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SURFACE VEHICLE RECOMMENDED PRACTICE

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LIFE CYCLE TESTING OF ELECTRIC VEHICLE BATTERY MODULES

1. *Scope*—This SAE Recommended Practice defines a standardized test method to determine the expected service life, in cycles, of electric vehicle battery modules. It is based on a set of nominal or baseline operating conditions in order to characterize the expected degradation in electrical performance as a function of life and to identify relevant failure mechanisms where possible. Accelerated aging is not included in the scope of this procedure, although the time compression resulting from continuous testing may unintentionally accelerate battery degradation unless test conditions are carefully controlled. The process used to define a test matrix of accelerated aging conditions based on failure mechanisms, and to establish statistical confidence levels for the results, is considered beyond the scope of this document.

Because the intent is to use standard testing conditions whenever possible, results from the evaluation of different technologies should be comparable. End-of-life is determined based on module capacity and power ratings. This may result in a measured cycle life different than that which would be determined based on actual capacity; however, this approach permits a battery manufacturer to make necessary tradeoffs between power and energy in establishing ratings for a battery module. This approach is considered appropriate for a mature design or production battery. It should be noted that the procedure defined in this document is functionally identical to the USABC Baseline Life Cycle Test Procedure.

1.1 Field of Application—Electric Vehicles

1.2 Product Classification—Electrochemical Storage Devices

1.3 Form—An Electric Vehicle propulsion battery will consist of a battery configuration of several (typically 12 V) modules interconnected in one or more series strings. This document provides test methods to determine the life expectancy of such modules, including but not limited to modules built in accordance with SAE J1797. Use of this document is intended for single independently packaged modules operating at ambient conditions (i.e., standard room temperature). Testing of a fully configured propulsion battery system, especially when designed to operate at elevated or reduced temperatures, usually results in reduced expected service life and requires testing methods beyond the scope of those included in this document.

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2. *References*

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J1715—Electric Vehicle Terminology
SAE J1797—Recommended Practice for Packaging of Electric Vehicle Battery Modules
SAE J1798—Performance Rating of Electric Vehicle Battery Modules

2.2 Related Publication—The following publication is provided for information purposes only and is not a required part of this document.

U. S. Advanced Battery Consortium Electric Vehicle Battery Test Procedures Manual, Revision 2, January 1996

3. *Definitions*—See SAE J1715.

4. *Test Conditions*

4.1 Test Samples—The number of test samples to be subjected to the test regime in this document will be determined by the entity sponsoring the testing based on the confidence level or statistical significance desired from the results. Determination of this value is outside the scope of this document, which is limited to defining the testing method to be used for any individual module. One commonly used approach is to establish some desired level of conformance. For example, if 23 modules are tested and the value corresponding to 1.28 standard deviations below the average is reported, 90% of the modules from which this sample is drawn can be expected to perform above this value.

4.2 Test Temperature—Testing shall be performed at a controlled ambient temperature of 25 °C (or at the target temperature specified by the test sponsor for the application) within ±2 °C. Measured module temperatures shall be stabilized within this range at the start of discharge or charge cycles. This may require cooling to be applied to reduce the time between the end of a charge or discharge and the beginning of the next discharge or charge. If required, cooling shall be applied using the manufacturer's recommended temperature control means, which shall specify the required coolant flow rates, heat transfer properties, etc. If these are not specified, modules under test shall be cooled by the presence of ambient air, i.e., cooling below ambient temperature shall not be used.

4.3 Temperature Sensing—A minimum of one ambient temperature measurement and one temperature measurement per module, insulated from ambient environment, is recommended. Different battery manufacturers may recommend specific locations for temperature sensing such as the center of the case side wall, one of the terminals, or the center of the end wall. In the absence of a manufacturer-specified location, use the center of the side wall as a default. Placement in any of these locations should not affect the results as long as the device is not exposed to external conditions that may skew the readings. Locating the sensor on a module terminal may require precautions to assure there is no shock hazard. The temperature sense location(s) should be reported with the test results.

4.4 Data Recording—Data recording should include time, temperature, voltage, current, and visual observations. Data should include a record of any maintenance performed on a module during testing.

4.5 Data Sampling Frequency—All parameters should be measured at a sample rate adequate to ensure that the coulombic and energy capacities of the module under test are accurately determined. For tests involving short-term transient conditions (i.e., dynamic capacity or peak power tests), this will typically require a sampling frequency of once per second during any transient portions of the test and a time skew between corresponding current and voltage measurements of 0.1 s or less.

5. Test Procedure

5.1 Determination of Test Ratings and Limits—Conduct of this procedure requires knowledge of the rated coulombic and energy capacities of the module, and of its rated peak power capability at 80% depth-of-discharge. Additionally, any manufacturer's limits on charge or discharge, such as minimum voltage, maximum current, or maximum or minimum temperature, must be known. The manufacturer's recommended charge regime shall be used for recharging the module after each discharge. However, the specified charge regime shall not result in a recharge period exceeding 12 h.

5.2 Preconditioning and Baseline Performance—A series of three baseline performance tests shall be performed prior to the start of repetitive cycling, as defined in 5.4. Any preconditioning tests required by the manufacturer shall be done prior to the performance of these baseline tests. Use of such preconditioning tests is discouraged unless modules have been subjected to an extended stand period prior to the start of testing under this procedure. In no case shall more than 10 discharge/charge cycles be required for preconditioning.

5.3 Repetitive Discharge Cycling—The discharge test to be used for this cycling is the Dynamic Capacity Test defined in SAE J1798, with power levels scaled as required in that procedure. The module shall be discharged to 80% DOD based on its dynamic rated capacity (in ampere-hours) using this test and then immediately be fully recharged. These discharge/charge cycles shall be repeated end-to-end (i.e., continuously) without interruption for a period of approximately 28 days. (A longer or shorter period may be appropriate if 28 days of cycling represents less than 5% or more than 20% of the anticipated module life.) If delays are necessary between the end of a charge or discharge and the following discharge or charge due to module temperature limits, this will reduce the number of cycles which can be performed during each cycling period. With some batteries it might also result in significant stand losses during the delay period. Consequently this delay interval should be limited to 1 to 2 h or less wherever possible, and it should be consistent in length. In order to reduce stand loss, the manufacturer is permitted to specify any reasonable cooling method to reach the required start-of-test temperature within such a time interval.

5.4 Reference Performance Tests—Prior to the start of cycling, and at the end of each period of repetitive cycling as defined in 5.3, a series of three reference tests shall be performed to determine the present capacity and peak power capability of the module, for comparison both to rated values and to those measured at the start of testing. These shall be done in the following order:

a. A Capacity Test at the C/3 constant current rate as defined in SAE J1798.
b. A Dynamic Capacity Test to a maximum of 100% of rated capacity as defined in SAE J1798.
c. A Peak Power Test as defined in SAE J1798.

5.5 End of Testing and End of Life—Section 5.3 and 5.4 shall be repeated until the module reaches an end-of-life condition as measured by the Reference Performance Tests. End-of-life may be any of the following conditions:

a. The measured capacity (either static or dynamic) is less than 80% of rated capacity, or
b. The peak power capability is less than 80% of its rated value at 80% depth-of-discharge

Since the repetitive cycling is done to 80% DOD based on its rated dynamic capacity, failure to achieve this capacity during cycling may indicate that end-of-life has been reached. Cycling may be suspended immediately and the Reference Performance Tests performed to verify this, or cycling may be continued until the next periodic tests. In either event, the Reference Performance Tests must be performed to confirm whether end-of-life is reached. If the periodic tests indicate that end-of-life is reached, they should be repeated for confirmation.

The life cycle expectancy of the module under this procedure shall be considered to be the total number of cycles accumulated when end-of-life is reached, including Reference Performance Tests but not including any cycles which fail to achieve 80% of rated capacity (i.e., those cycles performed after capacity drops below 80% but before the Reference Performance Tests verify end-of-life should not be counted in the reported life.)

Testing may be discontinued after end-of-life is reached, unless the testing sponsor elects to continue cycling in order to monitor the continuing degradation of the module.

5.6 Data Acquisition and Reporting Requirements—Reporting of this testing shall include a cycle-by-cycle summary of the measured net discharge capacity (in ampere-hours and watt-hours) and other results from the Reference Performance Tests. The capacity results may be reported in either tabular or graphical form. Other recommended information to be reported for these tests includes test duration, recharge energy and ampere-hours, charge/discharge efficiency, end-of-charge and end-of-discharge open-circuit voltages, and initial and final temperatures.

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