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High-Speed hybrid Battery End-Of-Line Test System

Dean Geroux
Bitrode Corporation
1642 Manufacturer's Drive
St. Louis, MO 63026
(636) 343-6112 / www.bitrode.com

Abstract

High-speed end-of-line battery testing is based upon measuring the electrical response of a cell in a module or pack to an applied test signal in a production setting. The intended result is to determine the cell's state of health from the measured response and determine the integrity of the module or pack overall. Such testing represents a faster, less expensive alternative to traditional end-of-line testing, which is the most accurate way to qualify pack or module efficiency. Recognizing this, Bitrode Corporation has partnered with the leader in production test control systems to create a fully automated turn-key end-of-line system.

The main advantages of the Bitrode/Bauer test system over load-cycle testing are fast turn-around time, accuracy, and low personnel requirements, all achievable because the battery does not have to be disconnected from test line for the test. With the development of advanced chemistries and test procedures, it is critical to have a system with a flexible user friendly interface.

The Bitrode/Bauer system has integrated high-speed data acquisition with wave form analysis, GM LAN, UDS, and KWP2000 protocol, Meg-ohm meter, milli-ohm meter, internal battery control via PWM, and connectivity to a supervisory database system. The Bitrode/Bauer automated charging and test system provides a complete turn-key solution for production manufacturing of tomorrow's intelligent hybrid electric energy storage systems. The system can be set up to record hundreds of static test points as well as performing signature waveform analysis at sample rates in excess of 1MHz. Multiple communication protocols are supported and all safety conditions are monitored in real-time. Multiple battery types can be tested, each with individual test profiles and test limits. Up to 2,000 test records can be stored on the local hard drive, and the capability of uploading test information to a supervisory database server allows the user to produce production and statistical reports.

Keywords: data acquisition, control system, battery, instrumentation,

Introduction

The successful installation of a production test system project requires more than just a great test system. Coordination is required to ensure the automated test system is operating as a fully integrated piece of the overall assembly line. Several key aspects are discussed in this paper, which should give the reader a good understanding of the general requirements in order to ensure a reasonable chance of success for any project.

1.1 Project Management

Perhaps the most important factor to consider when undertaking an automated test system project is the project manager. This individual will be responsible for pulling together information from several different organizations, and individuals. Typically, key people the project manager must interact with will include:

- Hardware Designers
- Test Engineers
- Software Programmers
- Product Engineers
- Assembly Line Supplier
- Training Professional
- Etc.

1.2 Specifications and Documentation

At least two manuals should be produced with the project (operator manual and test application manual). The operator manual will provide an operational description regarding the automated test system user interface menus and provide some detail on common tasks such as recovering from an emergency stop. The test application manual is much more technical in its content and provides the following details:

- PC hardware components
- I/O assignment and scaling (digital, analog, PWM, etc.)
- Machine interface (PLC, battery intelligent controller, RF tag, etc.)
- Details about the test
- Special hardware jumpering information
- Third party software setup procedures

1.3 Hardware Engineering

Custom hardware engineering is required for the design and implementation of the automated test system interface to the assembly line PLC, electrical cabinet drawings, custom connectors, etc. PLC interface can be as simple as a digital I/O handshaking scheme, or as sophisticated as the latest industrial Ethernet protocols (e.g. Profibus, RSLinks, etc.). In addition, custom hardware engineering will be required for command and control interface to the battery pack intelligent control module’s low voltage connectors and the high voltage interlock circuitry.

1.4 Systems Software Design

The development of project specific software is sometimes required in order to allow the automated test system to communicate to the intelligent battery pack controller using customer proprietary protocols. Other custom communications drivers may also have to be developed for interface to third party instrumentation or a supervisory database system that might be used for the collection and long-term storage of test results.

1.5 Test Design and Development

Test design refers to determining what test conditions will be applied to the battery pack being tested. Product engineers will most likely have a good idea as to the type of setup conditions they will want applied during the test and the response readings that should be received back if the unit is functioning properly.

However, product engineers may not have knowledge about the capabilities of the automated test system or be fully aware about any limitations in the ability to test the product in a real-world manner without having all real-world I/O present. As an example, product ready - fully programmed intelligent battery control modules will be expecting to see all of the input signals normally present when installed in the automobile. All of these signals, of course, are not present when the battery is being tested on the assembly line, and therefore – to the extent possible, the automated test system must try to replicate these signals so as to give the intelligent battery control module the impression that it is actually installed in the car.

There are always some limitations to simulating real-world I/O. Test system providers and customer product engineers must work closely together in order to determine to what extent real-world I/O can be simulated in the automated test system. In this way, customer product engineers can begin to make trade-offs on the testing that will actually be performed on the battery pack and then understand if normal test readings will have to be adjusted for test purposes in the automated test system on the production line.

1.6 Application Software Engineering

Once the test has been designed, it then falls upon the application engineer to program the automated test system to perform the test in the chosen computer language of the automated test system. The test is typically broken into several steps with each test step having a pre-defined set of test conditions that should be set prior to taking test readings. For instance, charge and discharge profiles will be determined in the test development phase with test readings being prescribed at certain points within the test profile. The application engineer must program the test system to command the charge/discharge profiles in the proper sequence and ensure that test readings are recorded at the proper time.

1.7 Integration and Debug

Once the test application has been programmed into the test system PC, it then is time to perform integration and debug of the complete automated test system. The automated test system must perform its functions as an integrated part of the assembly line. This means the automated test system supplier will be working closely with the assembly line supplier in order to work out several of the following issues:

- I/O handshaking between the assembly line conveyance and the automated test system
- Providing the automated test system with some means of uniquely identifying each unit to be tested
- Safety and abort condition definition

1.8 Runoff Support at the Integrator

Customers will typically want to see a demonstration of a fully functional assembly line and automated test system prior to allowing tear-down and shipment to the final installation site.

It is common for most customers to insist upon an extended test run (or Run-Off). The run-off is performed by equipment suppliers and is intended to demonstrate the system can function continuously in a production simulated situation without the need to stop. Statistical data is sometimes recorded in order to show consistent readings are being obtain when testing one unit to the next, and (if identical test systems are being purchased), that test readings are consistent from one system to the next.

1.9 Final Install Support

The assembly line integrator or other third party contractors will be used for shipment of the new assembly line and automated test equipment from the original build site to the final installation facility. Final install support is usually provided once the placement of the equipment has been completed. Final install support is provided to ensure the assembly line and automated test equipment is functioning on the factory floor, just as they did before approval to ship. Statistical readings are sometimes collected again in order to ensure that they are consistent with those readings that were collected prior to shipment of the equipment to the final install site.

1.10 Training

Typically, there are three different types of training that are provided for automated test equipment:

- *Operator Training*: Test systems used in high production environments can be fully automated or sometimes are semi-automated. Operator training is provided to instruct personnel on proper procedures for connecting battery pack to be tested to the automated test equipment. Additional training is also sometimes provided to instruct the operator on how to initiate the test, how to initiate a retest, how to recover from an abort condition, safety instructions, and how to recover from an emergency stop condition.
- *Maintenance Training*: Maintenance training usually means calibrating any transducers that have the potential to drift, or wear out over time. The automated test system should provide user interface screens intended for maintenance personnel so that a record of calibration can be maintained for ISO9000 recording keeping purposes. Maintenance training is then performed to instruct plant personnel in the proper techniques for calibration and the procedures to be followed in the event that a transducer has failed.
- *Test Engineer Training*: A good test system should be adaptable to changes in the product and/or production process. This means the automated test system should have an open architecture that will allow customers to be self supportive when these eventual changes occur. Test engineer training is then provided in order to show customer engineers

responsible for the test systems how to make changes to the system when needed. This could be something as simple as changing the limits on a single test point, all the way up to development of an entirely new test script.

1.11 Production Support

Production start-up support is usually provided to customers once the production assembly line begins to see a significant number of components being built. At this point it is common to notice that test system readings are indicating a higher percentage of failures than was previously experienced during the test development phase. This is understandable given the test system was developed and preliminary test point limits were established using pre-production parts. It is quite common to see changes in test readings once the product is being produced on the production line. Automated test system suppliers will provide production start-up support intended to assist the customer engineers understand the nature of the change in test point readings and help determine if the root cause of the change in readings is being caused by the product, the automated test system, or the production process.

2 Production Test System

The DLS850 End of Line Battery Test System is a full featured data acquisition and test control solution targeted for intelligent hybrid battery manufacturers. The system software runs on the Microsoft® Windows® XP operating system and its standard resources. This is a real-time control system designed for manufacturing and process control solutions that require high-speed data acquisition and data analysis. Its object-oriented, layered configuration has a lean architecture that provides uncompromising speed and allows individual processes to run simultaneously. As the testing process matures, the systems open architecture allows customers to easily change configuration parameters to help improve battery pack quality and reduce manufacturing costs.

The system features a graphical user interface (GUI) that is intuitive and easy to learn. Combined with a library of tools that have been developed specifically for battery pack End-Of-Line (EOL) testing and analysis, the DLS850 provides a powerful platform to ensure the integrity of the Battery Pack EOL Test Station. Turn-key project engineering, installation and support are also offered for each DLS850 system and are tailored for the specific needs of the production process and the product being tested.

3 Sequence of Operation

The DLS850 can handle all aspects of I/O monitoring, control, and communication required for fully testing the battery pack. And, in the absence of a of an automation PLC, can also be used for control of conveyance traffic required for directing battery packs in to, and out of the test station. A typical sequence of operations may include:

- Battery pack enters EOL test station
- Read barcode to determine battery pack model type
- Automatically engage proper low voltage and CAN communication connectors, or illuminate proper test stand connector to be manually connected to the battery pack
- Perform cable verification tests
- Perform software verifications tests
- Perform safety checks
- Perform pre-defined test sequence
- Perform battery charge / discharge sequence
- Perform data analysis
- Power down and disconnect cables
- Communicate test results to supervisory information system
- Move battery pack out of EOL test station

4 Multiple Battery Technologies

A single DLS850 system is capable of testing a wide variety of batteries using various technologies (e.g. NiMH, NiCd, Li-Ion, etc.) and has the capability to run a different test sequence on unique battery models (types) that may be intended for different customers. This can be accomplished simply by reading a unique identifying model number via barcode label, pallet Radio Frequency (RF) tag, dot-matrix pattern, or other means to uniquely identifying the particular battery model to be tested

5 Test System Capabilities

The DLS850 software is a high-speed, real-time, multi-tasking test control system designed to test the performance and verify the quality of your battery throughout the production process. This system works with any manufacturing equipment requiring high-speed data collection, accurate measurements, and comprehensive analysis tools and provides the following benefits:

- Communication with machine motion control software and other test station components that control machine motion.
- Optional embedded machine motion control eliminating the need for a separate PLC for a more efficient test suite.
- Standard PC system using Microsoft® Windows® operating system and readily available PC hardware components,
- Intuitive application design that is simple for operators to use and for engineers to maintain.
- Easy to use editors for modifying the test sequence and application.
- Multilingual capabilities for international installations. Translation is available, based on customer needs, as an option for windows, messages, descriptions, and documentation.
- Personalized technical support, remote debug services, and network connectivity to decrease downtime and increase productivity.
- Central Control and Version Control features for managing and tracking test application changes.

5.1 Data Collection

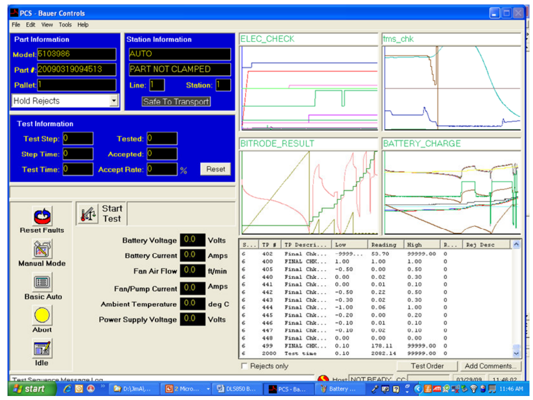
The test sequence is designed as a series of procedures, called test steps that can be run in sequence as a complete test or manually as individual tests. The test control system collects data at high speed and displays test point values in real-time. To minimize test time, the test control system performs multiple tasks simultaneously while continuously monitoring safety conditions and communicating with external test station components.

5.2 Machine Motion Control

The DLS850 embedded ladder logic module can be used to maintain control of machine motions via communication with distributed I/O modules. If a separate PLC is used for motion control, the DLS850 maintains continuous handshaking with third-party machine control software to command test station motion and to monitor safety conditions. The DLS850 also controls other test station components (including drives, Pulse Width Modulated - PWM devices, servo motors, and counter/timer boards) to ensure accurate timing during the test sequence.

5.3 Automatic Testing

While in Auto Mode, the DLS850 automatically performs the entire test sequence after each part is clamped into the test station. During the test, the system displays test variables, test result values, and waveform collections on the Auto Mode window.

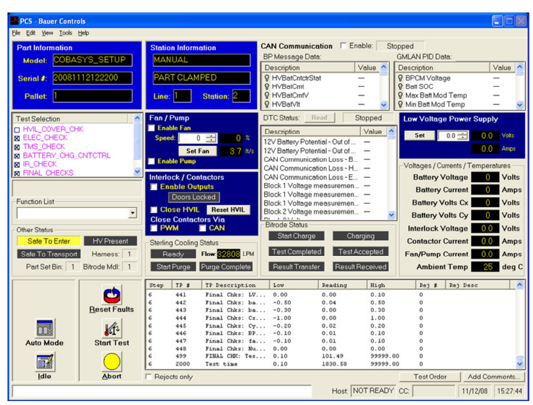


The Auto Mode window displays data in real-time as it is being collected.

- Readings from analog input and output channels are displayed based on preference settings.
- Thumbnail graphics are displayed as each data collection is completed. Double-clicking on a thumbnail opens the recording in the DLS850 Digital Oscilloscope.

5.4 Manual Testing

Each step in the test sequence is an individual method that can be manually performed as an independent test. The Manual Mode window allows you to specify the test(s) to perform and to control variable test parameters such as drive speed, PWM duty cycle, or line pressure.



The Manual Mode window also contains controls that allow you to specify analog output values and collect data under your choice of test conditions. The window also contains a list of special functions that permit such changes as modifying solenoid settings, tuning PID loops, performing shunt calibrations, manually reading or writing to the RF tag, and setting valve configuration.

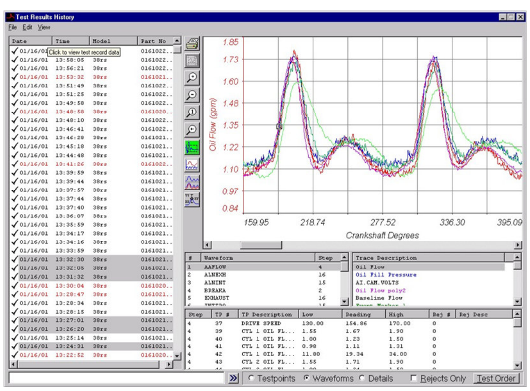
5.5 Viewing and Analyzing Data

The DLS850 makes it easy and convenient to locate the test results you need. The system presents test results throughout the testing process and stores the test result records in a queue on the local computer. When connected to a Bitrode host information system, the DLS850 can transfer test results and waveforms to a database for long-term storage and generation of production and statistical reports. Test results from the local queue, remote test stations, and specified databases are used for the following:

- Viewing in the Test Results History Window
- Querying and analyzing data with the Data Analysis tool
- Generating reports
- Accessing test and reject information

5.5.1 Test Results History Window

The Test Results History window is used to view data from previously tested parts.

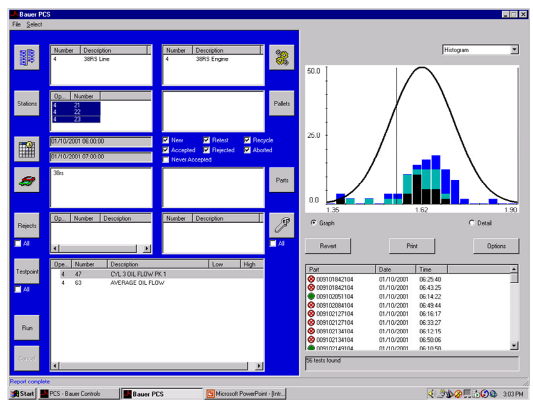


The Test Results History window includes the following features:

- Overlay capabilities for simultaneously viewing and comparing waveforms from multiple test records.
- Zoom tools for an up-close view of the entire waveform or a specified rectangular range.
- Comment capabilities for adding comments and attaching files to test result records.
- Color-coded test result records and test points for an at-a-glance view of whether each test and test point was accepted or rejected.
- One-click sorting for organization of test results and test points.
- Rejects-only filtering for easy identification of rejected tests and test points.
- Tools for viewing test point markers and editing test point limits.

5.5.2 Data Filtering and Analysis

The Data Analysis window provides tools for querying the Bitrode information database, remote test stations, and the local test results queue for specific test results. You can search for test results based on specific criteria such as line, operation type, test station, pallet, date and time, model number, serial number, repairs, and test points. You can also include criteria in your search to find accepted, rejected, aborted, recycled, and/or retested parts. Queries can be saved and easily retrieved.



The following analysis capabilities are built into the system:

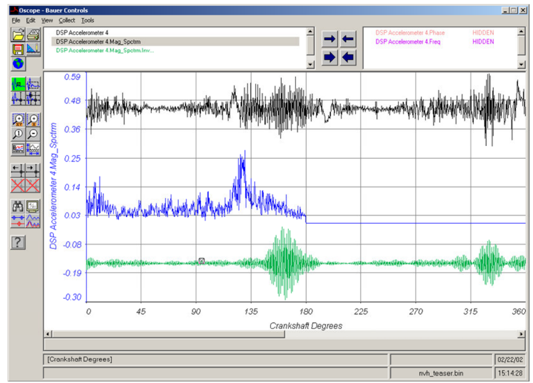
- *Correlation*—The Correlation analysis determines the degree of linear relationship between two test points by calculating the Pearson Correlation Coefficient. The analysis helps identify areas of concern in the production process.
- *Histogram*—The Histogram analysis graphs the frequency distribution of test point values and includes test point limits and statistical information (such as mean, standard deviation, and cpk).
- *Test point Limits Evaluation*—The Limits Evaluation analysis demonstrates the potential impact of modified test point limits. This type of analysis allows you to specify proposed

changes to test point limits and see how those changes would impact test results.

- *Test point Limits Suggestion*—The Limits Suggestion analysis calculates limits for specified test points based on the value of standard deviation over a group of test records that meet the filter criteria. When the new limits are suggested, you can perform a limits evaluation analysis on them to determine how they would impact test results. If necessary, you can edit the suggested limits before applying them to the local model table.
- *Scatter Plots*—The Scatter Plot (X-Y) analysis plots individual test point values as a function of time or another test point. Time-based graphs can indicate if test point values have changed over time or if they show a pattern. Test point comparison graphs can also indicate a relationship between test points.
- *Top N Reports*—The Data Analysis window contains a set of analyses used to determine the most frequently failed test points, the most common reject and repair codes, and the pallets with the highest number of failed operations for specified test stations. The results of the Top N Rejected Test points, Top N Reject Codes, Top N Repair Codes, and Top N Pallet Numbers can help identify anomalies that may require attention.
- *Statistical Summary*—The Statistical Summary analysis displays the number and percentage of accepted, rejected, and aborted tests.

5.5.3 Waveform Analysis

The DLS850 Digital Oscilloscope (Oscope) contains an extensive library of functions used for performing, viewing, and analyzing data collections. Test engineers can use Oscope to analyze the characteristics of tested parts and to detect noise and vibration anomalies.



Waveforms are stored in files called recordings, which can be compressed to save disk space. Recordings are sets of data values collected at a specified rate. Recordings are linked to the related test result records for easy access.

Oscope contains a simple interface for setting up the parameters associated with a recording. You can specify the type, rate, duration, and variables of a data collection or import the scaling and trace settings from another recording file. After performing a data collection, you can configure the waveform display to simplify your analysis of the collection. Oscope contains the following tools to accentuate the view:

- Zoom tools for an up-close view of the entire waveform or a specified rectangular range.
- Trace setup feature for changing trace color, view, and scaling.
- Event markers for adding comments to specific points on individual traces or an overall recording.
- Test point markers for easy identification of test point location and related information.
- Strip chart plotting for separating traces on the same graph.
- Point mode for viewing actual sample points on the grid.
- Preview capabilities for easy viewing and printing of stored waveforms.

You can use Oscope's powerful analysis tools to perform the following functions:

- Search traces for points of interest, such as peaks, valleys, and settle values.
- Perform mathematical trace analysis, such as integration, mean/variance, pulse counting, polynomial filtering, FFT, and power sum.
- Measure period/frequency or define a search/analysis range with dual cursors.
- View recordings as waterfall plots for order-based analysis.

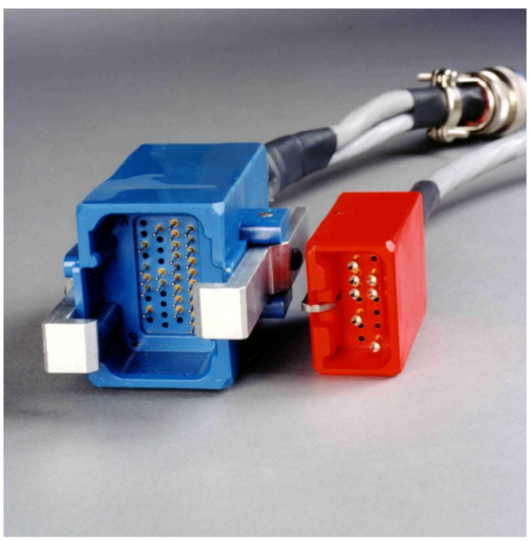
- View recordings as color density plots for detecting areas of increased noise and vibration.

5.6 Battery Management System Communication

Communication with today's high tech hybrid batteries means monitoring and control signals are passed to an intelligent battery control module using industry standard CAN protocol, written to common interfaces such GMLAN, KWP2000, or UDS. It is typical that intelligent. battery modules will also employ a secondary "service" CAN (or redundant CAN) communication path that must also be tested. This redundant CAN port serves as a backup in the event the primary CAN port fails to operate.

5.7 Adaptive Connections

The automated test system should provide a means of testing multiple types of battery packs in a single test station. Connectors of various shapes and sizes can be used to mate up to the various connections that might be present on different battery packs - all within the same automated test system.



6 Test Sequence

The test sequence is comprised of multiple test steps. Each test step contains a number of test points designed to validate the operation of the battery pack. A test point is an individual reading that is compared against model-specific low and high limits to determine a pass or fail rating. All test points must pass for a battery pack to be accepted. Different test sequences can be executed depending upon the model of the battery under test. Model differences are accommodated using test point limits and parameters within model-dependent tables.

Each test step in the test sequence functions independently and remains visible in the user interface window until the next test step is in progress. A test step can be recycled if any test point in the test step fails. Test step recycling is configurable on a step or test point basis. The maximum number of recycles per test is also configurable. The Test Setup Editor allows any step to be arranged in any order of execution, except the first and last test steps.

Test results are saved into a test result record, regardless of accept/reject status or abort condition. A test result record consists of the test step test points and any associated recordings (or waveforms). Many test step sequence functions are based on the values of parameters that can be modified in the Test Setup window. Each test step description in this section includes the parameter values that are used to perform the test step. Following is a general description of a typical production battery test sequence:

6.1 Electrical Checks

Typical electrical checks will perform tests such as enabling the low and high voltage interfaces and CAN communication to verify the basic electrical integrity of the battery. Test parameters include:

- Check intelligent battery management system on-board Diagnostic Trouble Codes (DTCs).
- Clear, enable, and verify correct operation of battery internal high voltage interlock circuit.
- Verify primary and redundant CAN communication capabilities.
- Record battery initial temperatures, voltages, and current readings.
- Record batteries pack intelligent software version information.

6.2 Thermal Management System Check

Confirm functionality of the fan and pump, which are critical to the integrity of the battery pack.

- Perform inlet temperature test and coolant temperature test.
- Test system takes over control of battery pack thermal management system.

- Measure fan electrical current and air flow rates.
- Measure coolant pump electrical current.
- Test system returns control to the battery pack on-board control module.

6.3 Charge / Discharge Capabilities

The Bitrode model FTF is used to perform consistent and reliable charge/discharge routines on the battery packs. Easily programmable test sequences can be modified to adapt to multiple battery models. The FTF is capable of additional data logging of various battery parameters including but not limited to:

- • Charge sequence
- • Discharge sequence
- • Continuous monitoring of DTCs
- • Coolant inlet temperatures
- • Battery Voltage
- • Battery Current
- • Module Voltage Spreads
- • Rebound Voltages
- • Minimum and maximum voltage slopes
- • Battery current sensors

The switch mode technology used in the automated test system should allow for a power factor of greater than 0.98. This, combined with putting the battery's discharge energy back onto the AC line, provides an efficient and economical method for performing the test regimes.

6.4 Battery Cover Checks

Perform various tests on the battery cover to ensure correct assembly. Typical tests might include:

- Perform meg-ohm isolation resistance check to ensure battery outer casing is properly isolated from the low and high voltage circuits of the battery.
- Perform milli-ohm resistance check to ensure no connection between battery covers and safety ground.
- Perform high-current ground bond test between battery covers and safety ground to burn off frayed wire connections.

7 Conclusion

All automated assembly system projects of any significance these days involve an ever-increasing spectrum of individual professional and trade skills. Consequently, a project can only be achieved satisfactorily through a comfortable working relationship between many people, with many different personal or collective objectives. Good working relationships with all parties involved will go a long way towards resolving problems that eventually occur with large scale projects.

Experience and professional project management can go a long way in overcoming these problems especially when the different aspects of a project are well understood as we have tried to demonstrate in this paper. In addition, a highly capable automated test system with a strong complement of features and capabilities also discussed in this paper will provide customers with the flexibility to adapt to changes in the product, or production process over time.

Acknowledgments

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Author:

DEAN GEROUX, Sales Engineer, Bitrode Corporation

Dean joined Bitrode in March of 2009 and has a strong presence throughout the Detroit area. Before coming to Bitrode, Dean worked collaboratively with Bitrode on the end-of-line systems used for testing a U.S. based Nickel Metal Hydride (NiMH) battery manufacturer, and the one of the "big three" for testing a new Lithium-Ion (Li-Ion) battery targeted for a new plug-in hybrid car.

Dean earned his Bachelor of Science degree in electrical engineering and is finishing his executive MBA at the University of Michigan this September. He is widely respected in the automation community and within the battery industry in Michigan.