1):

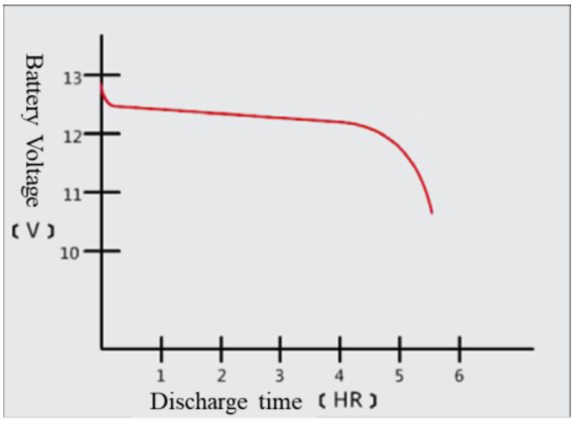

Fig. 1 Relationship between the open-circuit voltage and state of charge of a battery.

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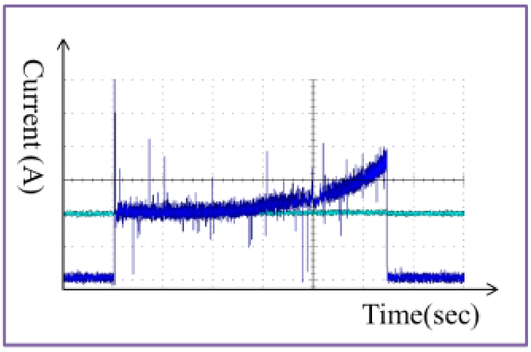

Fig. 2 Operating current variation of the electric hydraulic pump system during lifting.

$$E = E_0 - I \times r \tag{1}$$

where E is the voltage during discharge; E_0 is the open-circuit voltage; I is the discharge current; and r is the battery's internal resistance. The product of I and r denotes the internal voltage drop of the battery. According to Eq. (1), a large discharge current (I) will result in a large voltage drop and hence a low voltage (E) during discharge; however, the battery voltage will return to the original open-circuit voltage (E_0) once the discharge stops.

2. Character of the Operating Current in the Electric Hydraulic Pump System

The operating current of the electric hydraulic pump system employed in this study was associated with three factors: the lifting height (*H*), lifting load (*W*), and battery state of charge (*C*). The state of charge level is represented using open-circuit voltage in the following paragraphs. Fig. 2 depicts the system's operating current variation when it increased the lifting height (*H*) from 0 to 600 mm. The operating current remained constant during the first half of the lifting phase and increased gradually with the lifting height (*H*) in the second half. Let the starting current be *Is*, ending current be *Ie*, and the required operating time be *T*, with $Is \le Ie$. The operating current peaked when the lifting height reached the maximum of 600 mm.

3. Experimental Result

Fig. 3 depicts the operating current of the electric hydraulic pump system when it increased the table height (*H*) from 0 to 600 mm with the same state of charge (*C*) and a load (*W*) of 150 or 300 kg: when *W* = 150 kg, *Is* = 8 A, *Ie* = 11.5 A, and *T* = 17 sec; and when *W* = 300 kg, *Is* = 12 A, *Ie* = 19.5 A, and *T* = 22 sec. The system exhibited a greater starting current (*Is*), ending current (*Ie*), and required operating time (*T*) when it had a 300-kg load than it did with a 150-kg load. Accordingly, in the same state of charge (*C*), a load (*W*) rise increased the operating current and extended the operating time (*T*).

Fig. 4 presents the operating current of the system when it increased the lifting height (*H*) from 0 to 600 mm with the same load (*W*) and an open-circuit voltage of 11.5 V (low level of charge) or 12.6 V (high level of charge). When the open-circuit voltage was 11.5 V, *Is* = 11.5 A, *Ie* = 19.5 A, and *T* = 21.6 sec; and when it was 12.6 V, *Is* = 12 A, *Ie* = 19 A, and *T* = 18.8 sec. The different levels of charge resulted in a < 5% difference in operating current and a > 12% difference in operating time. Accordingly, under the same lifting height (*H*) and load (*W*) conditions, the operating current remained the same regardless of the level of charge; however, the low level of charge resulted in a poor power supply and hence an extended operating time (*T*).

The system's operating time was directly proportional to lifting height (*H*). Additionally, the aforementioned experimental results revealed how the load (*W*) and battery state of charge (*C*) were related to the system's operating current and lifting height (*H*) as shown in Fig. 5. The system's operating current was constant when lifting height (*H*) and load (*W*) remained the same, regardless of the battery state of charge (*C*). With the state of charge (*C*) held constant, a smaller load (*W*) resulted in a smaller operating current and shorter operating time, whereas a larger load (*W*) resulted in a greater operating current and longer operating time.

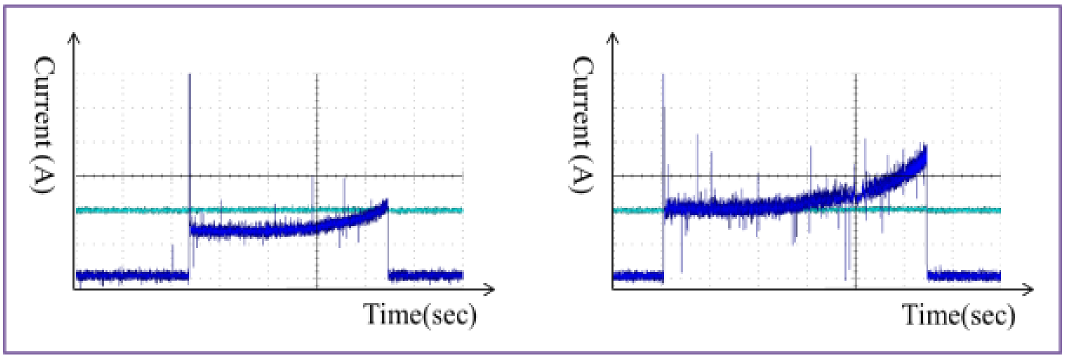

Fig. 3 Operating current variation of the electric hydraulic pump system during lifting with the same state of charge and a load of 150 kg (left) or 300 kg (right).

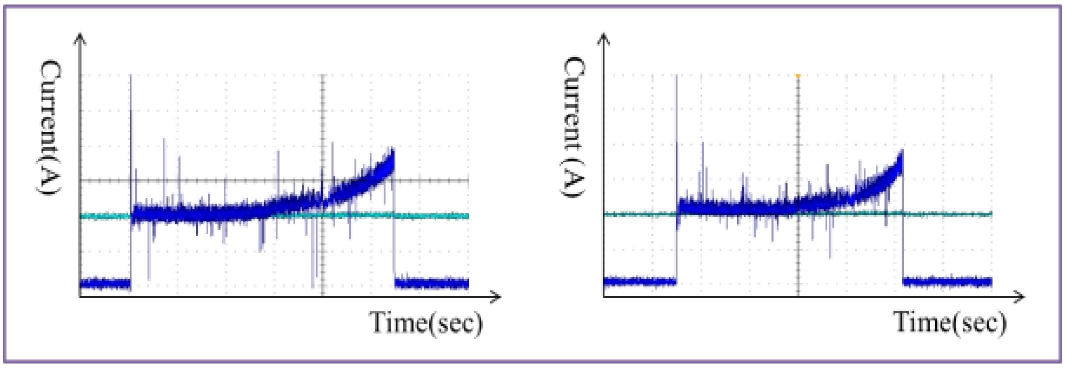

Fig. 4 Operating current variation of the electric hydraulic pump system during lifting with the same load and a low (open-circuit voltage = 11.5 V; left) or high (open-circuit voltage = 12.6 V; right) level of charge.

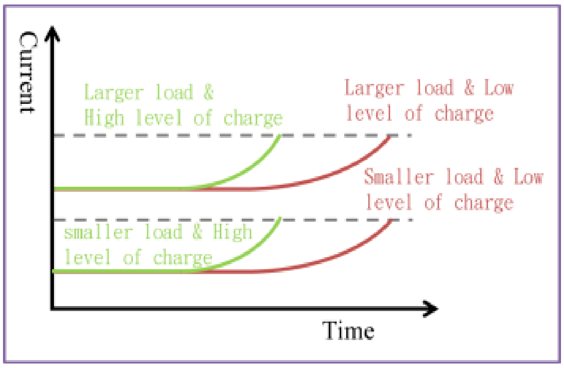

Fig. 5 Operating current of the electric hydraulic pump system.

4. Conclusions

The power management approach for the electric hydraulic pump system featured the following basic functions: overcharge protection, over-discharge protection, short-circuit protection, overload protection [2], and an operating timer established in accordance with the system's operating current variation. Overcharge of a lead-acid battery will result in the water inside being electrolyzed into hydrogen and oxygen; the increase of gas in the battery will then cause the internal pressure to rise, thus damaging the battery casing and even causing fire or an explosion. Therefore, battery charging must stop when the battery voltage surpasses 14.4 V. Over-discharge of a lead-acid battery will lead to the supersaturation and precipitation of lead sulfate, a product of the electrochemical reaction, and also sulfation of the battery, in turn reducing the battery's capacity and life. Accordingly, battery discharge must stop when the battery voltage falls below 10.8 V. According to the manufacturer-defined maximum lifting load and lifting height of the lifting trolley, this study conducted experiments to obtain the maximum required operating time (T_0). An operating time greater than T_0 indicates the occurrence of an unexpected event, such as the trolley being unable to lift to the expected height due to external forces; in this case, to ensure the safety of personnel and prevent damage to the trolley's mechanical structure, discharge should be stopped until the fault is resolved.

References

[1] Taiwan Yuasa Battery Co., Ltd. 2016. "Car Battery Characteristics." http://www.yuasa.com.tw/service_and_knowledge03.php?lang=.

[2] Chatzakis, J., Kalaitzakis, K., Voulgaris, N. C., and Manias, S. N. 2003. "Designing a New Generalized Battery Management System." *IEEE Transactions on Industrial Electronics* 50 (5): 990-9.