OPERATIONAL PERFORMANCE OF THE SAC-C SATELLITE NICKEL-HYDROGEN BATTERIES

Barsellini, D.R; Garaventta, G.N.; Bisaccio, G.**; Visintin, A.; Triaca, W.E*.

*Instituto de Investigaciones Fisicoquímicas, Teóricas y Aplicadas (INIFTA), Facultad de Ciencias Exactas, Universidad Nacional de La Plata. Suc. 4, C.C. 16, 1900. La Plata, Fax:+54 221 4254642, E-mail: wtriaca@inifta.unlp.edu.ar

**Comisión Nacional de Actividades Espaciales (CONAE). Paseo Colón 751. Buenos Aires.

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Dedicated to the memory of the late Prof. Hans J. Schumacher on the occasion of his 100th birthday

Abstract

Processing and analysis of telemetry data of the Argentine SAC-C satellite Ni-H_2 batteries are presented. Diagnostic indicators were established in order to evaluate the performance in-flight of the satellite's electricity storage system. The state of charge of the batteries was related to the hydrogen pressure. A predictive analysis allowed us to early detect failures in the electricity storage system.

Resumen

Se presentan los resultados del procesamiento y análisis de los datos de telemetría de las baterías de Ni-H_2 del satélite SAC-C en vuelo. Se determinaron indicadores de criterio de diagnóstico que permiten evaluar el estado operativo en tiempo real del sistema de almacenamiento de electricidad del satélite. Se correlacionó el estado de carga de la batería con la presión de hidrógeno. Se realizó un análisis predictivo del sistema de recarga que permitió detectar en forma temprana fallas operativas.

Introduction

The Argentine SAC-C satellite (satellite of scientific application) uses nickel-hydrogen batteries to store electric energy in its power system. The satellite orbits the earth at an altitude of 705 km, performing 14.7 orbits each day at a speed of 7 km/s. Each flight path lasts 98 minutes, from which 64 minutes are under sun light and 34 minutes in the dark (eclipse). During the light period the sun energy is converted into electricity by the solar panes. During the eclipse the energy is provided only by the batteries.

The nickel-hydrogen battery is a hybrid system that combines advanced technologies of batteries and fuel cells [1]. The nickel hydroxide positive electrode is largely used in NiCd and NiMH alkaline batteries, and the hydrogen negative electrode is a gas-diffusion porous electrode catalyzed with platinum such as those of fuel cells. This type of battery is widely used in space technology because of its large reliability, high specific energy (60 Wh/kg), long cycle life (30000 cycles at 40% depth of discharge), high tolerance to overcharge and, mostly, for its ability to determine the actual state of charge through a pressure measure [2,3].

In this work, results of the processing and analysis of telemetry data from the SAC-C satellite Ni-H_2 batteries are presented. The investigations have allowed us to determine diagnostic indicators (DI) to daily check the performance of the electricity storage system of the satellite.

Experimental

The satellite electricity generation and storage system is mainly composed of two solar panels, with a peak generation of 712 W and average generation of 500 W at the beginning of its lifetime, and two Ni-H_2 batteries connected in parallel. Each battery has eleven cells connected in series. These cells (Eagle Picher RNHC-12-3) are of the common pressure vessel type (CPV) in which there are two unit cells connected in series that share the container. The cells have a nominal capacity of 12.8 Ah (at 10 °C) and a tension of 2.5 V.

The distant measurement of the working parameters of the battery (tension, current, hydrogen pressure, and temperature) is called telemetry. From each battery the current, total battery tension, half battery tension, two temperatures and two hydrogen pressures (in two cells) are measured. A measure of each of these variables is stored every eight seconds, therefore 13000 points of each variable are generated every day. By analyzing and processing these variables, two DIs were determined. The DIs allow evaluating the performance of the electricity storage system.

Results and Discussion

The basic electrochemical reactions that occur in the Ni-H_2 battery are

$$\mathrm{Ni(OH)_2} + \mathrm{OH^-} \rightleftharpoons \mathrm{NiOOH} + \mathrm{H_2O} + e^- \tag{1}$$

at the positive electrode, and

$$\mathrm{H_2O} + e^- \rightleftharpoons \frac{1}{2}\mathrm{H_2} + \mathrm{OH^-} \tag{2}$$

at the negative electrode.

The overall reaction that takes place in the battery during a charge-discharge cycle is

$$\mathrm{Ni(OH)_2} \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftharpoons}} \mathrm{NiOOH} + \frac{1}{2}\mathrm{H_2} \tag{3}$$

As can be seen, hydrogen is generated in the charge reaction and consumed in the discharge reaction, and thus, the state of charge (SOC) can be followed by the measure of the hydrogen pressure. To correlate the hydrogen pressure (P) with the SOC, the diagnose indicator $\Delta P/Q$ (psi/Ah) is used, which indicates the hydrogen pressure variation (ΔP) per unit of circulated charge (Q). The $\Delta P/Q$ is calculated from telemetry data by dividing the pressure change during the discharge by the total charge delivered by the battery on each orbit and averaging the values of the day. For a correct battery behavior, at constant temperature, this DI should be constant. As the inner cell temperature may vary within a few degrees due to several factors, which will be described below, a small variation of the DI according to temperature is accepted. Therefore, any departure from the expected values would indicate probable failures occurring in the battery. Figure 1 shows the variation of the battery capacity on one telemetry day calculated from the ΔP/Q. It can be seen that the capacity at full SOC is higher than the capacity established by the manufacturer [4]. The depth of discharge is ca. 30 % and under this condition a lifetime of about 40000 charge/discharge cycles is expected, while SAC-C has performed up to date only ca. 24500 cycles. It can be seen in figure 1 that the capacity values go through a series of maxima and minima on each day corresponding to the orbits of the satellite. An average of the maximum and minimum values can then be used as an estimation of the values of the day.

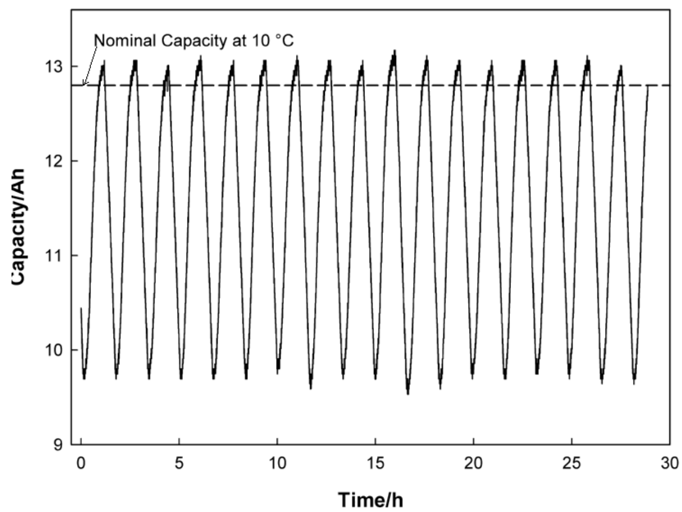

Figure 1. *Battery capacity corresponding to 04/21/05 calculated from the DI ΔP/Q.*

The charge efficiency (CEF) DI indicates the difference between the total charges delivered (discharge) and received (charge) by the battery during the day. Figure 2 shows the daily average charges delivered and received by the battery. The CEF allows diagnosing deficiencies in the charge system of the battery and then taking corrective actions in order to maintain the capacity in a safe range of operation values.

Figure 3 shows the time evolution of the daily average values of maximal and minimal capacities along with that of CEF. As the relationship between the capacities and the CEF depends upon the SOC and temperature, a clear correlation cannot be derived.

Since November 2002 the SAC-C satellite has been operating with only one battery, so the operating conditions have become more demanding. The charge and discharge currents were doubled and then the control of the temperature became difficult since the heat generated in the battery can not be removed. Under these conditions the variations in temperature can be attributed to several factors, a chemical reaction associated with the overcharge reaction (alkaline water electrolysis) and the Joule effect, both being the most important sources of heat release. During the charge process and before the 100 % SOC is reached, a parallel reaction -called overcharge- starts, by which oxygen is produced in the positive electrode. This reaction is very harmful to the battery because oxygen chemically reacts with the hydrogen at the platinum electrode producing a significant temperature rise. Furthermore, when oxygen reacts with hydrogen, micro explosions

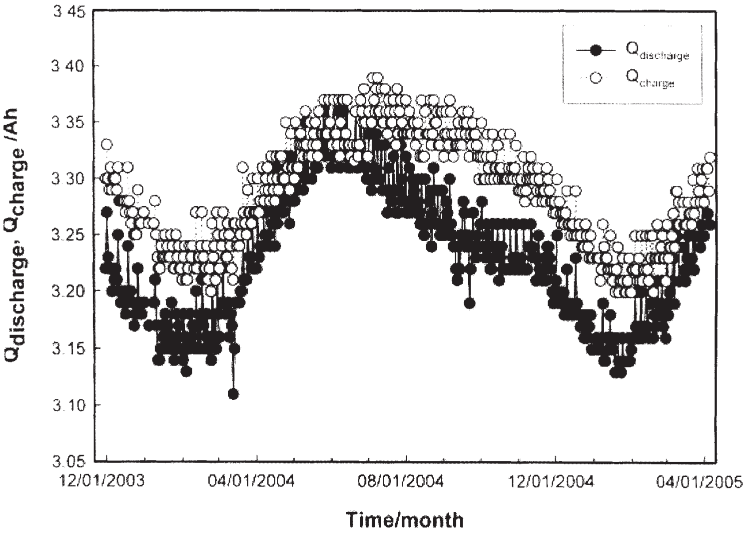

Figure 2. *Time evolution of the daily average charge delivered and received by the battery starting on 12/01/03.*

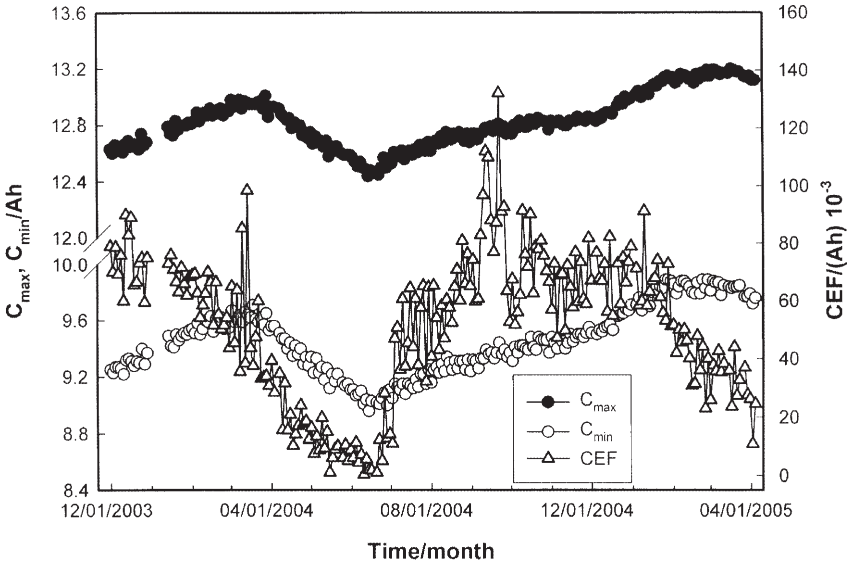

Figure 3. *Variation of daily average values of CEF and maximal and minimal capacities with time starting on 12/01/03.*

can occur and under these circumstances the electrode can be perforated. The overcharge reaction is favored when energy consumption is low and the SOC is near 100 % and for high CEF values. However, the main contribution to the temperature profile is given by the Joule effect ($Q = I^2 R$).

Figure 4 shows the daily variation of the maximal and minimal values of the battery temperature. From this figure and figures 2 and 3 the influence of charge consumption and CEF on the battery temperature is clearly evidenced. High values of consumption mean high levels of current and then the temperature rise by the Joule effect takes place. The influence of CEF on temperature rise can only be observed at very high values where the overcharge reaction occurs.

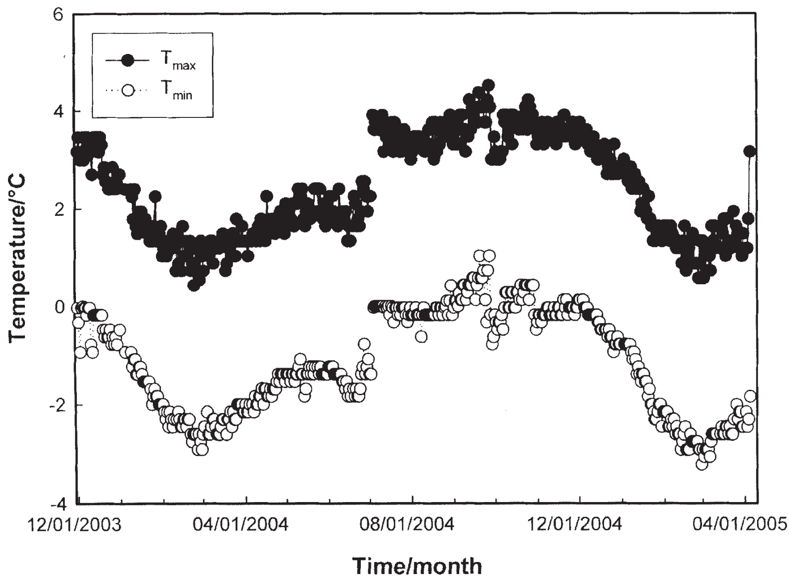

Figure 4. *Daily variation of maximal and minimal temperature values with time starting on 12/01/03.*

Conclusions

Diagnostic indicators were established correlating hydrogen pressure with battery capacity ($\Delta P/Q$ DI) and, in this way, monitoring the state of charge of the battery.

The CEF DI allows controlling the battery state of charge, the temperature and detecting early failures in the electricity storage system.

Predictive analysis from telemetry data allowed the SAC-C mission control engineers to take corrective actions in order to maintain the operating parameters of the energy storage system at an optimum level.

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