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Evaluation of supercapacitors for space applications under thermal vacuum conditions

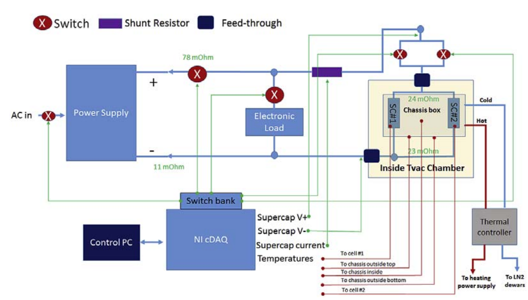
Keith C. Chin, Nelson W. Green, Erik J. Brandon*

Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA

HIGHLIGHTS

- Interest in supercapacitors for space applications is growing.
- Commercial supercapacitor cells were evaluated under thermal vacuum conditions.
- Charging and discharging of cells was executed following each temperature soak.
- Cells from three different vendors survived this testing protocol.
- Exposure to these conditions resulted in no significant impact on performance.

GRAPHICAL ABSTRACT



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ABSTRACT

Commercially available supercapacitor cells from three separate vendors were evaluated for use in a space environment using thermal vacuum (Tvac) testing. Standard commercial cells are not hermetically sealed, but feature crimp or double seam seals between the header and the can, which may not maintain an adequate seal under vacuum. Cells were placed in a small vacuum chamber, and cycled between three separate temperature set points. Charging and discharging of cells was executed following each temperature soak, to confirm there was no significant impact on performance. A final electrical performance check, visual inspection and mass check following testing were also performed, to confirm the integrity of the cells had not been compromised during exposure to thermal cycling under vacuum. All cells tested were found to survive this testing protocol and exhibited no significant impact on electrical performance.

1. Introduction

There is growing interest in the use of supercapacitors (also called ultracapacitors, or more generically double-layer capacitors or electrochemical capacitors) for power applications in space environments. This interest is motivated by their ability to support very high power pulses with only a moderate rise in cell temperature, their ability to operate over wide temperature ranges (typically -40 °C to $+65$ °C) and on their very long cycle life ($> 1 \times 10^6$) [1]. Supercapacitors have recently been used in a hybrid configuration in parallel with a low temperature lithium-ion battery, as a demonstration payload on an Earth orbiting small satellite [2]. They have also been baselined for use in ice transceivers to support sub-surface melt probes on Ocean Worlds [3], to support power for small distributed science probes on planetary surfaces [4] and for high power electro-mechanical actuators and electro-hydrostatic actuators for flight control actuation systems [5].

To support the widespread acceptance and application of this technology in space, more data are needed regarding their performance in a relevant environment. The ability of supercapacitors to operate over wide temperatures is well established, and the radiation tolerance

* Corresponding author.
E-mail address: Erik.J.Brandon@jpl.nasa.gov (E.J. Brandon).

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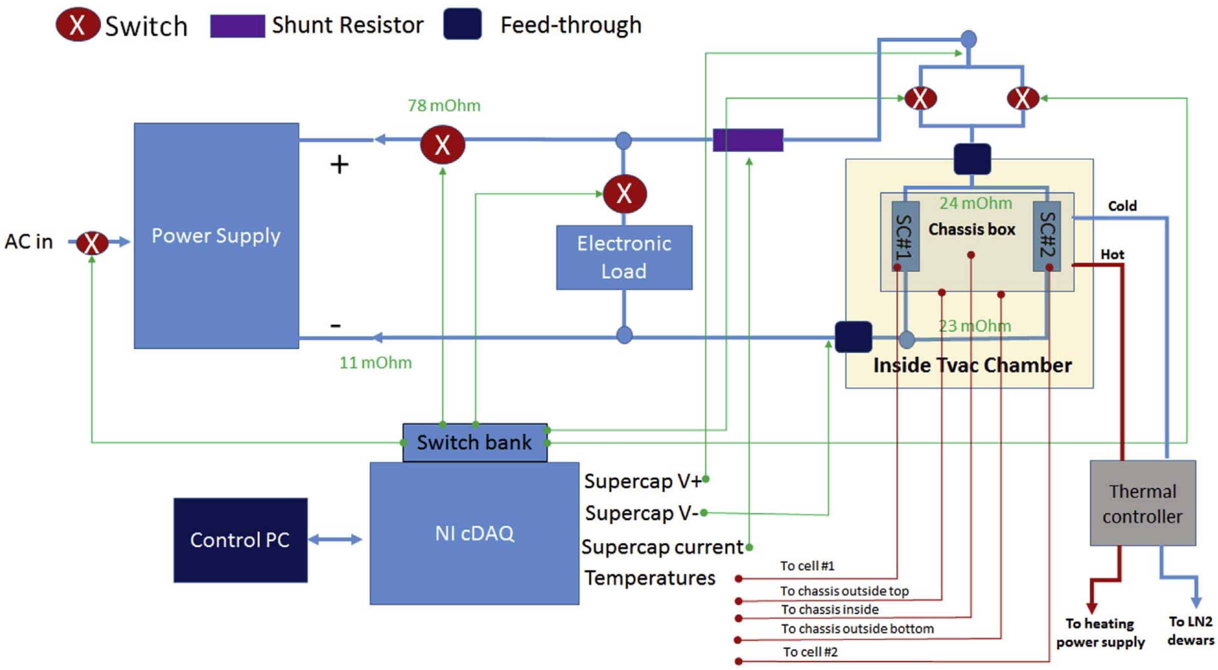

Fig. 1. Block diagram of thermal-vacuum (Tvac) chamber and data acquisition hardware.

Fig. 2. Vacuum chamber with supercapacitor cells in place (contained in steel chassis box), prior to closure of chamber.

Table 1
Thermal vacuum test sequence.

A	Determine mass of each cell and perform visual inspection
B	Perform a minimum of 3 charge/discharge cycles under ambient conditions to verify functionality and performance
C	Install test cells (contained in steel chassis box and surrounded by aluminum foil) in vacuum chamber and pump down to ~1 × 10−5 Torr prior to initiating cycling steps (between 0.5 and 2.7 V at 1 A):
	1 Perform minimum of 3 charge/discharge cycles under vacuum at +20 °C
	2 Increase temperature to +60 °C and dwell for at least 1 h (cell voltage at ~0.5 V during dwell)
	3 Perform minimum of 3 charge/discharge cycles under vacuum at +60 °C
	4 Reduce temperature to −40 °C and dwell for at least 1 h (cell voltage at ~0.5 V during dwell)
	5 Perform minimum of 3 charge/discharge cycles under vacuum at −40 °C
	6 Increase temperature to +20 °C and dwell for at least 1 h (cell voltage at ~0.5 V during dwell)
	7 Perform minimum of 3 charge/discharge cycles under vacuum at +20 °C
D	Backfill vacuum chamber with air, and open chamber
E	Remove chassis box and baseplate assembly, and disassemble the cells from the box
F	Determine final mass of each cell and perform final visual inspection

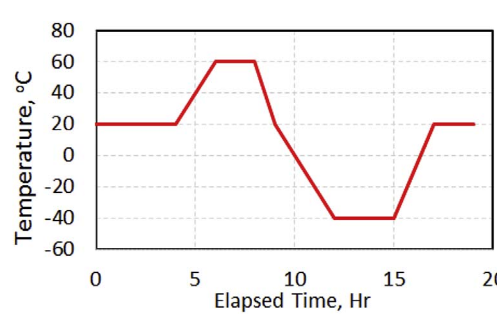

Fig. 3. Thermal profile used during thermal-vacuum testing.

for a representative cell type has been initially established with respect to proton and gamma radiation [6]. Recent research has indicated operation at temperatures significantly below that of commercial off-the-shelf cells (COTS) is possible, using modified electrolytes [7] [8] [9].

COTS supercapacitor cells are typically not hermetically sealed, and feature crimp or double seam seals between the header and can. This type of packaging is standard for terrestrial electrochemical cell technologies. The integrity of COTS based Li-ion cells in a space environment featuring similar packaging approaches has been established for many years [10]. The objective of this study was to determine the extent to which typical COTS supercapacitor cells can be considered for use in space power systems. Thermal vacuum (Tvac) testing is a