Introduction

Standby battery users are increasingly demanding long life batteries that can withstand high temperatures that allow reduced operating and capital costs to minimize Total Cost of Ownership (TCO). The highly competitive market place coupled with limited economic growth has increased the importance of minimizing waste and maximizing value while ensuring reliability. EnerSys® listened to our customers and developed the PowerSafe® SBS XL battery family, which features maximized float life with higher operating temperatures. By designing and manufacturing the battery specifically for high temperature float applications, EnerSys is able to offer a battery with significantly increased value to customers with this type of application. This paper provides an introduction to the background on the Thin Plate Pure Lead (TPPL) technology used in these new PowerSafe SBS XL batteries, an explanation of common lead acid battery failure modes in high temperature float applications, and the design features included in the PowerSafe® SBS XL battery that enable long life at high temperatures. The PowerSafe® SBS XL battery range has an extended design life of 10 years at 95°F (35°C) for float applications. EnerSys has met this need through continual development of the TPPL technology and customer collaboration over nearly 50 years.

TPPL Background

The Absorbed Glass Mat (AGM) cell was invented by Gates Energy in the early 1970s, revolutionizing the lead acid battery technology and industry. The original battery was a spiral wound 2 volt cell and was branded as CYCLON®. It was designed with many new and unique characteristics such as: the usage of 99.99% pure lead and very thin positive and negative plates, usage of absorbent glass mat separator, not having the electrodes flooded with electrolyte, and the incorporation of a pressure relief valve that contains the evolved gases up to particular pressures. This technology was then applied to traditional flat plate battery configurations in the early 1980s, which is when the SBS® battery series was launched. The TPPL nomenclature was applied to the technology to help distinguish its unique characteristics of electrodes made from highly pure lead at thicknesses significantly thinner than traditional lead acid batteries. EnerSys continues to manufacture the CYCLON® batteries today and has continued to launch more product form factors to meet unique application needs while continuously improving product designs and manufacturing technologies.

This technology has been deployed into a wide variety of critical applications for aviation, military, medical, Uninterruptible Power Supply (UPS) and telecommunications, as well as lawn and garden equipment, engine start and solar back-up for almost five decades. The technology adoption into a broad range of applications continuously drove the improvement of the technology as well as the development of a deep organizational knowledge base of the technology, applications and markets. The PowerSafe® SBS battery series has long since been the standard for long life in a wide range of applications including those with harsh temperatures, both hot and cold, as well as with stable grid, unreliable grid and off-grid conditions.

Leveraging the decades of experience and success, EnerSys launched the PowerSafe® SBS 110 battery for float telecom applications in Europe, which provided a 10-year design life at a continuous operating temperature of 86°F (30°C). This was achieved by

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freeing the product from design constraints necessary for achieving other performance criteria such as providing a high number of cycles and by fine tuning the product design specifically for long life in float conditions. With more than 15 years of success in this particular application, EnerSys continues to further develop the TPPL technology by optimizing it specifically for float applications and launching the PowerSafe® SBS XL range of batteries.

End of Life Failure Modes

Examining the end of life failure modes provides prospective on the key characteristics associated with long life. The Valve Regulated Lead Acid (VRLA) battery aging process generally involves changes in the positive active material, the positive grid, the electrolyte or changes in a combination of these components. These changes are highly related to the battery design, how it was manufactured and how it is used. For unreliable power grid and off-grid cycling applications, the most common battery failure mechanisms are sulfation, active material degradation, corrosion and stratification. For standby applications operating with reliable power grid where the battery is cycled infrequently and are on float charge, the most common failure modes are grid corrosion and dry out.

Positive Grid Corrosion

Independent of the application conditions, the positive polarized conducting components in the battery are constantly corroding from the point in time when the electrolyte is introduced to the lead components. The corrosion starts on the lead surfaces and propagates into the thickness of the lead components throughout the battery life. This corrosion is occurring on both the grid and current collectors of the positive electrodes but it is the positive grid that usually fails prior to the positive current collector in normal end of life conditions; thus preventing the positive grid corrosion failure mode is more important than the corrosion of the positive current collectors.

Corrosion is a result of electrochemical reactions occurring with the lead, alloying elements and impurities. The metallic lead (Pb) reacts with the water in the electrolyte by converting (corroding) to lead dioxide (PbO_2). This reaction occurs on the surface of the grid and forms a layer of lead dioxide on the grid surface. The lead dioxide layer is electrically conductive and allows further electrochemical reactions while also acting as a protective barrier to other types of grid corrosion processes. Additional reactions occur with any alloy elements and contaminant elements creating additional corrosion by products.

Non-lead elements tend to collect at the microscopic lead grain boundaries during the grid manufacturing process since they are less dense than lead. The concentrations of the other elements act as pathways for corrosion propagation through the grid cross section. These other elements are also more reactive than lead and as a result corrode faster than the lead and have a greater impact on grid life than the metallic lead conversion to lead dioxide. The rate of grid corrosion is also influenced by the grid manufacturing processes. The grid manufacturing process influences the internal microscopic structures of the grid, some of which are more resistant to corrosion than others. When a manufacturing process produces large grains there are fewer grain boundaries and shorter corrosion paths across the thickness of the grid. The grid manufacturing process also influences the porosity at the grain boundaries where increased porosity is related to increased corrosion rates.

The rate of chemical reactions is directly influenced by many factors such as temperature, charge voltage, acid specific gravity, and the lead alloy. The chemical reaction rate increases in a relatively predictable manner as the battery temperature increases and can be modeled by the Arrhenius equation. Since the chemical reaction rate is directly related to the rate of grid corrosion, the Arrhenius equation is also used for predicting battery life as a function of temperature. As an example, the Arrhenius equation can be used to extrapolate the design life of 10 years at 95°F (35°C) to 20 years at 77°F (25°C).

The corrosion products are less dense than the metallic lead and occupy more volume, so the corrosion production results in grid growth. As this corrosion byproduct is forming inside of the lead grid, the larger volume applies stress to the adjacent lead grains acting as a wedge for separating the metallic lead grains at their boundary. This stress initiates a microscopic crack at the grain boundary, which becomes a larger fracture that exposes fresh material that had not yet been corroded. This fresh material immediately reacts and begins to form additional corrosion byproducts. This grid corrosion process continues to repeat through the life of the product creating five conditions contributing to end of life failure modes.

1. The reduced cross sectional area of the grid created by the fractures, which limits the current flow during discharging and charging. Since the grid corrosion is constantly occurring and the cross sectional area is similarly decreasing, the grid thickness has to be designed sufficiently thick to accommodate the ever-present corrosion while achieving the desired float life. Eventually the fractures can become widespread and sufficiently large such that the voltage can abruptly drop during discharge.
2. The corrosion byproducts have lower conductivity, which impedes current flow. This lower conductivity results in short run times and lower capacities.
3. As the positive grid expands, it pulls away from the active material which decreases the current flow and utilization from the active material. Both of these conditions lead to lower capacity.
4. Excessive positive grid growth can result in the positive grid extending beyond the separator paper and making contact with the negative electrode or negative current collector, which results in an electrical short. Excessive positive grid growth can also result in excessive distension and stress on the battery container causing bulging, terminal leaks, case or cover cracking and case to cover seal leaks.
5. The positive grid corrosion reaction consumes water. This water is permanently lost in this reaction and isn't reversible such as the recombination reaction. Additionally, the water isn't replaceable since this is a sealed valve regulated battery. This water loss contributes to the separate failure mode called dry out. Dry out has multiple causes and is discussed separately below.

Dry Out

The other primary failure mode for VRLA-AGM batteries in float applications is called dry out, which results from excessive loss of hydrogen and oxygen; this is essentially water and thus this phenomenon is often referred to as water loss. There are two primary chemical reactions associated with water loss, namely the water consuming grid corrosion process and the hydrogen evolution reaction. The hydrogen evolution occurs at a relatively slow rate at the negative electrode and like grid corrosion, occurs during open circuit, charging and discharging.

Hydrogen is a very small and light element that can readily diffuse through container materials but under normal operating conditions this hydrogen loss isn't an issue. The hydrogen evolution reaction is interrelated to other secondary reactions that are constantly occurring as well as application conditions. If these secondary reactions are out of balance, the hydrogen evolution can increase accelerating the evolution rate. The rate of hydrogen evolution is significantly increased by impurities, which can come from any of the battery components. The hydrogen, as well as the oxygen, can also be lost through the venting process when sufficient internal cell pressure is created to open the valve. Hydrogen and oxygen can also be lost through plastic container components that are permeable but this can be minimized through proper mechanical design.

The permanent loss of water leads to an increased concentration of sulfuric acid within the electrolyte and a net decrease in total electrolyte. The higher electrolyte specific gravity raises the open circuit voltage of the battery, so with nominal charging voltage applied, it is likely that the battery won't be sufficiently charged. The resulting higher specific gravity is also undesirable because it degrades the active material faster, which results in less energy delivered during discharge. The decreased electrolyte volume reduces the conductivity since there is less electrolyte to carry electrons between the electrodes; this too decreases capacity.

As outlined above, VRLA-AGM batteries in float applications have two common failure modes, namely positive grid corrosion and dry out. These failure modes are influenced by a significant number of factors within the product design, manufacturing and application. Many of these influencing factors are interrelated and are driven by several product characteristics including grid alloys, contaminants, internal electrochemical reactions, grid casting method, AGM saturation levels, grid thickness, valve design and container design.

Design Features for Extra Long Float Service Life

Achieving the goal of a 10-year life at 95°F (35°C) was supported by the successful development and deployment of a 10-year at 86°F (30°C) battery previously mentioned. The PowerSafe® SBS XL battery range leveraged this success by further refining the design, based on delaying the grid corrosion and dry out failure modes common for float applications. These failure modes are delayed by seven key product characteristics, namely:

1. pure lead with no alloy elements in the positive plate grid,
2. strict control and minimization of impurities in all battery components,
3. controlling the internal microscopic structure of the grid,
4. precisely sizing the electrodes for long term growth with required capacity levels,
5. careful balancing electrochemistry for controlled secondary reactions,

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6. utilization of an engineered plastic that limits bulging and material degradation at elevated temperatures and
7. a long life terminal seal system.

The rate of positive grid corrosion is extremely low due to the lack of alloy elements and impurities within the grid. Minimizing the impurities in the grid prevents the accelerated corrosion propagation, fracturing and grid growth. The PowerSafe® SBS XL battery uses manufacturing technology that ensures a very fine grain structure with tight grain boundaries creating a torturous grid corrosion path that enables extended service life. Positive grids with an internal structure of large grains and open boundaries with concentrations of corroding alloying elements, allow the corrosive reactions to propagate through the cross section at a faster rate. Even though the oxidation of the pure lead is very slow compared to that of lead alloys and lead with impurities, the oxidation can still cause the pure lead positive grid to grow in size. To prevent the risk of failures associated with grid growth, the plate sizes are designed and strictly controlled to tolerate the anticipated growth while still being sized sufficiently for achieving the necessary capacity levels.

It’s not just the impurities in the positive grid that are important. The impurities within all the components used to manufacture the batteries are minimized for reducing the undesirable reactions outside the grid. Any impurities within the battery can cause additional undesired chemical reactions and gas generation that can lead to additional water loss and grid corrosion, which accelerates the aging process.

There are naturally occurring secondary reactions that also influence the aging process by causing water loss. These secondary reactions include hydrogen evolution, hydrogen oxidation, oxygen generation and oxygen reduction and they are occurring at various rates continuously through open circuit conditions, charging (float and otherwise) and discharging. The rate of these secondary reactions causing water loss is low when using pure lead positive grids and with tightly controlled impurities, but these secondary reactions are further minimized by carefully balancing the chemical design and controlling this balance in multiple manufacturing processes to limit additional water loss.

Mechanical design characteristics have to be addressed as well as the electrochemical characteristics previously discussed. In VRLA-AGM batteries the AGM material is compressed between the plates to keep the active material engaged with the grid and to mechanically stabilizing the stack of plates within the case. The AGM compression creates pressure against the case walls, which must be resisted by the mechanical properties of the plastic case. The plastic utilized in the PowerSafe® SBS XL battery series maintains sufficient stiffness at elevated temperatures to minimize loss of compression and to maintain appropriate performance and life. The particular plastic used is also designed to have minimal chemical degradation over longer periods and at elevated temperatures. The longer life and higher application temperatures also require a robust terminal seal system to be employed. The PowerSafe® SBS XL battery leverages the superior terminal seal system made robust to mechanical stresses from a clamped and potted joint construction. This seal system utilizes multiple materials including a rubber seal compressed in a gland to resist higher lead corrosion rates driven by higher temperatures.

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Lowest Total Cost of Ownership

The features and benefits of the PowerSafe® SBS XL series of TPPL technology batteries provide long life at high temperatures for float applications allowing users to decrease the frequency of battery replacements. Users of these batteries can also increase air conditioning temperature set points, or even removing air conditioning from some sites, to reduce operating and capital costs. The battery maintenance costs can be minimized by extending the maintenance interval during the early period of service due to the long battery life. This TPPL technology is a more economical alternative to the nickel cadmium batteries that are sometimes deployed into high temperature long life applications and the TPPL technology is easily recycled within normal lead acid battery recycling programs. The PowerSafe® SBS XL battery family leverages the long and successful history of TPPL technology deployment to provide confidence and reliability while allowing the best opportunity to minimize the lifetime cost of the battery.

ABOUT ENERSYS®

EnerSys, the global leader in stored energy solutions for industrial applications, manufactures and distributes reserve power and motive power batteries, battery chargers, power equipment, battery accessories and outdoor equipment enclosure solutions to customers worldwide. Motive power batteries and chargers are utilized in electric forklift trucks and other commercial electric powered vehicles. Reserve power batteries are used in the telecommunication and utility industries, uninterruptible power supplies, and numerous applications requiring stored energy solutions including medical, aerospace and defense systems. Outdoor equipment enclosure products are utilized in the telecommunication, cable, utility, transportation industries and by government and defense customers. The company also provides aftermarket and customer support services to its customers from over 100 countries through its sales and manufacturing locations around the world.

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