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SECONDARY BATTERIES SESSION. MONITOR/CONTROL AND WARNING SYSTEM--ETC(U)
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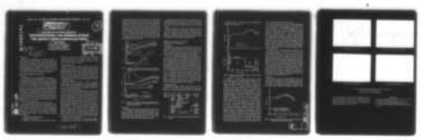

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SECONDARY BATTERIES SESSION.

MONITOR/CONTROL AND WARNING SYSTEMS FOR AIRCRAFT NICKEL-CADMIUM BATTERIES

Martin J. Sulkes
Power Sources Technical Area
US Army Electronics Technology and
Devices Laboratory (ECOM)
Fort Monmouth, New Jersey 07703

Introduction

Because of the possibility of "thermal runaway"[1] in nickel-cadmium aircraft batteries, the FAA required that all civil aircraft that use Ni-Cd batteries for engine starts would have to be equipped with a device to sense impending thermal runaway or a controlled charging system. This work considered the suitability of various commercial monitor/warning devices for use in Army aircraft, as well as one type of monitor/control on-board charging device.

MONITOR/WARNING SYSTEMS

Description

a. Thermal Measurement Monitor/Warning Systems

Measurement of battery temperature is a valid method for determining the presence of thermal runaway. Degradation of Ni-Cd batteries, particularly the cellophane separator, is a function of temperature. A very low temperature limit, such as 55°C or less, which may result in some nuisance signals, can provide a warning before extensive degradation has taken place. Consideration must be given to sensor location. Sensors may be placed within a cell, between cells, on a cell terminal or intercell link, on a metal heat collector plate, on a case interior wall, or pressed up against the battery case. Typical temperature ranges used for warning and/or caution indications are 55-71°C. Sensors may be thermal switches, thermistors, or thermocouples.

b. Current Measurement Monitor/Warning Systems

Current level detectors provide a visual indication when battery charging current exceeds the specified maximum steady state value, typically the C/3 to C/5 charging rates. These current values are normally exceeded immediately after startup of an aircraft for up to 10 minutes, and will not be exceeded again, except if a thermal runaway condition has developed.

c. Change of Current Measurement Monitor/Warning System

The initiation of a thermal runaway condition is accompanied and caused by an increase in current. Therefore, measurement of the rate of change of current with time (di/dt) should provide a relatively early indication of the onset of thermal runaway conditions.

Experimental Results

Rather than conduct extensive testing with individual devices, it was decided to fully instrument batteries undergoing high stress conditions simulating the operation of the OH-58A helicopter. The voltage, current, and thermal profiles of the battery under various conditions, including thermal runaway, were determined. Starting loads were simulated by a 300 A discharge for 20 seconds. Recharge was accomplished with a 150 A, OH-58A generator driven by a 7.5 hp electric motor.

When the BB-676/A battery with intact cellophane barrier separators was subjected to a constant potential of 28.4 V after a high starting load, with an initial temperature of 38°C, no thermal runaway was induced even when the battery contained one shorted cell.

Figure 1 gives the data obtained during a test of a BB-676/A with destroyed gas barriers and one shorted cell. This test clearly shows the cell to cell temperature variations. Warning signals would have been received from all devices. The case device set at 55°C for caution and 60°C for warning would have provided an early indication of a thermal runaway, (Points D and E, respectively, of Fig. 1). While the link mount device set at 65°C provided, first, a false indication (Point C), it then required 70 minutes to signal (Point F). The current level sensor provided the earliest indication since the current never fell below the minimum cutoff level. The di/dt device is considered extremely marginal based on a design sensitivity of 0.1 A/min using a 50 mV for 100 A shunt as the signal source, since the rate of current increase was consistent at approximately 0.1 A/min over a 50 minute period.

Another test, shown in Figure 2, measured the temperature distributions that would occur if a single cell hot shorted during charge. In this test one cell (#12) was deliberately hot shorted approximately 10 minutes after startup. The affected cell reached a temperature sufficient to evaporate electrolyte and char the separator and case. However, because of the localized nature of the heat, the link sensor did not generate a warning signal. The battery case temperature signals would have been somewhat more prompt, but were still 20° different from the battery internal temperature. In this test the di/dt device would have signaled shortly after the cell was shorted. The current level detector remained lit throughout the entire charge, as the current never fell below the minimum cutoff value.

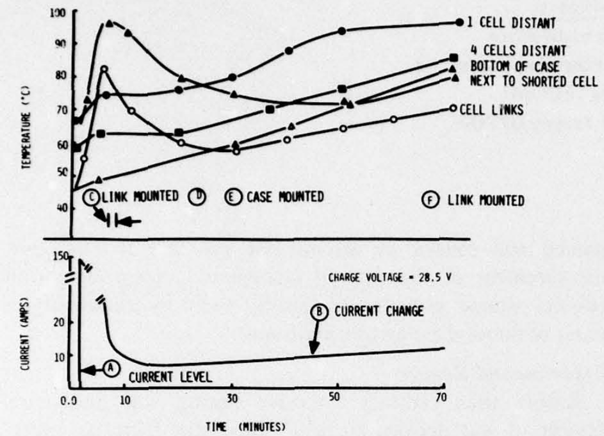


Figure 1. Temperature and current during constant potential charge of BB-676/A containing cells with destroyed gas barriers plus one shorted cell.

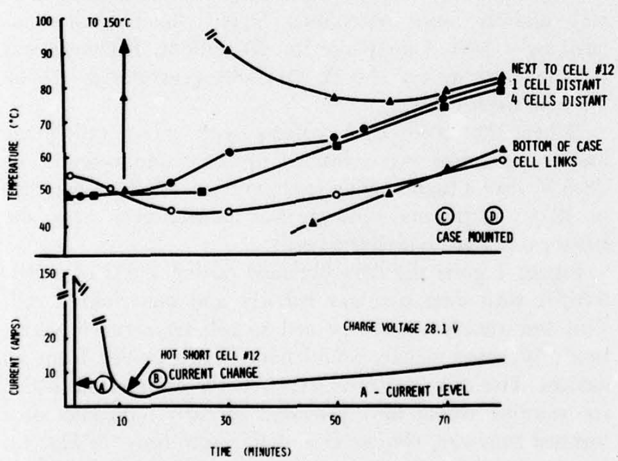


Figure 2. Temperature and current during constant potential charge of BB-676/A containing cells with destroyed gas barriers, hot short generated in cell #12.

Conclusions

Thermal runaway is generally caused more by the internal state of the battery than by the external temperature or bus voltage. Therefore, a device which only indicates the onset of thermal runaway will only protect the aircraft and not extend battery life significantly. However, if only safety requirements must be met, the following is applicable:

A current level sensor will provide an early indication of a potential problem. It only requires a shunt in the line as the signal source. Proper interpretation by the pilot is required as to how long current should exceed the set point after startup.

Thermal measurement on links can result in wide variations from actual battery temperature. Externally mounted case sensors which do not require battery modification can provide a reasonably accurate indication of high battery temperature. The best location for a thermal sensor would be between cells or mounted on a thermal collector.

MONITOR/CONTROL SYSTEMS

(Boost Type On-Board Chargers)

Description

Controlled type charging systems operating off an AC input have demonstrated significant increases in battery life, reduced maintenance and cost as well as freedom from thermal runaway. Senderak,[2] Gelinas,[3] and Cristofar[4] have discussed some of the types of charging systems available.

Our work considered the performance and suitability of a system which employs the voltage boost principle for the large numbers of Army aircraft which have DC generators. The charging mode used in the DC boost system is similar to that successfully used with AC inputs. The particular units evaluated were the models 2000B and D manufactured by the Utah R&D Co. under Contract No. N00164-75-C-0116. The 2000B is designed for 30 Ah batteries while the 2000D is for 10 Ah batteries. They are 6.6 lbs., 300 in^3 and 2.7 lbs., 147 in^3, respectively. Figure 3 gives the functional block design. The input switch isolates the battery from the bus in all hazardous fault conditions preventing charge if the battery is overheated (above 55°C) or contains a shorted cell, or if the bus is above 29.5 volts. The battery relay control automatically returns the battery to the bus through the battery relay, when battery power is required.

Experimental Results

Depending on battery voltage, input voltage, and temperature (in the absence of any faults), the units will function in 5 separate charging modes. These are illustrated

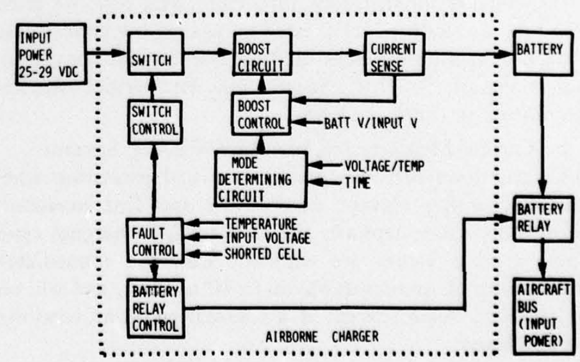


Figure 3. Functional Block Diagram—DC On-Board Airborne Battery Charger.

in Figure 4 which is a charge curve of a completely discharged BB-432/A battery.

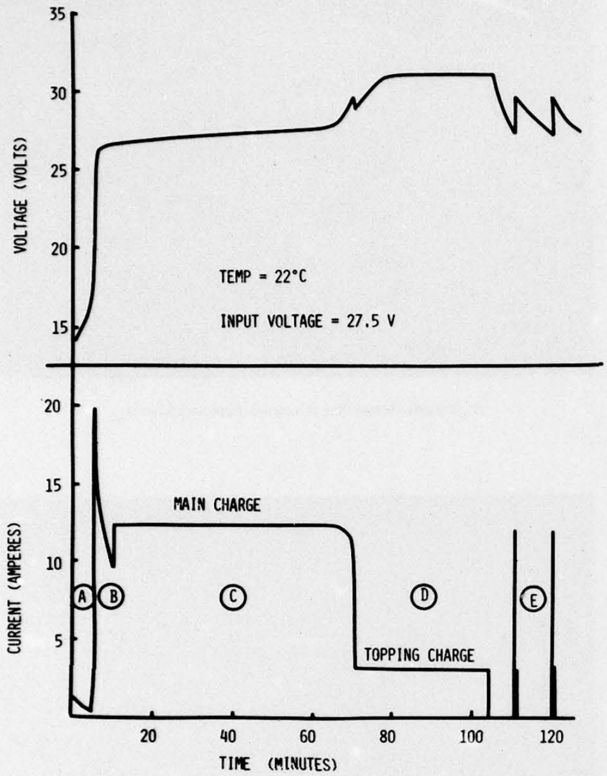


Figure 4. Charge Curve of 11 Ah, BB-432/A Nickel-Cadmium Battery with DC On-Board Charger.

In "Mode A" a trickle charge of less than 1 A flows across a bypass resistor to bring the battery voltage to 18 V. At 18 V the input switch of the charger is turned on, connecting the battery through the charger to the generator. "Mode B", which is a modified constant potential, continued until the battery voltage rose to within 1 volt of the bus. Main charge (Mode C) which was a repetitive series of pulses having a peak value of approximately 3 C and an average value of 1 C then commenced. Pulse frequency varied from approximately 1600 Hz to 7000 Hz as the battery voltage rose. When the battery reached full charge, the charger was automatically switched to topping (Mode D). The switchover point at 22°C was 29.4 V with a compensation of 50 mV/°C. The topping mode, which consists of a series of 1 C rate pulses at 5000 Hz yielding an average C/3 charge, continued for 1/2 the time of the main charge, for a total 15% overcharge. "Mode E" which is a periodic pulsing controlled by the battery voltage began when the topping charge was completed and continued until power input was terminated. The input from the Mode E pulsing was at the C/100 rate. Checks of the fault warning system indicated satisfactory operation for all possible faults with the exception that charge was reinitiated when battery temperature had fallen to 53°C rather than hold off until 46°C as desired. Equivalent test results were obtained with the 30 Ah chargers and BB-433/A batteries.

In order to determine the effect of battery temperature, an 11 Ah, BB-432/A Ni-Cd battery was charged with the on-board charger over the temperature range of −32 to 52°C. The battery was in the fully discharged state at the beginning of each charge. After the completion of charge, capacity was determined at the 1 C rate at 22°C. The data obtained are shown in Figure 5, as well as comparison data for constant potential charging. Capacity in excess of rated was obtained with the on-board charger over the entire temperature range. It averaged about 6% higher capacity than the constant potential. While this difference is not highly significant, experience has shown that capacity will fall off more rapidly with constant potential charging,[4] unless a high overcharge and subsequent frequent maintenance are employed.

The effect of the on-board charger on the ability to meet the ripple requirements of MIL-STD-704 (Aircraft Electrical Power Characteristics), was also studied. Previous DC charger designs which employed SCR switching had caused large voltage variations. The transistorized units caused no increase in ripple voltage amplitude beyond that occurring because of the loss of the filtering capability of the battery. Figure 6 shows the measured generator waveforms. During the course of this work, the pulse frequency of the charger was increased from approximately 600 Hz to above 1500 Hz so as to operate in a region of a larger ripple voltage, e.g. as specified in MIL-STD-704. Therefore, this type of on-board charger unit should be suitable for any aircraft electrical system which is capable of meeting MIL-STD-704A requirements without the battery on line.

Conclusions

The on-board charger units tested appear to be compatible with DC generated aircraft electrical systems and are capable of providing a full controlled recharge over a wide range of environmental conditions. The fault warning and control logic modifications developed during the course

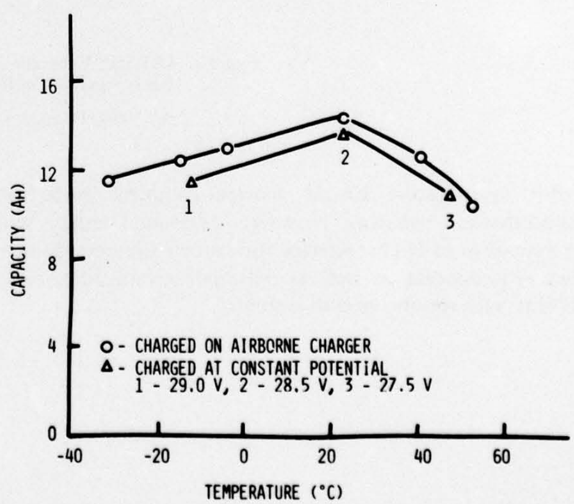
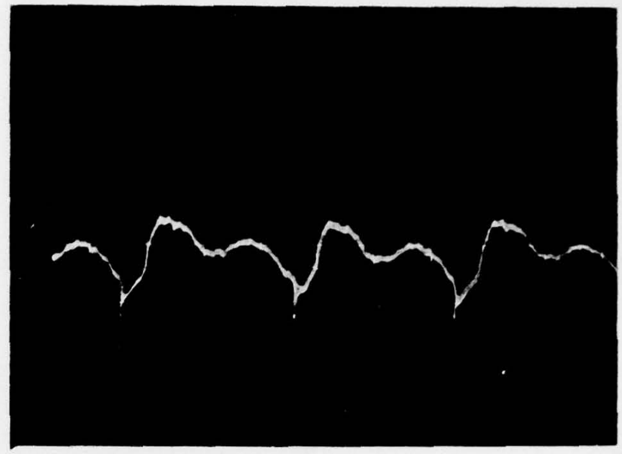
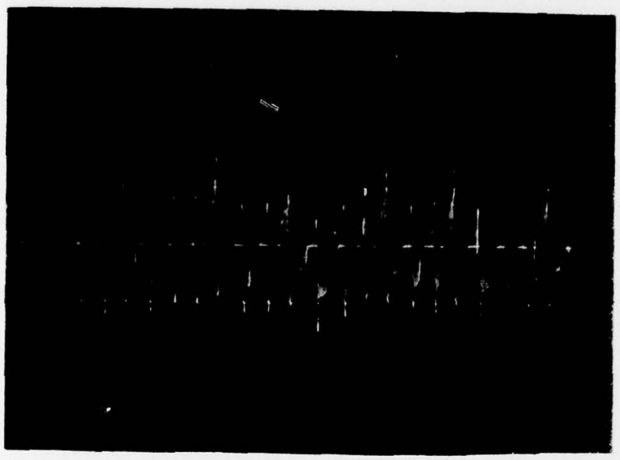


Figure 5. Battery Capacity as a Function of Charge Temperature for 11 Ah BB-432/A Nickel-Cadmium Battery.

A. Battery Off Line (End of Charge)



B. Battery Across Bus (Constant Potential Mode)



C. Airborne Charger in Main Mode

D. Airborne Charge in Topping Mode

Figure 6. OH-58A Generator Waveforms with and without BB-432/A Battery and/or On-Board Boost Charger

0.5 Volts/Division — 1 Millisecond/Division.

of this investigation should provide complete protection against thermal runaway. However, additional testing will be required to fully characterize the battery life and maintenance requirements as well as definitely establishing compatibility with specific aircraft systems.

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