

Battery Diagnostic and Prognostics for Aviation Batteries Via a Passive Diagnostic Device

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ABSTRACT

Aviation battery maintenance is continuing to evolve. Much recent effort has been devoted to battery redesign to totally maintenance free or non-maintainable batteries. These batteries are placed into service and replaced at predetermined intervals. Still, some batteries are failing before their scheduled replacement period. For this reason attention is being focused on methods to transition batteries to an on-condition maintenance status.

Nickel-Cadmium (NiCd) and Valve Regulated Lead-Acid (VRLA) are used to start engines, provide emergency back-up power, and assure ground power capability for maintenance and pre-flight checkout. Various Lithium-based battery chemistries are also now being developed and considered for use in these applications.

As these functions are mission essential, State of Health (SoH) recognition is critical. SoH includes information regarding battery energy, power and residual cycle life. This document describes an SoH recognition technique for on-board aviation batteries that utilizes a totally passive diagnostic device (PDD). The PDD monitors on-board electrical system for battery current, voltage and ambient temperature. Being totally passive, there are no active signals introduced to the battery or aircraft electrical system, thereby eliminating the possibility of any interference with the vehicle electrical and operating system.

A procedure for data sampling and analysis of transient and stationary battery voltage and current under normal aircraft operating conditions resulting in a matrix of battery parameters will be discussed. A matrix of parameters (MoP) including but not limited to, ohm and chemical resistance, instantaneous and dynamic open circuit voltage forms the basis for SoH recognition. Additionally, data from a demonstration of the PDD battery SoH determinations on actual F/A-18 equipment will be presented.

This presentation will further describe on-going efforts to develop an SoH recognition technique for on-board Li-Ion aviation batteries. Li-ion battery operation is accomplished under precise controlled conditions. In a Li-Ion battery system, PDD data are sampled and processed both in charging and discharging modes. Advantages of the capability of the PDD to provide early signs of impending battery failure or simply early identification of the inability of the battery to carry out a necessary function, or the need for off-line battery maintenance making the battery an on-condition maintenance item, will be discussed.

CITATION: James, J., "Battery Diagnostic and Prognostics for Aviation Batteries Via a Passive Diagnostic Device," *SAE Int. J. Aerosp.* 5(2):2012, doi:10.4271/2012-01-2239.

INTRODUCTION

GEM Power has developed intelligent battery charging technology under separate research and development efforts. This technology utilizes a unique approach in application of pulse charging. Battery chemistry, size, charge acceptance rates and other parameters are determined before charging commences and utilized to set charging parameters. An integral part of GEM Power's intelligent battery charging technology includes battery diagnostics and prognostics. Battery state of charge, state of health and other parameters are determined with a special pulse charging wave form used

for diagnostic and prognostics only. A myriad of parameters are determined and considered in making state of health determinations. GEM Power has identified these items as a matrix of battery parameters.

GEM Power's passive determination of battery diagnostics and prognostics is based on its pulse charging active approach. As with the active approach, a matrix of battery parameters, the key element of information concerning battery SoH, is again used in the final determination of battery status and can be obtained in charging and discharging modes. On-board battery charging

of VRLA and NiCd chemistries is provided in most cases through a 115V, 400Hz starter- generator, reduced by transformer and rectified with power thyristors. High output electrical ripples make sampling and treatment output voltage and current difficult. Therefore all voltage-current signals for a passive device are analyzed during battery discharge mode. Certainly prospective Li-ion chemistry batteries will require a much more refined output signal, which will open the opportunity to treat battery current and voltage in charging mode as well as discharge mode. The objective of this paper is to discuss a diagnostic algorithm of a PDD using as an example the 4-1 VRLA battery VRLA 24V 10Ah aviation battery along with a discussion of initial test data.

The PDD can be considered a component of diagnostic and safety subsystems, without the generation of any active signal. The creation of a PDD for a typical Li-ion battery provides a challenge. A lack of access to individual cells requires a very accurate recording and sophisticated interpretation of the variation of terminal voltage and battery current. However, the requirement for precision charging voltage and current for Li-ion chemistries presents the opportunity to sample and process information related to battery condition and to compare it with information from a MoP derived during discharging. Several Li-Ion battery chemistries with cells connected in series have been chosen for this study. Changes in Li cell design and chemistry will probably require some adjustments in the PDD algorithm but the basic elements of the PDD like power and state of charge (SOC) recognition along with cycle life prediction and safety features should remain constant between chemistries.

BACKGROUND

EQUIVALENT SCHEMATIC AND MEASUREMENT PROCEDURE

SoH recognition for aircraft batteries is based on the sampling of elements of a battery equivalent schematic [1]. The simple battery equivalent schematic on a cell and battery level is depicted in Figure 1. The schematic represents a DC circuit of electronic and ionic parts with ohmic resistances (R_{ohm}) for both electrodes and inter-electrode space. The chemical resistance (R_{chem}) can be defined as the ratio of chemical polarization to current, and may be an exponential function of current (Tafel kinetic) with empirical Tafel coefficients or a linear function (linear kinetic). Inductance can be mostly attributed to NiCd batteries with sintered electrode design containing magnetic metallic nickel. Sampling of true battery inductance is usually affected by cable inductance. Over different time sequences it is possible to sample ohmic and chemical resistance and Electrical Double Layer Capacity (EDLC) through the use of a dc current on/off switch technique during pulse charging or with a special diagnostic procedure. Indeed an equation for transient voltage under switching discharging current from

low (I_1) load to high current (I_2) for example can be written based on schematic Fig.1(B) as:

$$V(2) = V(1) - (I_2 - I_1)R_{ohm} - I_2 R_{chem} (1 - \exp(-t/t_c)) \quad (1)$$

Here I_1 and I_2 are discharging currents and voltages under low (I_1, V_1) and high (I_2, V_2) loads. Along with above mentioned transient measurement (t), some parameters are sampled in the stationary mode. This mode can be defined as a time interval much longer than the time constant (t_c).

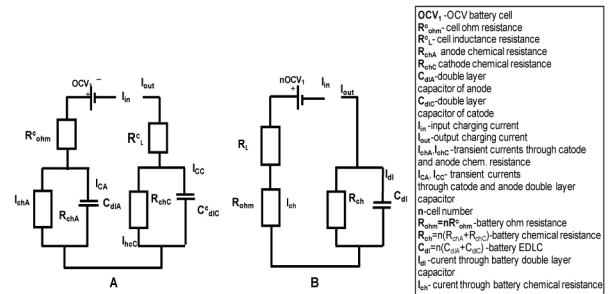


Figure 1. Equivalent schematic of individual cell (A) and battery (B)

The transient current across EDLC drops as:

$$I_{cdl} = I_2 \exp(-t/t_c) \quad (2)$$

Simultaneously the current rises across chemical resistance as:

$$I_{chem} = I_2 (1 - \exp(-t/t_c)) \quad (3)$$

Here t_c is time constant. The time constant is equal to the product of $R_{chem}C_{dl}$ and is equal to the time period required for dropping I_{cdl} e (2.7) times. Equations (1,2,3) reflect a situation, where $I_2 \gg I_1$ and the electrochemical kinetic is considered to be linear and R_{chem} is constant under constant temperature. This assumption is true for relatively low load current or for the very initial stage of a transient process, when most current passes across EDLC. Such an approach can be extended for non linear, empirical Tafel kinetics e.g. under some assumptions. Equations (1,2,3) give the opportunity for sampling battery parameters R_{ohm} , R_{chem} and C_{dl} using a difference in transient time. The t_c calculates to 120ms-150ms at 25°C for the 4-1 VRLA battery (a 7.5 Ah at end of life, sealed lead-acid battery used in the F/A-18 aircraft). The time constant sharply depends on temperature as per R_{chem} dependence, while C_{dl} is almost temperature independent. For the first 5ms after load rise the voltage drop across EDLC of 4-1 VRLA battery equals around 10% of the voltage drop across ohmic resistance. Therefore ohmic resistance can be safely sampled inside of 1-5 ms time