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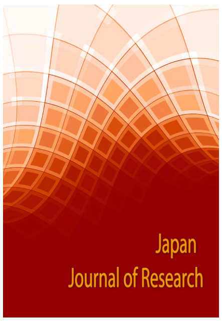

Design and Implementation of a Training Program for Hands-On Lithium-Ion Battery Testing in Automotive Engineering Education

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Abstract

The rapid transition from conventional internal combustion engines to electrified vehicles has revolutionized the automotive industry, demanding significant upskilling of the current and future automotive workforce. Among the most critical components of electrified vehicles is the lithium-ion battery, whose performance, safety, and lifetime directly impact vehicle efficiency, reliability, and cost. To address this challenge, this study proposes a comprehensive, hands-on training program to equip automotive engineers with practical skills in lithium-ion battery testing and data interpretation. Seven fundamental battery tests are integrated into the curriculum: continuous constant current discharging tests across different C-rates, discharging tests under varying ambient temperatures, surface temperature distribution measurements, open-circuit voltage vs. state-of-charge profiling, internal resistance measurements, battery aging studies, and internal short-circuit experiments. This article discusses in detail the experimental methods, instrumentation, procedures, and key observations of each test. The proposed program aims to bridge the knowledge gap between theoretical concepts and real-world applications, enabling engineers to design, analyze, and diagnose lithium-ion batteries effectively for next-generation hybrid and electric vehicles.

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Keywords

Lithium-ion battery, automotive engineering, training program, battery testing, electric vehicles, workforce development

Introduction

The automotive industry is experiencing one of its most profound technological transformations since its inception: a large-scale shift from conventional gasoline-powered vehicles to electrified vehicles, including hybrids, plug-in hybrids, and fully electric vehicles. This transition is driven by the demand for improved energy efficiency, reduced greenhouse gas emissions, and enhanced drivability, as well as the growing capabilities of advanced driver-assistance systems. Electrified vehicles possess fundamentally different powertrain architectures compared to their combustion-engine counterparts, with lithium-ion batteries serving as their central energy storage component [1-4].

The lithium-ion battery plays a pivotal role in determining the energy efficiency, performance, safety, and overall cost of an electrified vehicle. As a result, professionals in the automotive sector — both current engineers and future graduates — must develop a deep understanding of lithium-ion battery behavior and testing techniques [5-8]. However, traditional automotive engineering education and training programs have often focused on combustion engines, leaving a knowledge gap in the area of battery technology.

To address this challenge, it is crucial to develop targeted training programs that combine theory with hands-on practice. Practical experience in battery testing and data interpretation provides engineers with the essential competencies to design, improve, troubleshoot, and validate battery systems for advanced automotive applications. This article presents the design of such a hands-on training program focused on seven fundamental battery testing procedures. These tests, commonly applied in the industry, provide insights into battery performance under varying operating conditions, its degradation over time, and its response to potential abuse conditions.

The remainder of this article is organized as follows: Section 2 describes the experimental platform and equipment used for the tests; Section 3 details each of the seven fundamental tests, including objectives, procedures, and key results; Section 4 provides a summary and discusses the relevance of these activities in modern automotive engineering education.

Experimental Setup

To enable realistic, repeatable, and safe training in lithium-ion battery testing, a robust experimental platform is required. In this program, all experiments utilize EiG ePLB-C020 pouch-type lithium-ion polymer cells, each featuring a nominal capacity of 20

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Ah and a nominal voltage of 3.6 V. These cells use a lithium-nickel-manganese-cobalt oxide ($LiNiMnCoO_2$) cathode with a graphite-based anode, making them well-suited for plug-in hybrid electric vehicle (PHEV) and battery electric vehicle (BEV) applications. Standardizing on a single cell type ensures consistency across all tests, enabling clear comparisons and more effective training outcomes. Detailed battery cell specifications are summarized in Table 1.

Table 1. *Specifications of EiG ePLB-C020 battery cell.*

Length	196 mm
Width	127 mm
Thickness	7 mm
Weight	428 g
Nominal voltage	3.6 V
Nominal capacity	20 Ah
AC impedance (1 kHz)	<3 mΩ
Specific energy	174 Wh/kg
Energy density	370 Wh/L
Specific power (50% DOD, 10 seconds)	2300 W/kg
Power density (50% DOD, 10 seconds)	4600 W/L
Maximum charging voltage	4.15 V
Lower voltage limit for discharge	2.5 V

The experimental infrastructure comprises a Digatron charge/discharge unit (cycler) in conjunction with an Envirotronics temperature chamber. The Digatron unit, operated via Battery Manager software, allows for flexible programming of different testing protocols, including continuous, pulse, and dynamic charge/discharge cycles based on driving profiles. The software provides high-resolution data acquisition, recording current, voltage, and charge/discharge energy with a sampling resolution of 0.1 seconds, thereby delivering highly granular measurements crucial for education and research. Environmental control is achieved using the Envirotronics temperature chamber, which supports a wide temperature range from −70°C to 180°C. This capability allows students to simulate real-world temperature conditions, from winter cold starts to extreme summer driving, ensuring that temperature-dependent battery behaviors are thoroughly understood. An overview of the testing equipment and experimental setup is shown in Figure 1.

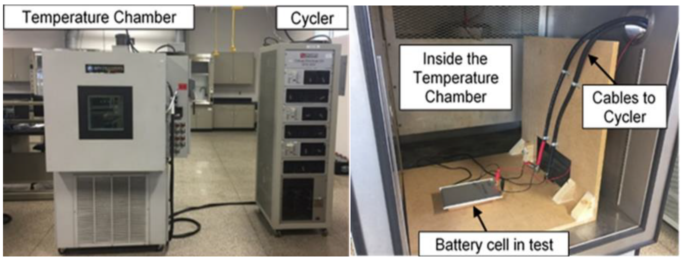

Figure 1. *Experimental setup of the battery testing: Cycler and temperature chamber (left); Battery cell testing inside the temperature chamber (right).*

For accurate surface temperature measurements on the battery cells, OMEGA SA1-K-SRTC surface thermocouples with self-adhesive backing are employed. These sensors deliver reliable temperature readings up to 175°C with a rapid response time of 0.3 seconds. The thermocouples connect to TEKCOPLUS 4-channel K-type thermocouple meters (model THTK-6), which continuously log surface temperatures at one-second intervals, giving students real-time insights into the battery's thermal profile.

This experimental configuration is intentionally designed to emulate industry-grade testing standards while being accessible and manageable for trainees. By exposing students to advanced battery testing equipment and standardized procedures, the program cultivates confidence and competence in handling battery systems safely and effectively.

Fundamental Lithium-Ion Battery Tests

The following seven tests are integrated into the training program to provide engineers with comprehensive, practical skills for assessing lithium-ion battery behavior. Each test is carefully selected to illustrate a critical aspect of battery performance, reliability, or safety.

Continuous Constant Current Discharging Tests at Different C-Rates

The first module examines how discharge current rates influence the usable capacity and voltage profile of a lithium-ion battery. This is critical since vehicle acceleration, regenerative braking, and accessory loads all impose varying current demands on the battery. The procedure begins by setting the temperature chamber to a controlled 20°C. Each cell is initially charged at 1C (20A) to 4.2V, then topped off using a constant voltage (CV) phase until the current drops to 5A, ensuring full charge. Following this, the cell is discharged at various constant currents corresponding to 0.33C (6.67A), 0.5C (10A), 1C (20A), 1.5C (30A), and 2C (40A), down to a cutoff voltage of 2.5V. The discharging voltage curves under different discharging C-rates are presented in Figure 2.

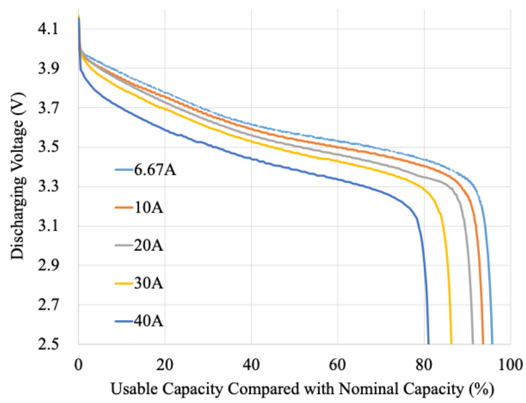

Figure 2. *Discharging voltage curves under different discharging C-rates.*

Analysis of these tests reveals that higher discharge rates reduce usable capacity due to voltage sag and internal resistance effects. At a 2C discharge, up to 20% of nominal capacity is unavailable without a subsequent CV discharge. In addition, the voltage drops more sharply at the onset of discharge as the current increases, with initial voltage dips of approximately 3.9V at 2C compared to around 4.0V at 0.33C. These results help trainees grasp how driving conditions influence battery state-of-charge (SOC) estimation and vehicle range predictions.

Discharging Tests Under Varying Ambient Temperatures

Temperature is a dominant factor affecting lithium-ion battery performance, particularly in automotive environments where batteries may experience −40°C to 60°C. This module explores these effects by discharging fully charged cells at 10A, 20A, and 40A under ambient temperatures of −20°C, −10°C, 0°C, 20°C, and 50°C. After stabilizing each cell at its target temperature for at least 15 minutes, the discharge cycle is initiated down to 2.5V. As shown in Figure 3, results consistently demonstrate that higher ambient temperatures improve both discharge voltage and usable capacity, while lower temperatures reduce them. Furthermore, increasing the discharge current amplifies these temperature effects, highlighting the interplay between thermal and electrical stresses. These experiments underscore the importance of battery thermal management systems in automotive design.

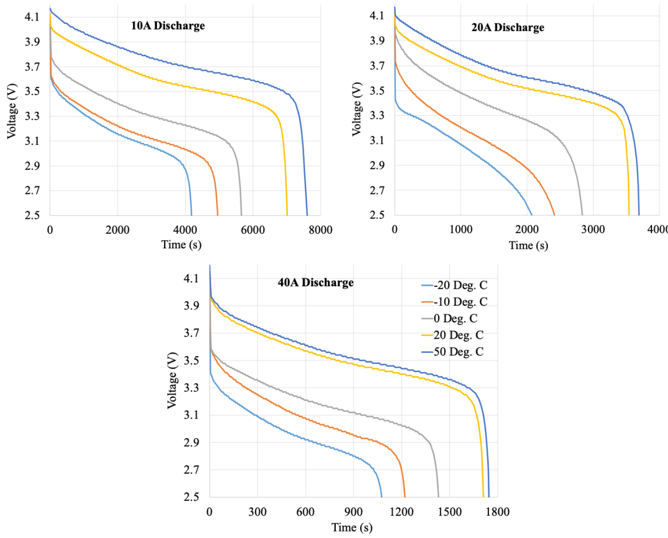

Figure 3. *Discharging voltage curves of the battery cell under different ambient temperatures and discharging currents.*

Surface Temperature Distribution Measurements During Operation

Battery safety and performance are strongly tied to thermal distribution across the cell, a critical factor in thermal management system (TMS) design. This test measures surface temperatures at eight locations on each cell using OMEGA surface thermocouples. Discharging is conducted at 20A, 40A, 60A, and 80A, while charging uses 20A and 40A. Figure 4 shows the experimental setup of the cell surface temperature distribution measurement.

Students observe how temperature distribution evolves, with higher currents creating significant hot spots, particularly near cell tabs. For example, in an 80A discharge, temperature increases up to 20°C were recorded, and location-dependent temperature differences exceeded 5.5°C. These insights help trainees appreciate the importance of even temperature distribution to avoid local hotspots that could trigger thermal runaway. Figure 5 shows the cell surface temperature variations at different locations during 20A and 80A discharges.

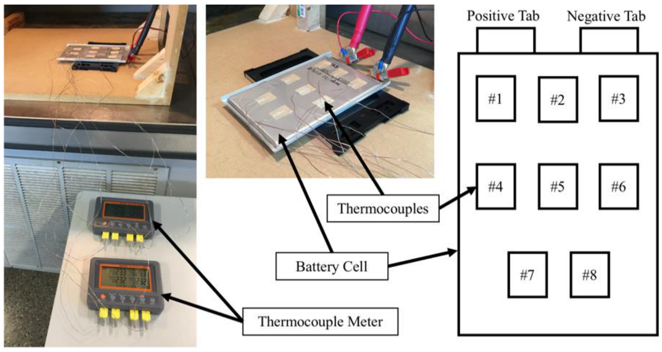

Figure 4. *Experimental setup for the battery surface temperature measurement and the locations of the thermocouples on the battery cell surface.*

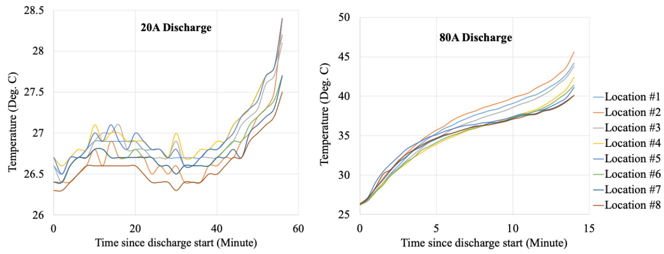

Figure 5. *Cell surface temperature variations at different locations during 20A and 80A discharges.*

Measurement of OCV vs. SOC and OCV vs. DOD

Accurate mapping of the open-circuit voltage (OCV) versus state-of-charge (SOC) or depth-of-discharge (DOD) is vital for battery management systems. Students perform pulse current tests with 5% SOC steps, allowing the battery to rest between pulses so that quasi-equilibrium OCV values can be measured. Tests use 2C and 3C pulses at 25°C with three-minute rest intervals. As shown in Figure 6, results demonstrate a largely linear relationship between OCV and SOC in the range of 10–90%, with OCV decreasing from about 4.02V to 3.51V during discharge. These measurements form the foundation for SOC estimation algorithms in real-world electric vehicles.

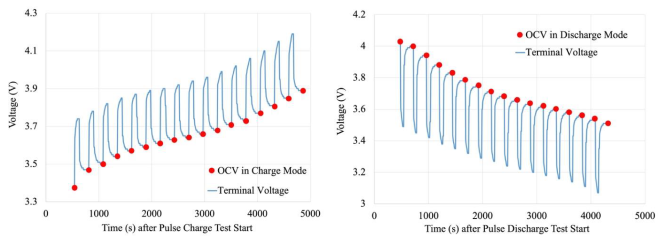

Figure 6. *OCVs obtained during pulse charge (left) and pulse discharge (right) tests.*

Internal Resistance Characterization

Understanding internal resistance is critical for diagnosing battery health and predicting performance under load. The voltage difference between OCV and discharging voltage during discharge as shown in Figure 7 is the voltage drop caused by the internal resistance. Using the voltage drop and discharging current values, students can calculate the battery cell internal resistance under different DODs (10–90%) and ambient temperatures (−25°C to 50°C). As shown in Figure 8, calculated results reveal strong temperature dependence: internal resistance at −25°C exceeds that at 50°C by more than sixfold, ranging from 0.003Ω to 0.035Ω across the tested DOD and temperature combinations. The DOD effect is minimal between 10–90% at moderate temperatures but becomes significant at high DOD levels under extreme temperatures. These experiments develop engineers' intuition about how internal resistance constrains battery power delivery.

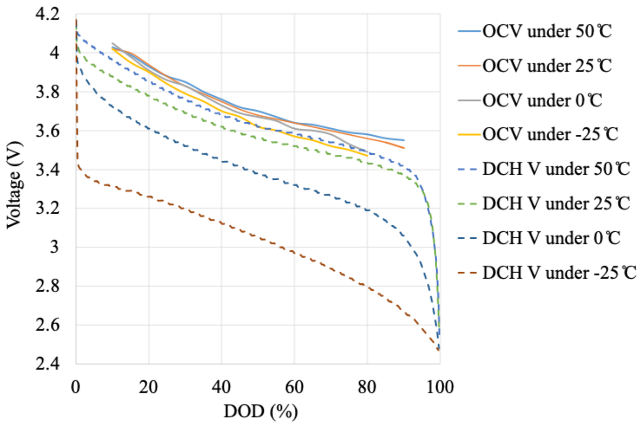

Figure 7. *Comparison between OCV and discharging voltage (DCH V) during discharge under different ambient temperatures.*

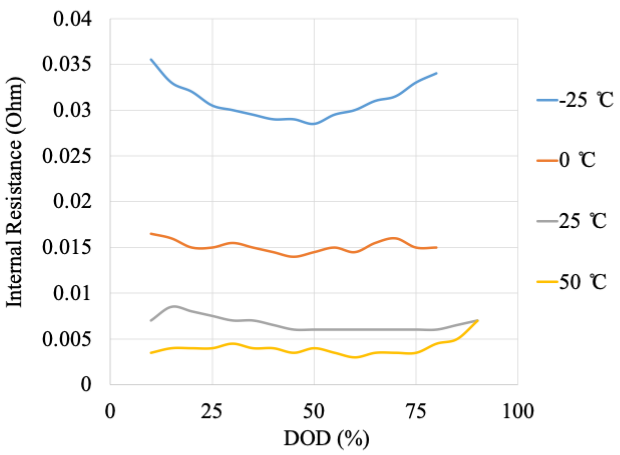

Figure 8. *Calculated battery cell internal resistance vs. DOD under different ambient temperatures.*

Battery Aging Experiments

Aging tests simulate how a battery degrades over time due to repeated cycling. After verifying initial cell capacity through three charge/discharge cycles, the selected cell is repeatedly cycled 800 times at 20A charging to 4.15V and 40A discharging to 2.5V under 25°C ambient temperature. Discharged energy in Ah from each discharging cycle is measured, revealing a steady decline in discharged energy from about 18 Ah to 13.5 Ah over 800 cycles, as shown in Figure 9. Internal resistance measurements are taken at baseline and after every 200 cycles. Figure 10 shows that internal resistance increases as battery cell ages, rising by nearly an order of magnitude after prolonged cycling. These findings help students understand capacity fade and internal resistance growth during battery aging, which are key to assessing battery lifespan and vehicle warranty planning.

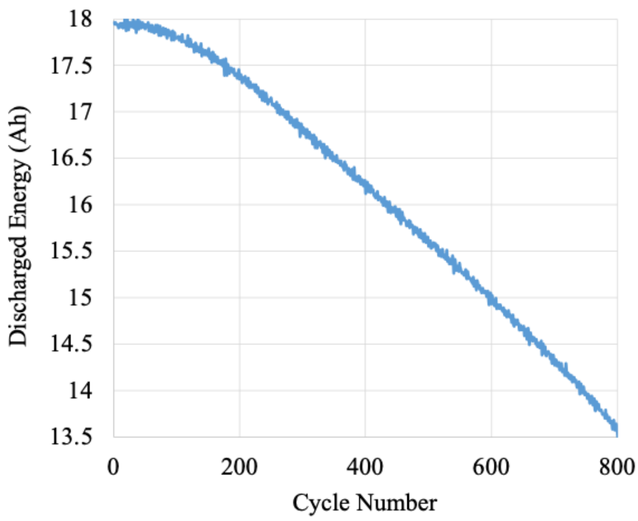

Figure 9. *Discharged energy from each discharge cycle during 800-cycle aging test.*

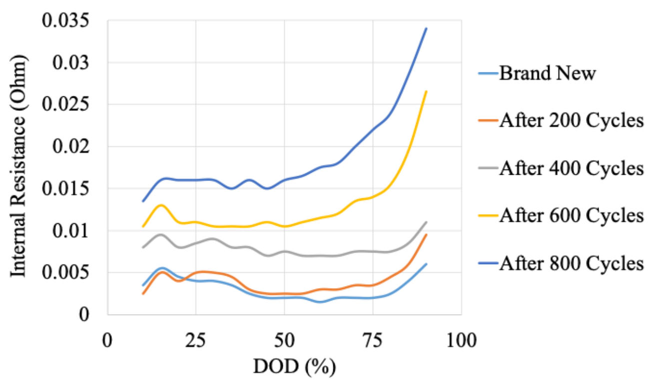

Figure 10. *Internal resistance of battery cell after different number of aging cycles.*

Internal Short-Circuit Experiments

To explore safety-critical failure scenarios, students perform penetration-induced internal short-circuit experiments. Nine cells are pre-conditioned to 10%, 50%, and 90% SOC and then penetrated with a conical probe at three different locations on the cell surface, as shown in Figure 11. Cell surface temperature and voltage responses are recorded at high resolution, revealing rapid voltage collapse and significant local heating, especially at higher SOCs. As an example, Figure 12 shows the variations of cell surface temperature at three thermocouple locations and cell terminal voltage during penetration-induced internal short-circuit experiments with 90% initial cell SOC and different penetration locations. Tests demonstrate that short-circuits near

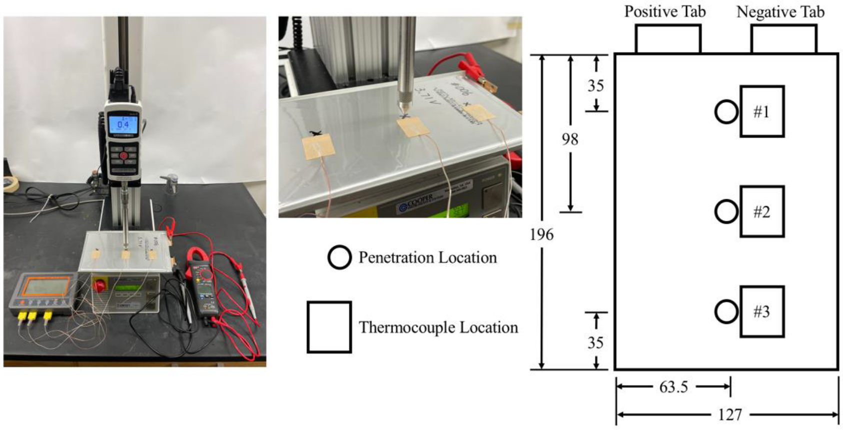

Figure 11. *Penetration-induced internal short-circuit experiment setup (left), a closer look of penetrating conical probe (middle), and a diagram showing penetration locations and thermocouple locations with unit in mm (right).*

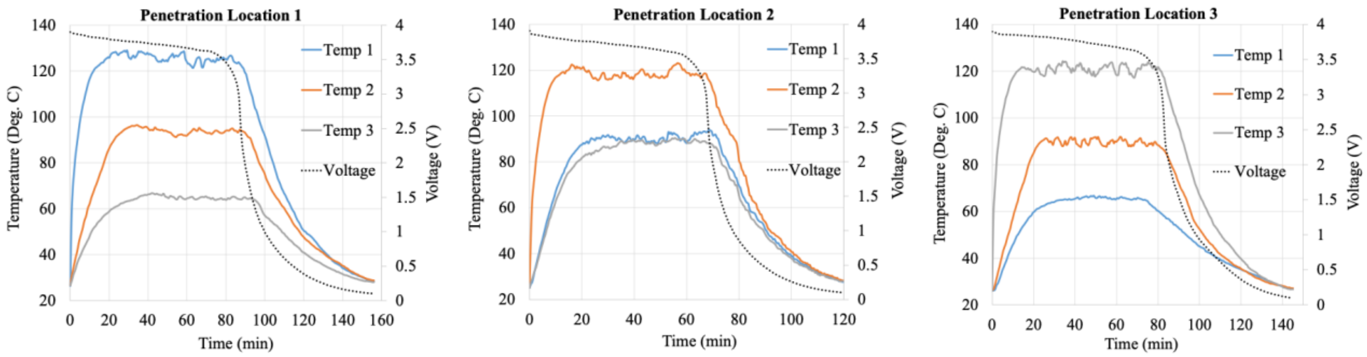

Figure 12. *Variations of cell surface temperature at three thermocouple locations and cell terminal voltage during penetration-induced internal short-circuit experiments with 90% initial cell SOC and different penetration locations.*

the edge of the cell result in more severe thermal responses due to constrained heat dissipation. Such experiments build respect for battery hazards and the importance of robust safety features in battery systems.

Summary and Conclusion

The automotive industry is undergoing a profound transformation as electrified vehicles replace traditional internal combustion engines. This shift demands that both current and future automotive engineers develop deep expertise in lithium-ion battery technologies, which lie at the heart of modern electrified drivetrains. However, knowledge of battery chemistry alone is insufficient; engineers must also gain hands-on skills in the testing, evaluation, and safety assessment of lithium-ion batteries to meet industry requirements.

To address this critical upskilling need, this paper proposed a comprehensive training program integrating seven essential lithium-ion battery tests. These hands-on modules include:

1. Continuous constant current discharging tests at different C-rates — to teach the effects of varying load demands on usable capacity and voltage profiles.
2. Discharging tests under various ambient temperatures — highlighting how environmental conditions influence battery performance and electric vehicle range.
3. Surface temperature distribution measurements — revealing heat generation and gradients during charge/discharge cycles, which informs thermal management strategies.
4. OCV versus SOC and DOD mapping — providing essential data for battery state estimation models in vehicle battery management systems.
5. Internal resistance characterization — establishing how temperature and depth-of-discharge affect the battery's electrical impedance and power delivery.
6. Battery aging tests — simulating long-term cycling to measure battery usable capacity fade and internal resistance growth, key indicators of end-of-life and warranty considerations.
7. Internal short-circuit experiments — developing awareness of catastrophic failure modes, thermal responses, and critical safety measures.

For each test, the article described detailed experimental setups, procedures, and key findings. The EiG ePLB-C020 pouch-type lithium-ion polymer cells, with their 20 Ah nominal capacity and 3.6V nominal voltage, served as a consistent baseline for these tests. Supported by advanced industry-scale laboratory equipment — including Digatron cyclers, Envirotronics temperature chambers, and precise surface thermocouples —

the proposed training program offers an industrially relevant and academically rigorous approach.

The knowledge gained through these experiments will directly support the design, validation, and troubleshooting of battery packs for hybrid and electric vehicles. By exploring performance, temperature effects, internal resistance, degradation, and safety, engineers will build a holistic understanding of battery systems that extends far beyond theoretical models. Furthermore, the proposed program promotes critical thinking about trade-offs in power density, thermal management, capacity utilization, and long-term durability, which are vital to advancing the next generation of electric propulsion systems.

Going forward, the training curriculum could be further expanded to cover advanced battery chemistries beyond lithium-nickel-manganese-cobalt-oxide, such as lithium iron phosphate or solid-state batteries. It could also incorporate more sophisticated testing protocols including driving-cycle-based profiles, fast charging, or abuse testing beyond internal shorts, to mirror the rapidly evolving standards of electric vehicle development.

In conclusion, this proposed training program bridges a significant skills gap by equipping both current and future automotive engineers with the hands-on experience and technical knowledge necessary to design, analyze, and manage lithium-ion battery systems safely and effectively. By grounding students in essential testing skills while encouraging exploration of emerging technologies, the program will help build a workforce ready to lead the electric vehicle revolution.

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