Performance of a New Line of Large Carbon Double Layer Capacitors

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ABSTRACT

Evans new MegaCap™ line of large carbon double layer capacitors combine high capacitance and energy density with a low ESR. These capacitors are constructed using carbon electrodes operating in a potassium hydroxide electrolyte and are contained in an efficient metal and polymer package. Devices from this line are available in sizes to over 40 kJ and have energy densities of up to 4 J/cc. The electrical characteristics of a 14 V, 65 F capacitor from this line are reported and indicate its suitability for a variety of high current applications. The capacitor had an RC product of 0.6 and reliably delivered high power discharges into a variety of loads.

INTRODUCTION

Double layer capacitor technology using high surface area carbon materials is well known and noted for it's ability to produce high capacitance density (1). Evans has been developing large carbon capacitors for several years and previous devices have demonstrated some of the possibilities with this technology (2). The MegaCap line places this carbon double layer technology in a high capacitance, commercially producible product with a useful voltage rating.

CAPACITOR CONSTRUCTION

MegaCap line capacitors consist of many individual sealed symmetric capacitor cells stacked in a series/ parallel arrangement. Each cell is composed of two particulate carbon electrodes formed on conductive polymer films. The electrodes are separated by an ionically conductive membrane and operate in a potassium hydroxide electrolyte. The conductive films extend beyond the electrode edges and are sealed together with a gasket. The cells are thin squares, approximately 0.040 x 5.75 x 5.75 inches.

The cells are stacked in series groups that are wired in parallel within the capacitor. The basic sealed cell construction allows for modular construction of a range of devices of various voltage and capacitance ratings.

Packaging the cell stacks to form large carbon capacitors of useful voltage presents some difficulties. The particulate carbon electrodes must be held under pressure to maintain the contact between particles that is needed to provide high conductivity. A pressure of 80 psi results in a compressive load of about 2600 lbs for this cell size. To contain the cells under this load, a steel sleeve capped by stiff polymer end plates was designed. An air spring was placed between the cell stack and one

Fig 1. Photograph of the 15 V, 65 F MegaCap capacitor tested.

end plate to maintain the compressive load. This packaging system used inexpensive materials, added minimal volume, and required little assembly time.

Capacitor voltage is determined by the number of cells stacked in series. In theory, each cell is capable of being operated at 1.0 V, however in practice the operating voltage must be reduced when cells are stacked in series (3). After designating the operating voltage, the capacitance is adjusted by specifying the number of cell stacks wired in parallel.

The capacitor tested consisted of five 18-cell stacks and was conservatively rated at 14 VDC (0.75 volts per cell). A photograph of the capacitor appears in figure 1. The outside dimensions were 5.75 x 5.75 x 5.00 inches and the mass was 5 kg.

MEGACAP PERFORMANCE TESTING

The capacitor was tested in several charge and discharge configurations. Prior to each discharge test the capacitor was charged to 14.0 V until the charging current dropped below 50 mA. For charging tests the capacitor was discharged into a load and subsequently shorted for at least one minute. All testing was conducted at room temperature.

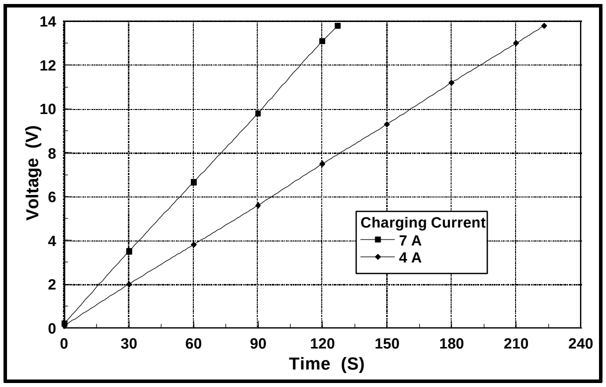

Fig. 2. Voltage vs time during constant current capacitor charging.

Calibrated currents and voltages were supplied with an HP E3632A power supply. A Kikusui PLZ153W electronic load was used to conduct the constant current and constant power discharges. This data was recorded using an HP 7132A strip chart recorder.

Constant current charging curves at currents of 4.0 A and 7.0 A are presented in figure 2. The capacitance value calculated from this data was 65.5 F. There was no significant variation in the capacitance measured at the two charging currents.

Constant power and constant current discharges of the capacitor are shown in figures 3 and 4 respectively. Voltage was plotted verses time for constant power (150 W, 100 W, and 50 W) and constant current (10.0 A, 7.5 A, and 5.0 A) discharges.

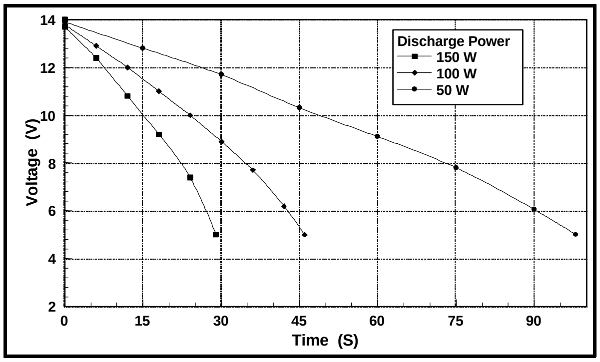

Fig. 3. Voltage vs time during constant power capacitor discharges.

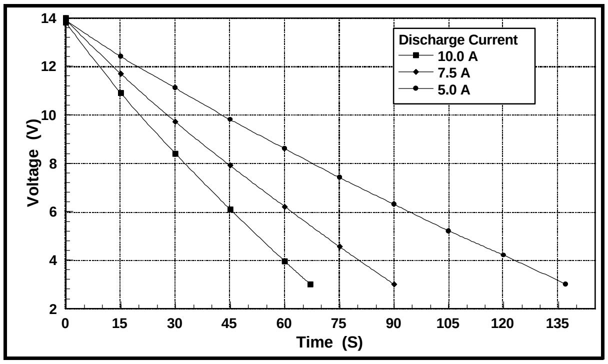

Fig. 4. Voltage vs time during constant current capacitor discharges.

For high power discharge testing, a low resistance, resistor was constructed. The resistor consisted of 20 ft, 3 in of ½ inch sch. 40 steel pipe assembled into a large ‘ U’ shape. Connections to the capacitor and switch were made using large, low resistance copper cables. A schematic and photograph of the setup are shown in figures 5 and 6 respectively.

With the capacitor removed from the circuit, calibrated currents of 1.00, 5.00, and 7.00 A were applied. The voltage readings on the circuit, made with a Fluke 8060A multi meter, were used to calculate the total resistance of 7.9 mΩ. The large mass (7.6 kg) of the steel pipe resistor ensured that the energy released did not heat it enough to change the resistance value of the circuit. To provide current measurement, the voltage across a portion of the circuit with 1.0 mΩ of resistance was monitored. This ammeter was also calibrated in the above manor. The circuit inductance, measured on a Philips 7132A RLC meter, was 8 µH.

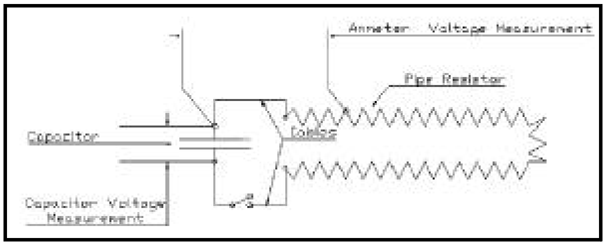

Fig. 5. Schematic of high power test circuit.

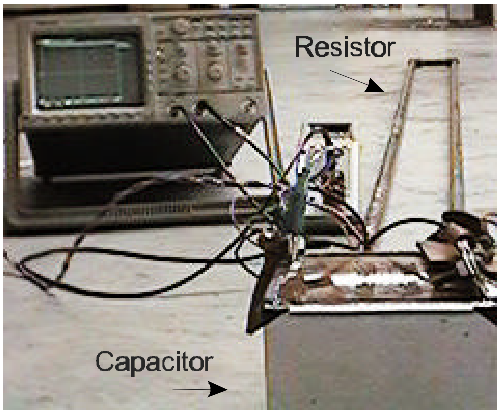

Fig.6. Photo of High power discharge setup.

A Tektronix TDS 320 digital oscilloscope was used to record the capacitor and ammeter voltages during discharges. The scope automatically multiplied the capacitor and ammeter voltages to provide a plot of power.

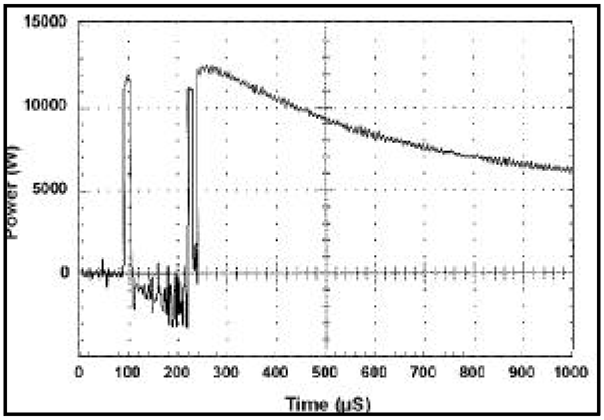

Fig. 7. Power output during the first millisecond for discharge into a 7.9 mΩ resistor.

During the test shown in figure 7, a sampling rate of 500 KS/s was used to observe the first millisecond of the discharge. The spikes appearing prior to the discharge curve were believed to be due to switch bounce. A peak power of 12.5 KW was recorded.

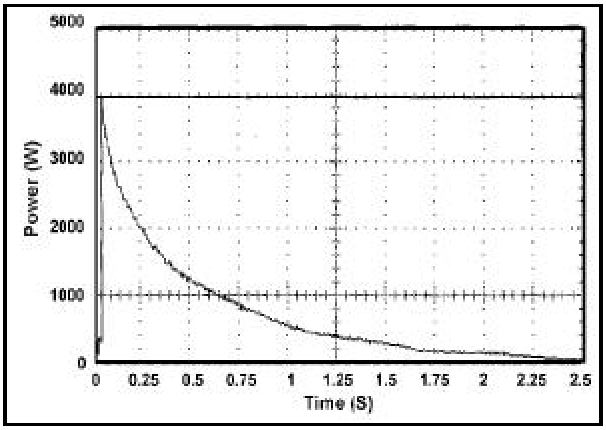

Fig. 8. Power output for a complete discharge into a 7.9 mΩ resistor

A second test with data recorded at 100 samples per second is shown in figure 8. The power curve presented shows most of the discharge, however the initial peak is missed.

The leakage current of this capacitor was very low. After an initial 24 hour ‘burn-in’ charge, the leakage dropped to less than 2 mA at 14.0 V. In subsequent testing after discharges, the leakage routinely dropped to this level after less than an hour.

The self discharge rate of an earlier prototype MegaCap is presented in figure 9. This capacitor was a 14 VDC, 25 F device of similar construction and had the same per cell voltage rating. Similar results are expected from the 65 F device.

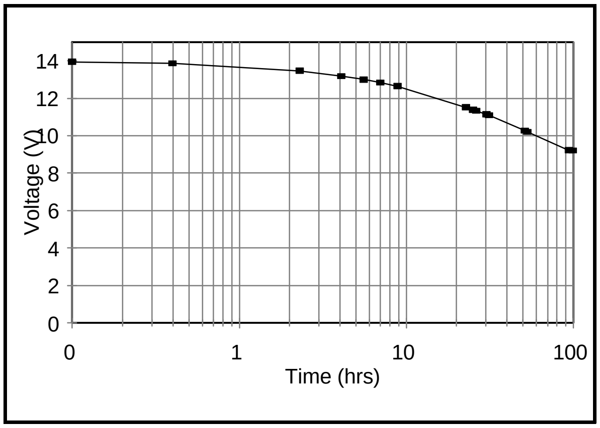

Fig. 9. MegaCap self discharge curve

The equivalent series resistance (ESR) of the MegaCap was 9.0 mΩ and the calculated R x C product was 0.6 seconds. The measurement was taken on a GenRad 1658 RLC Digibridge.

DISCUSSION

The device tested stored 6.4 kJ of energy at 14.0 V for a calculated energy density of 2.4 J/cc. This prototype had a conservative voltage rating to compensate for cell variation inherent in prototype construction. Rated at 0.9 V/cell, the energy density rises to 3.1 J/cc. Very large versions of this MegaCap (10 x 10 x 9 inches) are planned that will store over 40 kJ of energy at up to 4 J/cc.

The data presented shows the high power capabilities of the MegaCap line. Informal testing revealed that the capacitor tested was capable of starting vehicles although a higher capacitance rating would likely be specified for that application. The low leakage current and ESR are also good indications of the MegaCap's suitability for practical high power applications.

CONCLUSION

The 14 VDC, 65 F MegaCap preformed reliably and stored 6.4 kJ of energy. The R x C product was 0.6 seconds. Discharge rates of up to 12.5 kW were observed and the self discharge current was very low for a capacitor of this size. Modular cell construction and packaging simplify production. Overall, the MegaCap capacitor tested has all of the necessary characteristics for practical commercial application.

REFERENCES

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