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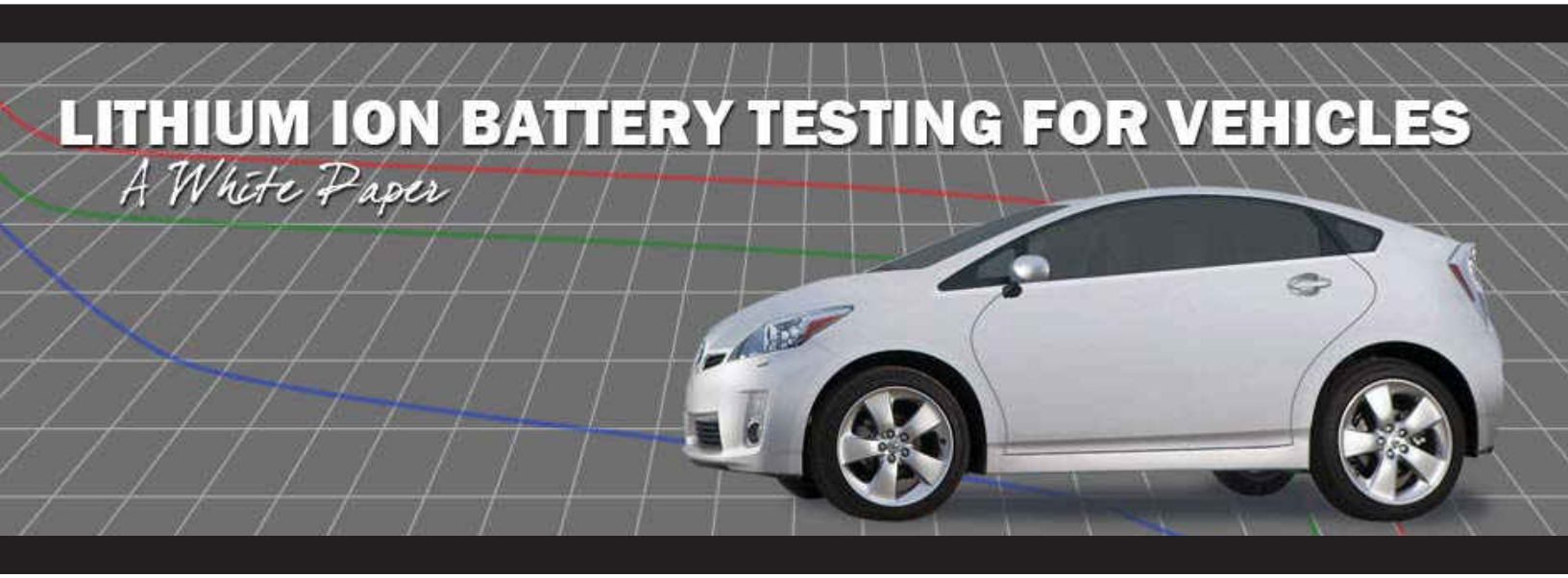

Environmental tests to improve durability of lithium-ion batteries
Environmental test equipment considerations for reliability & safety testing

September 2010

"If we want to reduce our dependence on oil, put Americans back to work and reassert our manufacturing sector as one of the greatest in the world, we must produce the advanced efficient vehicles of the future."

–President Barack Obama

INTRODUCTION

Lithium-ion batteries are used in many types of devices including over 60% of mobile phones and 90% of laptop computers. These batteries are inside iPods and iPads, as well as military and medical hardware. They are even powering pacemakers in the human body. However, the most significant growth in demand for Lithium-ion batteries is in the hybrid/electric vehicle market. This market is conservatively-estimated to grow from 2,400 units in 2008 to 1.53 million units by 2015.

Lithium-ion Battery Module

A major contributor to the increased development of battery-powered vehicles is President Obama's economic stimulus plan. The plan includes $5 billion for the development of a domestic battery industry including: $2 billion in loans, grants and tax credits to help stimulate the development and large-scale domestic production of advanced, lithium-ion batteries for hybrid and electric cars. Up to $2.4 billion in tax credits for building battery plants. Another bonus included is a $7,500 tax credit for people who purchase plug-in hybrid cars, which will indirectly boost lithium-ion battery production.

In recent years, the public has insisted on renewable energy sources in their vehicles to end dependence on traditional fuel sources. Soaring gas prices, national security, federal incentives, ecological risks associated with oil drilling, and global warming have accelerated the need to develop alternative fuel sources. As a result, safe and effective Lithium-ion batteries have never been more in demand.

NECESSITY OF TESTING

Stringent testing is required before any product is released into the market. This is especially true for Lithium-ion batteries. They are less durable than other types of batteries and can be very dangerous if mistreated. High temperatures can cause Lithium-ion batteries to easily rupture, ignite, or explode.

Understanding the decisions that need to be made when purchasing test equipment and the regulations that batteries need to be tested to are paramount for a successful end-product.

COMMON TESTING SPECIFICATIONS

To ensure that lithium-ion batteries are safe for use in HEVs many manufacturers are employing various methods of environmental testing. Manufacturers are looking to find a lithium-battery with a life expectancy of 10-15 years and thousands of charge and discharge cycles while maintaining safety and reliability.

The following are the most common test standards to test to, however testing to more extreme conditions than the listed standards will better protect the battery's brand and end-users.

Standards	Application
SAE J 2464	General guidelines for rechargeable energy storage system safety and abuse testing on electric and hybrid electric vehicles
UL 2580	General guidelines for batteries in electric vehicles
USCAR	Battery safety and performance from the Electric Vehicle Battery Test Procedures Manual, Battery Technology Life Verification Test Manual
FreedomCar	Power-Assist Hybrid Electric Vehicle Test Manual for analyzing battery performance
IEC 60086-4	Safety standards for primary lithium batteries
IEC 61960	Safety standards for secondary lithium cells and batteries
IEC 62281	General guidelines for the safety of lithium cells and batteries during transport
UN/DOT 38.3	Standards for shipping lithium batteries, either alone or as part of a device

TYPE OF TEST PROCEDURE

Many types of tests need to be performed for each specification. Besides the vibration and functional tests, the following are typical performance tests that are required by FreedomCar.

- **Thermal Performance Tests** show the effects of the ambient temperature environment on device performance. It uses the static capacity test, lower-current HPPC test and/or cold cranking tests at various temperatures ranging from -30°C to +52°C to characterize the performance of the technology and to see if a thermal management system is needed.
- **Cold Cranking Tests** are intended to measure power capability at low temperature (-30°C) in order for comparison against the FreedomCAR power goal of between 5 to 7kW.
- **Static Capacity Tests** measure device capacity at a constant current discharge rate determined by the manufacturer's rated capacity.
- **Hybrid Pulse Power Characterization (HPPC) Tests** determines dynamic power capability over the device's usable charge and voltage ranger using a test profile that incorporates both discharge and regen pulses in order to find available power and available energy.
- **Self-Discharge Tests** demonstrates the temporary capacity loss resulting from a cell or battery standing without use for a predetermined period of time. Lithium-ion batteries have a shelf life of 10 years or more, with self-discharge rates of 2-3% per month.
- **Energy Efficiency Tests** involve separate efficiency test profiles for minimum (25 Wh) and maximum (50 Wh) power-assist modes in order to see how efficient the battery can be.
- **Operating Set Point Stability Tests** verifies that the target life-cycle conditions are reached and that stable cycling can be conducted at a fixed state of charge or depth of discharge.
- **Cycle Life Tests** demonstrate device life when subjected to different energy use levels and patterns. The life cycle is defined as the number of cycles a cell can perform before its capacity drops to 80% of its initial specified capacity.
- **Calendar Life Tests** shows the degradation of a battery or cell as a result of the passage of time with minimal usage. It may use elevated temperatures in order to accelerate the life of the battery.
- **Reference Performance Tests** are a set of tests performed at periodic intervals during life testing to establish the condition and rate of performance degradation of devices under test.
- **Impedance Spectrum Measurement Tests** use special testing requirements for device-specific test plan in order to verify battery module control behavior.
- **Thermal Management Load Tests** verifies the overall thermal behavior of the entire system at a broad range of temperatures (-30°C to +52°C) in accordance to FreedomCAR goals. The performance of lithium-ion batteries deteriorates as the operating temperature decreases (see Chart 1)

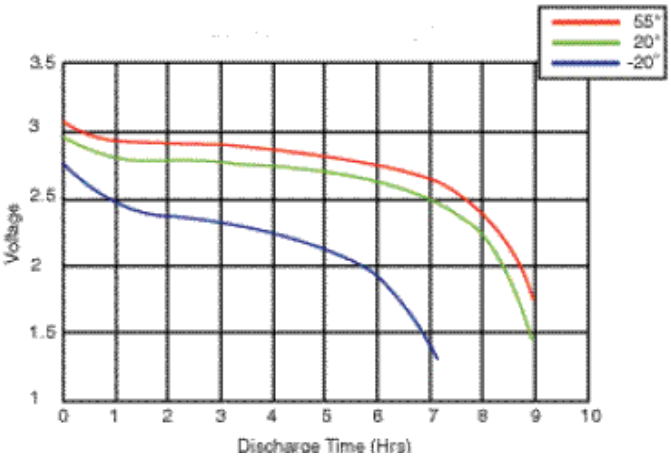

***Chart 1**: Thermal Behavior of Lithium Ion Batteries*

- **System-Level Combined Life Verification Tests** combines cycling operation and storage at elevated temperatures with the objective of validating a battery system life model at accelerated stress conditions. It is performed concurrently on multiple complete systems.
- **Vibration Endurance** tests the durability of the battery by simulating its lifecycle. Testing the battery in high vibration levels on the x, y and z axis helps pinpoint areas of weakness and fatigue. Vibration testing can also take place in an environmental test chamber where temperature and humidity is strictly controlled.
- **Functional Tests** acquires test data from the battery and its components. This test validates the functionality of the battery by itself or during extreme climatic testing.

TEST EQUIPMENT CONSIDERATIONS

Depending on the chosen testing specification, different equipment may be needed. However, even though there are many options to choose from, the equipment components are standard.

1. ENVIRONMENTAL TEST CHAMBER

Several environmental tests, including resistance to moisture, thermal abuse, fire, low temperature, vibration endurance, shock tests, etc., are required to ensure that battery life cycles, performance and method of shipping are up to standards. Optimized airflow systems in test chambers provide conditioning throughout the entire workspace, minimizing gradients and improving consistency. Temperature change rate is dependent specific compressor sizes and needs to be considered based on the testing specifications selected.

2. SAFETY FEATURES

Due to the risk of explosion or rupturing, several safety features need to be included on test equipment. Interior workspaces designed to minimize sparking, greatly reduces the risk of explosion during testing. A blow off pressure relief panel in the ceiling allowing for controlled pressure relief in the event of explosion. Sturdy door clamps ensures a tight seal during testing and helps to prevent door damage should an explosion occur.

Environmental Test Chamber with Safety Door Latch

Depending on the application, lithium-ion battery test equipment can incorporate gas detection, pressure relief, air or nitrogen purging, intrinsic barriers, fire suppression and more. Other safety features include: thermal protection devices to protect the product and the equipment, redundant breakers and heat links, emergency power off buttons, electrical disconnect switch, and high and low pressure limit switches.

3. FIXTURING

Proper fixturing of devices can increase throughput, provide consistency, increase product connection reliability and allow for easy loading and unloading. The fixture may be as simple as a drawer, rack, or shelf, or as complex as a fully powered cart with electrical connectors, outlets, and mating pins. Dedicated custom fixturing can be design specifically for the end use, reducing product handling, contributing to test accuracy, and improving throughput. Airflow, proper temperature and humidity distribution, corrosion, and vibration must be anticipated and controlled.

SUMMARY

Lithium-ion battery testing solutions can be specifically designed to enhance the development, optimization and certification of batteries and their components. For nearly 50 years, Thermotron has partnered with the automotive industry to meet reliability test standards. Our proven test solutions are found in the test labs of the world’s largest automotive and battery manufacturers.

Exposing lithium-ion battery technology to extreme temperature, humidity, altitude and vibration conditions helps manufacturers improve durability, reliability, safety and performance.

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