

SoH Recognition of Aviation Batteries Via Passive Diagnostic Device

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ABSTRACT

Aviation battery maintenance is trending toward on-condition maintenance. Nickel-Cadmium (NiCd), Valve Regulated Lead-Acid (VRLA), or prospective Li-ion batteries are used to start engines, provide emergency back-up power, and assure ground power capability for maintenance and pre-flight checkout. 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 paper describes an SoH recognition technique for on-board aviation batteries and presents a passive diagnostic device (PDD). The PDD monitors on-board system battery current, voltage and ambient temperature and utilizes no active signals to the battery which can be restricted or even prohibited in order to avoid any interference with the vehicle electrical system. A procedure for sampling, treatment and analysis of transient and stationary battery voltage and current under changeable thermal condition resulting in a matrix of battery parameters is discussed. A matrix of parameters (MoP) like ohm and chemical resistance, instantaneous and dynamic open circuit voltage forms the basis for SoH recognition.

INTRODUCTION

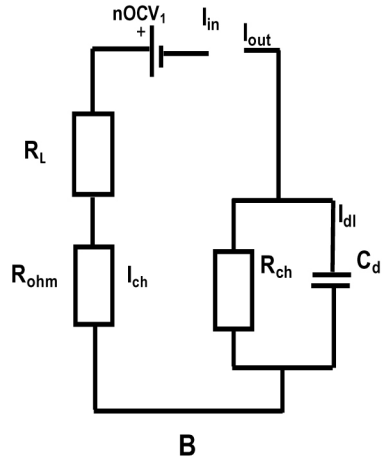
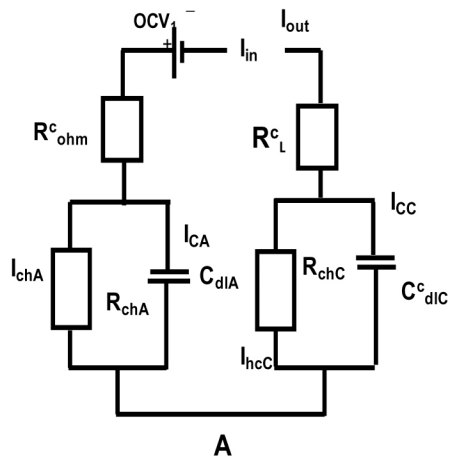
A matrix of battery parameters, the key element of information concerning battery SoH, can be obtained in charging and discharging modes. On-board battery charging of VRLA and NiCd chemistries is provided in most cases through a 115V, 400Hz starter- generator, reduced by transformer and rectified with power thyristors. High output electrical ripples makes 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.

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:

$$V(2) = V(1) - (I_2 - I_1)R_{ohm} - I_2R_{chem}((1 - \exp(-t/t_c)) \quad (1)$$



OCV_1 -OCV battery cell
 R_{ohm}^c - cell ohm resistance
 R_L^c - cell inductance resistance
 R_{chA} - anode chemical resistance
 R_{chC} - cathode chemical resistance
 C_{dlA} - double layer capacitor of anode
 C_{dlC} - double layer capacitor of cathode
 I_{in} -input charging current
 I_{out} -output charging current
 I_{chA}, I_{chC} -transient currents through cathode and anode chem. resistance
 I_{CA}, I_{CC} - transient currents through cathode and anode double layer capacitor
 n -cell number
 $R_{ohm} = nR_{ohm}^c$ -battery ohm resistance
 $R_{ch} = n(R_{chA} + R_{chC})$ -battery chemical resistance
 $C_{dl} = n(C_{dlA} + C_{dlC})$ -battery EDLC
 I_{dl} -current through battery double layer capacitor
 I_{ch} - current through battery chemical resistance

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

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).

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 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 interval after switching to higher load. EDLC is sampled directly after R_{ohm} measurement and calculated as per expression: $C_{dl} = I_2 \Delta t / \Delta V$, by taking Δt interval equal to 1-3ms in order to consider current across EDLC as constant. The minimum time interval for sampling chemical resistance is around 360-450ms, which almost eliminates effect of EDLC. The upper range for R_{chem} sampling is limited by effect of battery ampere -hour capacity on R_{chem} only. A longer time interval allows for a more complete value of R_{chem} . In the particular case of the 4-1 VRLA battery, 4100ms time interval is used after a current change. Expression for sampling summary of $R_{ohm} + R_{chem}$ after 4100ms of load change is:

$$R_{ohm} + R_{chem} = R_{4100} = (V_0 - V_{4100}) / (I_2 - I_1) \quad (4)$$

Here V_0 and V_{4100} are discharging voltage under current I_1 and at 4100s after switching current to I_2 value. Summary of R_{ohm} and R_{chem} make up battery DC impedance under linear electrode kinetic. All samples are provided by using a pulse discharging profile with average discharging current of 25A which drops to zero for a time period equal to 12s.