

Improvements in the Performance and Life Characteristics of Deep Cycle Batteries

By K. Fred Wehmeyer, Vice President of Product and Process Engineering, U. S. Battery Manufacturing Company, Inc.

Deep cycle batteries used in golf cars, utility vehicles, plant maintenance equipment, and myriads of other light to medium duty, battery-powered material handling and personal mobility vehicles have recently undergone significant improvements in their performance and life. The performance and life characteristics of this class of batteries are typically determined using testing procedures specified by the Battery Council International¹ in BCI Battery Technical Manual - Procedures BCIS-05 (Rating and Capacity Testing of Electric Vehicle & Cycling Batteries), BCIS-06 (Constant Current Cycle Life Testing of Deep Cycle Batteries), BCIS-07 (Cycle Life Testing of Batteries for Golf Cars), and BCIS-08 (Cycle Life Testing of Deep Cycle Marine/RV Batteries). These test procedures are used by battery manufacturers to quantify the effects of improvements in the design and production of deep cycle batteries. U. S. Battery's Xtreme Capacity Diamond Plate Technology™ is a prime example.

Battery capacity and cycle life are typically determined at a discharge rate of 56 amps for 48 volt systems, 75 amps for 36 volt systems, and 25 amps for smaller 12/24 volt RV/marine systems. When testing and evaluating deep cycle battery packs, it should be noted that premium deep cycle batteries typically 'cycle-up' over the first 50-150 charge-discharge cycles as shown in Figure #1. This means that the battery's 'initial capacity' as received from the battery manufacturer will be somewhat lower than the full rated capacity at its peak. Premium deep cycle batteries typically deliver 75-80% of their rated capacity within the first 1-5 cycles, full rated capacity with the first 100 cycles, and >100% of rating at peak capacity. This is an important characteristic of a true deep cycle battery that helps it to deliver optimum performance over many deep discharge cycles.

It should also be noted that charging methods can have a profound effect on both the rate of 'cycle-up' and the overall cycle life of deep cycle batteries (also shown in Figure #1). A fundamental technique for determining differences in charging methods is to measure the percentage of amp-hours returned on charge as a function of the amp-hours discharged on the previous discharge (% Ah Return). Battery chargers have historically been designed to recharge batteries to 110% to 125% Ah Return. With better control over the charge profile, a charger can be designed to control the amount of overcharge such that optimum performance over the life of the battery can be obtained. For example, Figure #1 shows that a U.S. Battery Xtreme Capacity battery recharged to 120-125% Ah Return can deliver 100% of rated capacity within 50 cycles and peak capacity of 108% of rated capacity within 150 cycles. When the overcharge is reduced to 110-115% Ah Return, rated and peak capacity are achieved later in life, but the overall cycle life can be extended by 10% or more. Recharging below 110% Ah Return on a frequent basis will tend to undercharge batteries without regular 'equalization charging'. However, with precise control over Ah Return and regularly scheduled equalization charging, battery life can be extended by an additional 50% or more with minimal effect on peak performance. This

type of charge profile typically requires a programmable (smart) charger using any of a number of user selectable or controlled charge algorithms.

(Note: Equalization charging is defined as an increased overcharge done on an infrequent but regular basis to overcome the effects of progressive undercharge and/or sulfation resulting from severe undercharge or prolonged inactivity.)

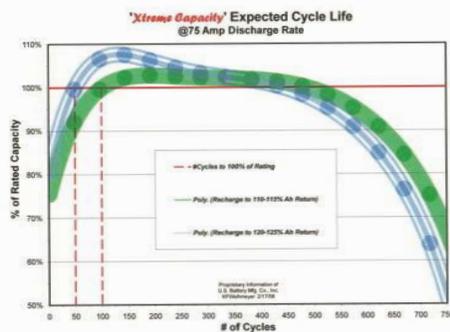


Fig #1

Battery cycle life is a function of depth of discharge (DOD) - as the depth of discharge per cycle decreases, the cycle life increases. As shown in Figure #2, this is a non-linear (logarithmic) relationship. This means that not only does the cycle life increase with each incremental decrease in DOD, but with each incremental decrease in the DOD the incremental increase in cycle life increases at a progressively higher rate. In the example of the Xtreme Capacity™ cycle life in Figure #2, the cycle life at 80% DOD is 675 cycles. If the DOD is reduced by a factor of 2 to 40%, the cycle life increases by more than a factor of 2 - not to 1350 cycles but to 1475 cycles. This means that with proper battery sizing and taking advantage of 'opportunity charging' to extend run-time without over-discharging, overall battery cycle life and service life can be extended.

(Note: Opportunity charging is defined as recharging whenever there is a significant discharge and there is a convenient opportunity for recharging. Unlike other battery chemistries, lead-acid batteries do not suffer from 'cyclic memory'² caused by shallow discharge/recharge cycles. Also, lead-acid batteries are more resistant to the effects of overcharge than they are to over-discharge effects. Lead-acid batteries should always be maintained at the highest possible state of charge and should never be stored in a discharged state. Opportunity charging not only maximizes available run-time, but also maintains the battery in a healthy, fully charged state.)

Not only can the performance and life of batteries be improved by optimizing the charger/battery interface and controlling depth of discharge, but continuous improvements in lead-acid battery design and electrochemical processing have also been found to produce significant gains. U.S. Battery's Xtreme Capacity Diamond Plate Technology™ uses improvements in

electrochemical processing to achieve improvements in performance, energy density and specific energy, cycle life, resistance to shock and vibration, and recharge-ability.

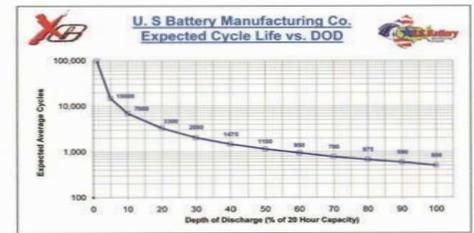


Fig #2

Premium deep cycle lead-acid batteries have historically been manufactured with a relatively high percentage of tetrabasic lead sulfate (TTBLS) in the unformed plate material crystal structure. This TTBLS crystal structure produces a strong active material structure in the formed plates required to achieve the long cycle life needed in deep cycle battery applications (similar to the strength added to concrete by the addition of rebar).

Prior to the introduction of synthetic TTBLS additives, the plate production process utilized a high temperature, high humidity curing process designed to achieve a relatively high percentage of TTBLS in the unformed plates. Even though this curing process is well controlled and produces consistently high levels of TTBLS, it is not well suited for controlling the size of the individual crystals that are 'grown' in the crystal development process. The resultant crystals vary widely in size and if the crystals grow too large, the plates are difficult to form and recharge and have lower capacity than those with smaller crystal sizes. Through the addition of synthetic TTBLS seed crystals with a uniformly fine crystal structure to the paste during mixing; a smaller, more uniform TTBLS crystal structure is produced throughout the plate structure. This uniformly controlled TTBLS crystal structure results in the following enhanced performance, charging and life characteristics of the U.S. Battery Xtreme Capacity Diamond Plate Technology™.

Features and Benefits of U.S. Battery Xtreme Capacity Diamond Plate Technology™

- Increased initial capacity
Synthetic TTBLS (tetrabasic lead sulfate) additive in the paste mix provides uniformly controlled crystal size of the resulting TTBLS in the cured plate and higher conversion efficiency of TTBLS to lead dioxide in the formed positive plate giving higher initial capacity.
- Higher peak capacity
The same controlled TTBLS crystal size results in a higher conversion of TTBLS to lead dioxide in the cycled positive plate with greater and more uniform porosity and surface area for higher peak capacity.

¹Detailed test procedures are available from: Battery Council International, 401 N. Michigan Ave., Chicago, IL 60611-4267 Ph: 312-644-6610

² Isidor Buchmann, Batteries in a Portable World (2001), Cadex Electronics, Inc., Richmond, BC, Canada V6W 1J6 (p.152)

- Improved energy density and specific energy
Since there is no increase in the size or weight of the battery, higher capacity translates to improved unit performance or energy density (watt-hours/liter) and specific energy (watt-hours/kilogram).
- Enhanced recharge-ability
The more uniform crystal structure of the formed positive plate results in enhanced recharge-ability particularly at low temperature and from varying states of discharge.
- Fortified plate construction (improved vibration and shock resistance)
The more uniformly controlled TTBLs crystal size results in a stronger crystal network within the formed positive plate

active material resulting in decreased active material spalling from vibration and shock.

- Improved cycle life

The stronger crystal network within the formed positive plate active material also results in decreased active material shedding from deep cycling – the primary failure mode in deep cycle batteries

About the Author: Fred Wehmeyer is Vice President of Product and Process Engineering for U. S. Battery Manufacturing Company, Inc. in Augusta, Georgia. Fred is a seasoned battery professional with over 35 years experience in the design, manufacture, and quality assurance/testing of rechargeable batteries including lead-acid, nickel-cadmium, nickel-metal hydride, and lithium based chemistries. Fred's previous experience was as Vice

President of Quality Assurance for EnerSys and Director of Product and Process Engineering for C&D Technologies. Fred has a Bachelor of Science Degree in Electrochemistry and has done graduate work in Engineering Management and Six Sigma/Lean Engineering.



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Ohio, AC and DC electric motors from New York, and has manufacturing facilities in China. (Advanced Motors and Drives of Syracuse, New York, a Kinetek company, has successfully placed its product in a number of end-use vehicles, including Tomberlin's Emerge, Fairplay golf cars and personal use vehicles, Tung Keng's Green Olympic vehicles.)

PGA Show and GIS Becoming Showplaces for Innovation and Global Diversity

Overall, the PGA Show and the GIS have become showplaces for innovation in utility vehicles, golf cars, and an emerging class of personal use vehicles. Consistent improvement in basic vehicular platforms and drive systems, the diversity of customized applications, and the progressive attention to environmental concerns have positioned these traditional, golf industry-oriented trade shows into a forum for cutting edge developments that are likely to shape the transportation/mobile work vehicle products of the future—and at the same time give impetus to a significant and continual broadening of the market base.

In addition, the exhibitors have become far more geographically diverse both with respect to end products and components. This development, with U.S.-based companies highly competitive in product design and cost and possessing established distribution and sales channels in the world's largest market, bodes well for the future of the small, task-oriented vehicle industry in a world where the outlook for the larger mainstream, fuel inefficient cars and trucks is, if nothing else, problematic.

About the Author: Senior Editorial Advisor, Industrial Utility Vehicle & Mobile Equipment Magazine.

Stephen Metzger is Managing Director of International Market Solution (IMS), a management consulting firm, whose prime focus is putting companies into the international market arena on a cost-efficient basis. Mr. Metzger is also Principal of International Competitive Assessments (ICA), the market research arm of IMS, which he founded in 1980. ICA has undertaken extensive market research and consulting assignments covering a broad range of products and markets over the firm's 25-year history. Mr. Metzger and his staff and associates have produced three ground-breaking studies of small, task-oriented vehicle market in the United States since 2000 and devote most of their efforts to this rapidly emerging area. Mr. Metzger, an economist by background, is, in addition to his full time consulting work, adjunct professor of business and economics at Iona College and Mercy College, both located in Westchester County, New York.



U.S. Battery Manufacturing with Diamond Plate Technology™ Produces the Longest Lasting, Most Powerful & Reliable Batteries in the World.

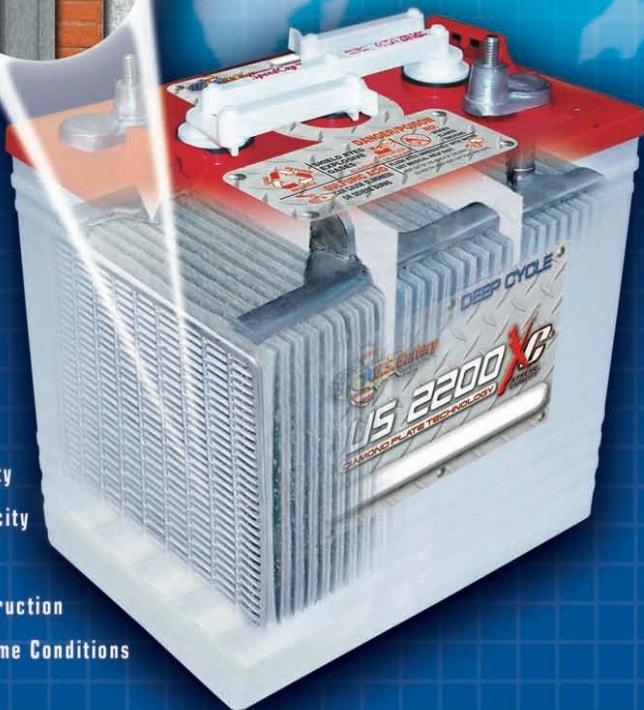
Our New **XG™** battery line will outperform our closest competitor's battery by as much as **10%**

Batteries utilizing Diamond Plate Technology™ have been engineered using a superior plate design specifically created to out perform and outlast all other batteries in the industry



Advantage:

- XG Durability**
- XG Reliability**
- XG Maximum Cycle Life**
- XG Easiest to Charge**
- XG Highest Initial Capacity**
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