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REAL-TIME CONSTANT POWER FEEDBACK

Executive Profile: John Craig of EnerSys Inc.

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Real-time Constant Power Feedback Optimizes Resistance Welding Processes for Lead-acid Battery Manufacturing

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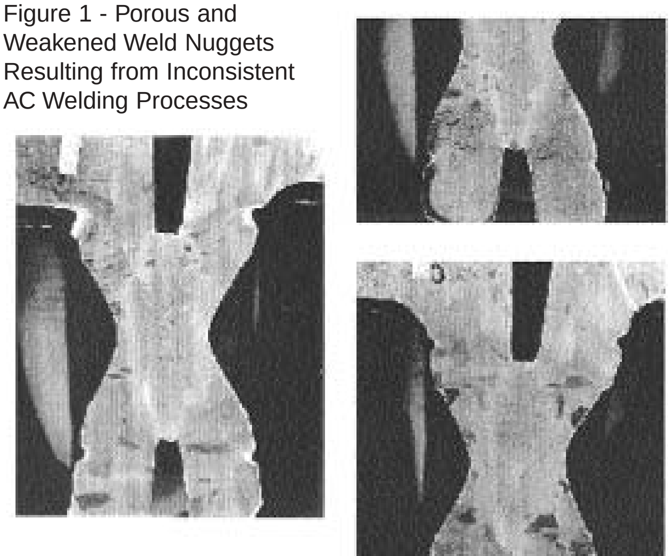
Miyachi, *A Unitek Miyachi International Company*

The manufacture of reliable, high-performance lead-acid batteries for use in demanding automotive, marine and industrial applications poses significant challenges in the arena of resistance welding. The central issue involves welding together a series of lead castings, called "tombstones", which constitute the cores of the individual battery cells. These lead tombstones must be linked together using consistent and precisely controlled weld nuggets in order to assure proper operation and long-life of the final battery assembly.

Unfortunately, the intrinsic properties of the lead castings present a high level of variability that makes it very difficult to achieve consistent results with traditional AC resistance welding processes, which are also susceptible to current spikes and inherent variability in the welding process. Even the use of advanced AC weld controls, with more consistent secondary current output, is not enough to completely overcome the dynamic variability of the lead castings, requiring production floor operators to constantly tweak the weld parameters in order to maintain marginally acceptable consistency.

As will be explored in this article, the most effective approach to the unique challenges of lead-acid battery welding is to use advanced Inverter (DC) solutions that combine precision-controlled secondary Power (Vx I) with comprehensive monitoring and real-time feedback mechanisms. By sensing and adapting for differences in resistance in the lead castings as well as other variations in the weld process (*e.g.* electrode wear, cabling, etc.), these systems can automatically maintain Constant Power and consistent heating profiles at the weld nugget. As a result, Inverter controls using Constant Power feedback are able to deliver dramatically increased yields while simultaneously eliminating the inefficiencies and inconsistencies of operator-dependent process tweaking.

Figure 1 - Porous and Weakened Weld Nuggets Resulting from Inconsistent AC Welding Processes



Coping with Variability in "Tombstone" Resistance

As the molten lead moves from the smelting pot into the mold, its resistance properties begin a process of constant change that can continue unabated for up to eight days after the casting has been extracted from the mold. Because the welding step must be sequenced downstream from a number of other post-mold operations, such as hand-assembly of tombstones into the cells and insertion into the battery cases, it is not possible to precisely predict how long after the molding process each batch will be welded. Because the flow of overall production demands can require the welding process to occur anywhere from 5 minutes to 72 hours after extraction from the ➤

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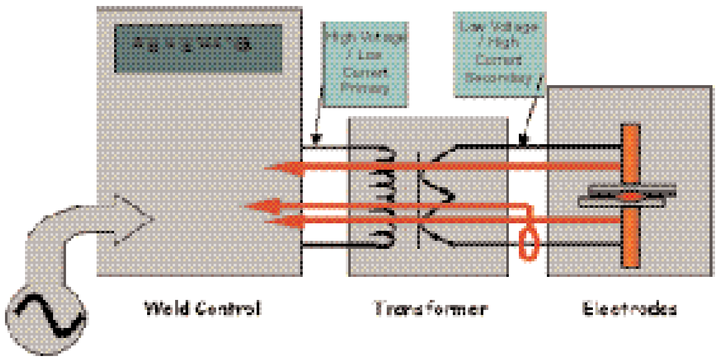
Figure 2 - Voltage Clips and Torriodal Coil attached to “Secondary Loop” to monitor Current **AND** Voltage.



mold, the exact resistance properties of each batch of assemblies represent a constantly moving target that cannot be accommodated by a static weld control.

The tombstones’ rate of resistance change is rapid enough that a particular set of weld parameters could be producing good welds at any specific point in time and then produce marginal or unacceptable welds twenty minutes later, even for units within the same batch. Similarly, a particular weld schedule could be producing an on-going flow of acceptable welds, and then, after stopping for a 30-minute lunch break, the welding parameters would no longer match the changed resistance profile in the remaining units to be welded.

As a consequence, production floor operators typically have had to readjust the weld process settings whenever the flow of production is interrupted for more than 15 minutes. With such a narrow process window and the need for constant adjustments, the resistance welding operation is never able to reach an acceptable level of on-going process stability needed to efficiently support sustained high volume production demands. Failure of the operators to proactively adjust the weld schedules also can result in cold welds or excessively porous weld nuggets, which could fail in subsequent high-pot QA testing or, worse yet, could fail in the field causing customer dissatisfaction as well as high return costs.

With a need to continually tweak process settings to avoid welding problems, the skills and attentiveness of individual floor operators become critical variables for maintaining production effectiveness and for meeting overall corporate business objectives. Needless to say, under such circumstances, issues of operator training, experience levels, learning curves and turnover rates can have a dramatic impact on the ability to maintain consistent production output and quality levels.

In order to overcome the above concerns, leading battery manufacturers are turning to more advanced resistance welding solutions that expand process robustness and reduce excessive dependence on operator intervention. To achieve optimal quality and production output, while minimizing both scrap and inefficiency, the resistance welding process itself must provide both a wider process window and the ability to automatically adapt to any changes that could impact the integrity of the weld.

Unitek Miyachi Corporation, via its Miyachi brand of resistance weld controls, has been researching the problem of welding lead acid batteries for several years. The Miyachi team has worked with leading companies in the Lead Acid Battery Industry, such as Exide Technologies, to characterize resistance welding processes and refine the effective use of Inverters with comprehensive feedback and Constant Power control. Among the most significant benefits has been the expansion of the effective process window for using the same weld schedule from only 15 minutes between updates, to as much as 72 hours without any operator adjustments. In addition, the use of secondary Power with real-time closed-loop feedback significantly increased the overall weld consistency and dramatically reduced bad-weld reject rates.

Fundamentals of Constant Power Control with Closed-Loop Feedback

The use of secondary constant Power allows for a much more consistent and controlled weld process, which is not subject to the fluctuations that can occur with the use of AC current. The ability of secondary Power systems to deliver cycles as short as a few milliseconds also allows for a much greater level of precision in the weld process. In addition, the integration of comprehensive closed-loop feedback into the secondary loop can allow for real-time monitoring of current, voltage, power and pulse width (see Figure 2), thus providing the foundation for precision control of Constant Power levels.

The definition of an Open Loop Control System is one that does not have feedback. Open Loop Controls, therefore, do not react to process variations that affect either the primary or the secondary of the power transformer. These limited techniques tend to be inadequate for addressing complex resistance welding challenges, such as those posed by the dynamically changing nature of lead-acid battery tombstone welding.

In contrast, Constant Power feedback can dynamically monitor changes in secondary voltage as they relate to changes in secondary resistance; secondary current can then be controlled in order to deliver consistent power levels from weld to weld. Ultimately, the use of comprehensive Constant Power control is the only practical method for ensuring uniform heating profiles in a situation where the resistance of the materials being welded shows a significant variation.

For lead-acid battery manufacturing, a Constant Power system is ideally suited to compensate for the differences in resistance that occur as lead tombstone castings age during the production process and to automatically adjust the total power to deliver consistent levels of joule heating into the weld nugget.

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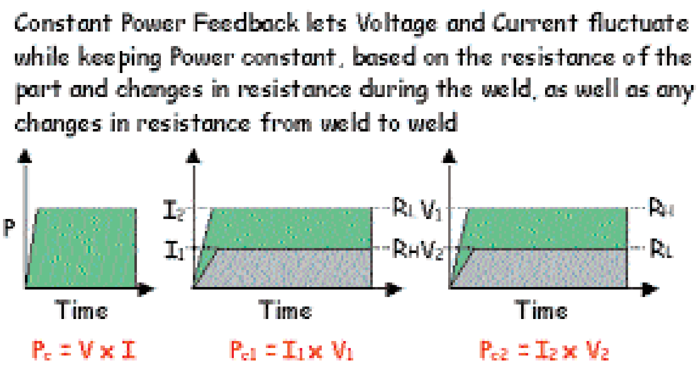
Real-world Bottom Line Results

Figure 3 - Constant Power Feedback Relationships



According to Mike Brown, Manufacturing Project Engineer at Exide, "We'd been using AC controls since the 1970s and they had always represented a problem area because of inherent variability in the welding process. Any number of external factors, such as electrode wear, loose cabling connections or variations in the lead castings themselves, all can have an impact on the amount of energy focused on the weld point, with a resultant variation in the quality of the weld nugget. Because a lack of process control can mean excess porosity and/or cracks in the weld nugget resulting in weakened or cold weld joints, you end up paying a price in extra quality control inspections, scrap, waste and rework costs. By transitioning our production lines to Miyachi's ISA-500 inverter systems, with secondary power and real-time feedback controls, Exide has been able to achieve much greater consistency and repeatability along with a 90% decrease in rejected welds."

Working closely together, Miyachi Engineers and Exide staff converted resistance welding systems in Exide's facility to use secondary power closed-loop feedback as well as establishing a fundamental set of weld parameters to create a solid foundation for immediately improving production requirements. As Exide's Mike Brown explains, "Initially, we focused on monitoring voltage levels and made great strides in identifying and managing issues such as electrode tip wear, cabling changes, etc., which has significantly improved our overall control of the welding process. Additionally, we have been very pleased with the support provided by Miyachi's technical staff, which has been a big help in the characterization of key process parameters and has enabled us to get the most out of our system investments."

Miyachi and Exide engineers jointly conducted in-depth testing and analysis in order to expand the process window and extend the time cycles between adjustments to the weld schedules. The batteries to be evaluated were set aside to allow them to age and were welded at different time points in relation to their original extraction from the mold. Then all of the welded batteries were shear tested and graded according to Exide's rigorous specifications. The age testing yielded very successful results, with acceptable grading for all of the tombstones welded at ages between 15 minutes and 96 hours, using a uniform weld schedule. These results confirmed that secondary Constant Power feedback completely compensated for the resistance changes that occur in the lead as the lead ages.

Another key indicator of the effectiveness of the new welding process and the integrity of the weld nuggets is a dramatic improvement in the yield from high-rate testing, in which completed batteries are stressed by being subjected to ultra high current levels for short periods. Using the new welding process, high-rate testing failures dropped nearly tenfold.

The transition to the new welding technology will provide a number of other benefits to the bottom line of battery manufacturers. Because constant secondary power with closed-loop feedback provides an expanded process window with much greater process robustness, it becomes more practical to adapt pre-established weld schedules throughout a facility rather than hand-crafting and hand-maintaining individualized weld schedules for every machine. In addition, on-going training expenses and maintenance costs can be significantly less because operators are not required to skillfully tweak each process in order to achieve acceptable results. In the longer run, additional savings can accrue for the battery manufacturer due to less downtime, shorter set-up times, improved equipment utilization rates, lower power usage and higher sustained production throughput levels.

Taking into account the measurable improvements in both quality and productivity, preliminary estimates indicate that a Return on Investment (ROI) period could be less than one year by converting to Miyachi's ISA - 500A Inverters with secondary Power feedback. In addition, greatly improved process control flexibility offered by the new technologies provides a solid foundation for rapidly defining and deploying new weld schedules to accommodate any future product changes or new product introductions.

The Unitek Miyachi part number for the sheet is 991-507. For more details contact Barbara Kuntz. Ph: (626) 930-8560; E-mail: barbara@unitekmiyachi.com.