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Recent Developments and Trends in Aerospace Battery Maintenance, Charging and Analysis

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ABSTRACT

Advances in communication & computer technologies and portable devices connecting to the internet are fueling energy efficient, high performance battery development and deployment into both civilian and military applications. The optimal performance of batteries requires advances in the area of cell/battery control using smart electronics. This article presents recent advances in battery analysis techniques, battery testing, control electronics and smart charging.

INTRODUCTION

Recent growth in communication technology, particularly mobile phones, has resulted in high demand for reliable and portable battery power. Similarly the advent of widespread internet usage and broadband applications has called for reliable uninterruptible power sources. As a result battery technology development is experiencing tremendous impetus to increase power and energy density and their reliability. Of late, it has been realized that the charger technology is as important as the battery technology. Emphasis is nowadays placed on the diagnostic and prognostic aspects of the charger as much as the speed of charging. Technologies developed for the above earthly applications may be transported to the aerospace applications too. This article takes a look at the factors contributing to battery performance improvement including developments in battery charging, testing and maintenance.

MAIN SECTION

CHIP TECHNOLOGY

Nickel cadmium and valve regulated lead acid batteries have dominated the aircraft applications, while nickel hydrogen is predominantly used in space applications. It is expected, that in five to ten years nickel metal hydride and lithium ion batteries may replace the above systems. For example, US Air Force and NASA has initiated a program with Yardney Technical Products and Eagle-Picher to develop lithium ion batteries for several aerospace applications. Batteries that came to market in recent years such as lithium ion, lithium polymer and nickel metal-hydride, are sensitive to charging methods, charging voltage, current and temperature. Both safety and performance are dependent on charging conditions. Therefore, there is a need to implement a well defined charging methodology. To aid this process and to control any desired charging algorithm several companies have introduced integrated circuit chips specifically aimed at charge control. They include Motorola, Texas Instruments, Burr Brown, Analog Devices and PowerSmart. The IC components help control charging parameters but also to measure and keep track of battery current, voltage and temperature. The chips also help to integrate the current in and out of the battery thereby indicating the state of charge at least approximately. They also help to keep track of the battery history including any abusive conditions the battery may have experienced. Such information is often helpful for battery manufacturers in their warranty claims as well as to improve their design to overcome such abuse in the future systems.

POWER TECHNOLOGY

Conventional battery chargers are of ferro-resonant type. They are inexpensive and charge voltage limited. Generally charging with this type of chargers use constant current until the voltage reaches the charger's voltage limitation. Then it becomes a constant voltage charger, which may not be the best way to charge certain type of batteries such as nickel cadmium battery systems. Also one may need one charger for each battery voltage level. Another type often used in the laboratory is the linear charger. which outputs any desired voltage and current level within its limits. They are accurate, not very efficient and expensive. All modern chargers use pulse width modulation technique. These chargers are very efficient and small in volume and weight. They are expensive. One can control voltage and current outputs to any desired value with good

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resolution. If not designed well, they can cause noise in the power lines.

CHARGER/ANALYZER TECHNOLOGY

Until recently there were no significant developments in diagnostic and charging methodologies and algorithms. Many investigations were focused on quick charging techniques. Pulse charging was claimed to charge all batteries, particularly nickel cadmium and lead acid batteries, in a short time. Another technique to charge rapidly is to follow the gas curve and adjust the current and voltage matching the gas curve. Practically there were no in situ diagnostic techniques to identify battery defects.

Honeywell International, formerly Allied Signal, developed pulse and current ramp techniques to diagnose the battery defects such as shorted cells, mismatched cells, sulfated battery and low electrolyte level in lead acid batteries[1-9]. This technology enables determination of battery capacity without discharging the battery. Prototypes were field tested by Strategic Air Command Offutt AFB, Nebraska and Minot AFB, North Dakota. Honeywell has introduced into the market an Advanced Battery Analyzer/Charger (ABAC) under the name, TruCharge™, for lead acid batteries based on this technology[10].

PULSE TEST

ABAC technology[1-9] involves the use of a charge or discharge current pulse to determine the battery internal resistance and polarization resistance. Internal resistance is a measure of the battery's instantaneous current output capability while the polarization resistance is a measure of the battery's continuous power output capability. Polarization resistance is caused by the difference between the electrolyte concentration inside the pores of the battery plates and that in the bulk electrolyte. When a battery is put under test these values will be determined using a pulse test and compared with those of a good battery. When they exceed certain limits, the battery is defective. For example, when the IR is high without any other defects, the battery capacity has decreased. When the PR is high the electrolyte level is low. As the electrolyte adequacy keeps decreasing the PR keeps increasing. Typically, the limit values for these parameters are determined with tests performed on good and defective batteries. The pulse width and height depends on the battery capacity and the rate capability of the battery.

CURRENT RAMP TEST

The current ramp test is mainly used to determine the gas point parameters, i.e., gas current and voltage according to the gas curve. The gas curve concept is well known for lead acid batteries (Fig. 1). It gives the maximum current that the battery can accept without evolving gas at a given state of charge. The gas curve depends on a wide number of factors such as the capacity, battery age, battery temperature, battery construction and its health. Therefore the battery characteristics have to be determined for the existent battery conditions before charging.

Honeywell's technology involves a technique to determine the battery gas parameters in situ. The gas curve cannot be stored in memory and used as needed since the number of affecting factors are too many. Honeywell's technique involves imposing a linearly increasing charge current into the battery and measuring the battery response voltage. Initially all the current can be used to charge the battery. When the current exceeds the battery charge acceptance level, the excess current goes to evolve gas by electrolysis which is the overcharge reaction. Also at this level, battery voltage exhibits an inflection. The overcharge reaction happens at a higher voltage compared with the normal charge reaction resulting in a rise in voltage. The transition from charge reaction to overcharge reaction can be accurately determined by inspecting the dV/dI versus the current curve. After this inflection the ramp current may be held steady for a few seconds, if desired for mixing the electrolyte. The end point of the current ramp depends on the battery's state of charge and the voltage limitation set experimentally. Generally 2.4 to 2.6 V/cell may be used for the voltage limitation. When the current limitation or the voltage limitation is reached the upward ramp is changed to a downward ramp or the current is held steady for a few seconds before beginning the downward ramp. The ramp current is decreased at the same rate as in the up ramp.

In the downward ramp the voltage keeps decreasing gradually. At a point when the current is small enough that it can be used entirely for the charge process without a fraction of it going to evolve gas, the voltage decreases sharply. The voltage of this inflection is generally closer to that in the up ramp. However, the current may differ significantly, especially when the state of charge is high. This is due to ramp dynamics and the capacitive nature of the battery. The down ramp parameters are close to an equilibrium situation while the up ramp parameters correspond to a dynamic situation. The current and voltage parameters for the inflection point in the down ramp are subsequently used in charging the battery.

SMART ANALYSIS

The ramp test also provides some defect detection capability. For example, when there are mismatched cells in the battery more than one peak is observed in the dV/dI versus t curve. Mismatching may arise from different electrolyte concentration or different capacity. Generally different electrolyte conditions are very rare within a given battery. However, mismatching due to different capacity may occur, especially in old batteries. The mismatch happens from the fact that cells degrade at different rates. This difference becomes significant as the battery gets older. Another defect detectable during ramp test is the presence of soft-shorted cells. A soft-shorted cell appears to be good during charge, but loses

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its voltage soon after the battery is placed in discharge mode. When there is a soft-shorted cell, one peak is observed during the up-ramp, but a corresponding peak is not observed during the down ramp.

DETERMINATION OF CAPACITY

The ramp test also provides an opportunity to determine the battery capacity without discharging. The magnitude of the gas current in the up ramp depends on two factors: 1. battery capacity and 2. battery state of charge. When the battery is fully charged, the state of charge factor is eliminated. Thus, by correlating the gas current in the up ramp, it may be used to determine the battery capacity after charging it to 100 percent.

This poses another question. How do we know the battery is fully charged? One indication is battery voltage. Also the gas current in the down ramp is close to zero. Under equilibrium conditions any current input into a fully charged battery will go for gas evolution making the gas current close to zero. Therefore the gas current in the down ramp can behave as a proxy for the state of charge. Thus, when the gas peak in the down ramp occurs below a predetermined current limit, the gas current in the up ramp is used to determine the battery capacity (Fig.2). Fig.2 provides a calibration curve for a given ramp rate and for all types of lead acid batteries. The accuracy may be improved if a separate calibration curve is made for each type of battery.

SMART CHARGING

Figures 3 and 4 show the charge current and voltage and the three ramp tests performed during this charge process of a valve regulated aircraft lead acid battery. Three stages of charging are seen in Fig. 3. Initially the battery is charged under constant current with a voltage limit. When the current falls to about 80 percent of the original value the battery is rested for 5 minutes and then a ramp test is performed. Based on the current and voltage parameters corresponding to the gas point subsequent phase 2 charge is carried out. The upper current limit equals the gas current and the charge voltage equals the gas voltage. When the current falls to a predetermined value, the charging is stopped again for 5 minutes. Another ramp test is conducted and the gas parameters are determined afresh. At this point the battery's state of charge is 90-95 percent. Phase 3 charging is continued at a low current with a time limitation and voltage limitation, if desired. When the voltage limit is reached or the voltage starts decreasing then the charge is terminated. After a 5 minute rest, the final ramp test is carried out to determine the gas parameters. Also the gas current in the down ramp is used to confirm that the battery is fully charged. The battery capacity is then calculated as outlined earlier using the gas current in the up ramp. The charger can detect conditions leading to thermal run-away, and charging is terminated immediately with a thermal run-away indication on the display.

Fig. 4 shows the ramp test curves of current, voltage and dV/dI as a function of ramp time. The ramp tests are performed at the end of each phase of charging. As seen in the figure, the peaks keep moving towards lower current as the state of charge increases. Also the peaks become sharper. Also note that the down ramp peak at the end of phase 3 occurs at near zero current indicating the battery is fully charged whereas the corresponding peaks at the end of phase 1 and 2 occur at higher significant current levels. The occurrence of only one peak in each direction indicates there are no mismatched cells. This figure does not indicate the presence of any other defects in the aircraft battery. Another important feature is the maximum current imposed on the battery during this test. The maximum current is lower at the end of phase 3 test compared with that of phase 2 test which in turns shows a similar behavior compared with that of phase 1. This technology has been developed further for other battery systems like nickel cadmium and silver zinc batteries. Efforts are underway to develop the diagnostic technology for lithium ion and nickel metal hydride aerospace battery systems.

ON-BOARD BATTERY SYSTEMS

Honeywell adopted the pulse and the ramp based diagnostic technology for on-board systems[2] like an automobile, aeroplane, non-interruptible power systems, etc. For example, the pulse test can be replaced with an on-board load discharge or a charge pulse from an on-board charger. The current-voltage data can be monitored in the on-board systems continuously which will help provide additional diagnostics, such as corroded terminals, low electrolyte level, and power output capability of the battery. It can even predict whether a critical function can be performed successfully. For example, in an automobile, the starting load is the most severe and critical. This technology can predict up to what low temperature limit the battery can successfully start the car under the present engine, starter and battery conditions. This technology is designed to answer the question if the battery needs to be changed or maintained. If it has to be maintained, it should advise the user how to maintain it. It can also distinguish between defective starter motor, alternator/regulator (on-board charger) and the battery problems. This technology may be hosted in the on-board microcontroller or may be integrated with the on-board charging system. Alternately, it may be made as an independent stand-alone system and interfaced between the battery and the host electronics

SMART BATTERIES

Many of the present batteries named as Smart Batteries have means to measure voltage, current, and temperature. They integrate the current going into and out of the battery to determine the state of charge, particularly for communications and other portable applications. When lithium ion batteries found their way into these applications, it was essential to monitor voltage and current for safety reasons. For long life,

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lithium ion batteries have to be used between 3 and 4.1 V. For this reason these batteries come with cell and battery control electronics. Smart battery electronics can enhance the performance of sealed lead acid batteries which predominantly fail due to the cell dry out mechanism. Presently even lead acid batteries with a built-in shunt are being evaluated for some applications. Since proper charge can reduce the cell dry out effect, significantly increasing battery life. Honeywell has not seen automatic diagnostics incorporated in battery electronics, but many vendors are working in this area.

BATTERY TRACKING

It is important to keep track of batteries, especially when they are expensive or critical mission applications. Aircraft batteries can be tracked when they are serviced and any observations regarding their health and performance may be recorded for future reference. Then any borderline battery or the ones susceptible under certain conditions of environmental and operational characteristics can be removed from service Improving reliability. Generally a bar code is placed on a suitable wall of the battery. The charger may be equipped with a bar code reader and a serial or other suitable interface for communication with a computer. When a battery is charged or analyzed, the diagnostics and health data can be transferred to a computer for storage in a database for future use. Economic benefits may also be realized by tracking each vendor's products and allows an estimate of the total life time cost of batteries including maintenance costs.

ENVIRONMENTAL BENEFITS

By reducing the premature disposal of batteries, a big reduction in battery disposal costs and reduced environmental costs can be achieved. For example, a large number of lead acid batteries are disposed of even though they may be only slightly sulfated. Based on our tests at a few Army and Air Force bases, Honeywell estimates close to 40 percent of the batteries may be recovered and reused. To facilitate this, Honeywell developed its TruCharge™ product, which can identify sulfated lead acid battery and automatically go through a recovery process. TruCharge™ is covered by one or more of the patents listed in the reference section[1-9].

CONCLUSION

This article indicates the need to pay attention to all aspects of battery processing including battery quality, charging and testing methodologies. New charging methodologies are important not only to charge the batteries in a safe way but also to adapt the charging process depending on the battery condition and health. Diagnostic and prognostic defect detection methodologies may help save time and money. Battery tracking is important to enhance the reliability in mission critical applications and to reduce acquisition costs.

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6. Method and apparatus for charging and testing batteries. U.S. Patent 5,160,880
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9. Apparatus and method for charging and testing batteries. U.S. Patent 4,876,495
10. TruChargeTM is a trademark of Honeywell International Inc.

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FIGURES

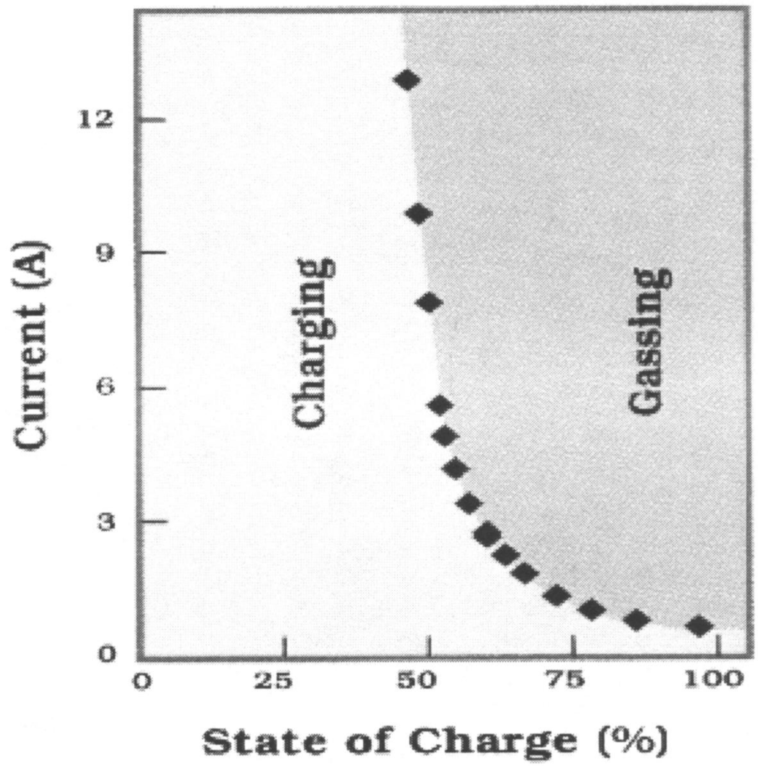

Fig. 1. Battery current acceptance as a function of state of charge (The Gas Curve).

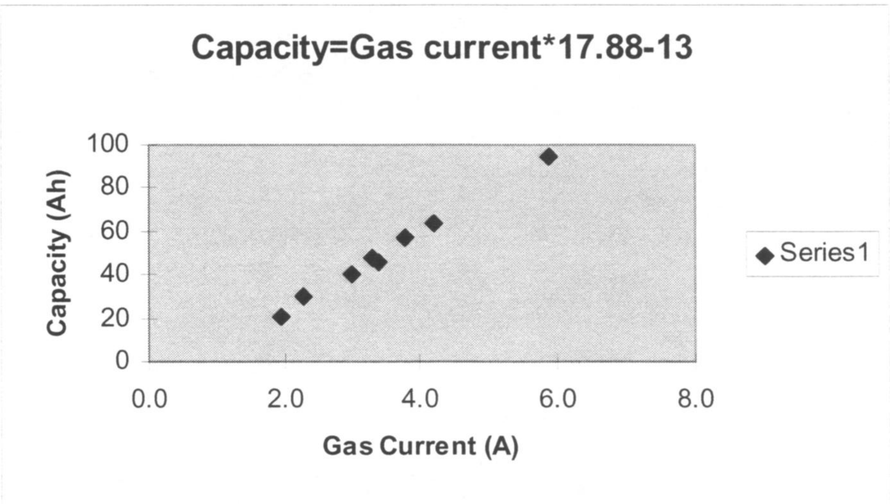

Fig. 2 Calibration Curve to determine battery capacity using gas current from the current ramp test data

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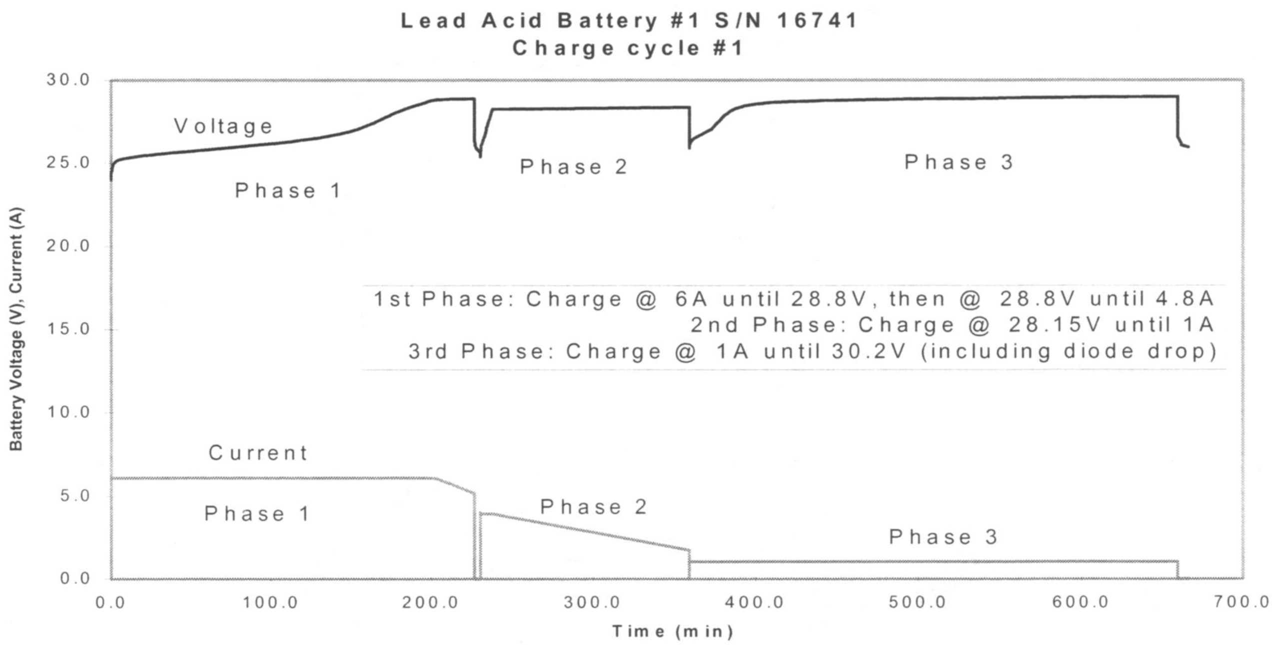

Fig. 3. Charge profile of an aircraft battery when charged with Honeywell's TruCharge™ product.

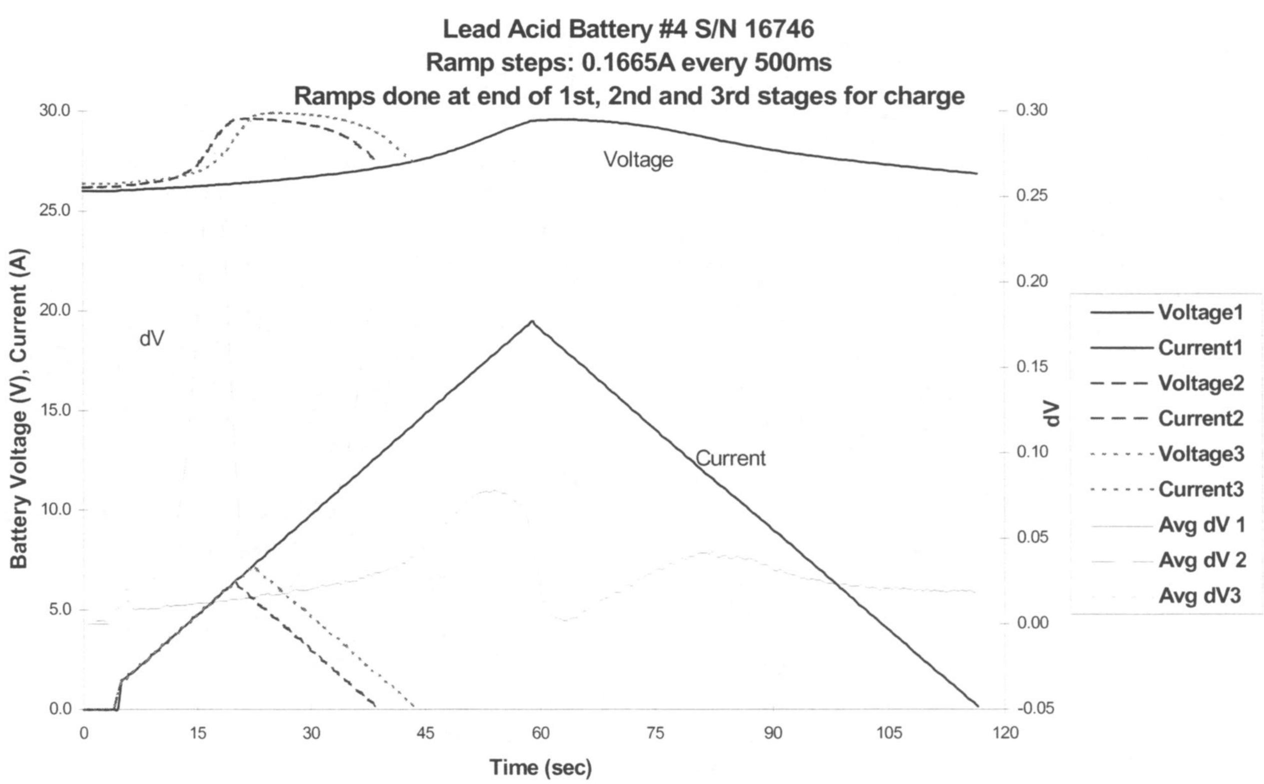

Fig. 4 Current ramp test data at different state of charge corresponding to the end of each phase of charging.

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