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Short communication

# Separator profile selection for optimal battery performance

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**Abstract**

Battery performance, depending on the application, is normally defined by power delivery, electrical capacity, cycling regime and life in service. In order to meet the various performance goals, the Battery Design Engineer can vary things such as grid alloys, paste formulations, number of plates and methods of construction. Another design option available to optimize the battery performance is the separator profile. The goal of this paper is to demonstrate how separator profile selection can be utilized to optimize battery performance and manufacturing efficiencies. Also time will be given to explore novel separator profiles which may bring even greater benefits in the future. All major lead-acid application will be considered including automotive, motive power and stationary.


*Keywords:* Battery separators; Lead-acid batteries; Profiles; Development trends; Characterization methods

## 1. Introduction

Battery performance, depending upon the application, is normally defined by power delivery, electrical capacity, cycling regime and life in service. In order to meet the various performance goals, the Battery Design Engineer can vary parameters such as grid alloys, paste formulations, number of plates and methods of construction. Separator profile modification is another design option available for optimizing battery performance.

The goal of this paper is to demonstrate how separator profile selection can be used to optimize battery performance and manufacturing efficiencies. Descriptions will be given for novel separator profiles, which may bring even greater benefits in the future. All major lead-acid battery applications will be considered including automotive, motive power and power backup systems, most often referred to as stationary.

Before considering separator profile design, it will help to define the primary function of the separator, especially the profile, and then to define the terms that will be used throughout this paper. A lead-acid battery separator is basically an acid resistant, flat sheet, porous membrane with ribs protruding from its surface. The separator must be porous for ions to flow between the anode and cathode. To prevent development of the electrical conductance between the positive and negative electrodes stemming from dendritic formation of lead particles, the separator should preferably be micro-porous. In a flooded or a gelled electrolyte lead-acid battery, the separator typically will have protrusions (i.e., ribs) projecting from the planar surface of the substrate, and typically aligned in the lengthwise direction of the plate. The ribs serve to maintain a fixed distance between the electrodes and ensure sufficient acid volume between the electrodes. In a lead-acid battery, the sulfuric acid functions as the electrolyte, the transport mechanism for ion flow between the electrodes. Secondly, the sulfuric acid is a reactant in the reversible charge/discharge reactions, and can be the limiting factor regulating the rate and termination point of the energy storage reactions. Consequently, as changes are made to the rib design, the quantity of acid between the plates will change, and may subsequently alter the charge/discharge reactions [1].

With the basic function of the separator outlined, now let us turn our attention to the nomenclature associated with the separator profile. Profiles can be classified in two basic categories: (1) universal and (2) paneled. The universal profile is fairly simple to understand. The ribbing configuration is repeated throughout the separator as is often utilized in motorcycle batteries (Fig. 1). Paneled profiles have two distinct rib sections; one that directly

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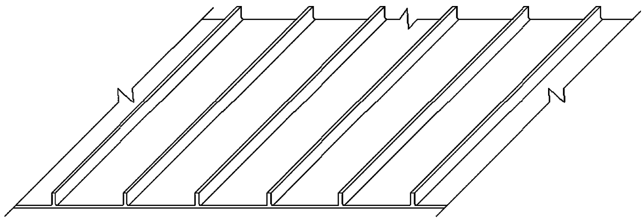

Fig. 1. Universal profile.

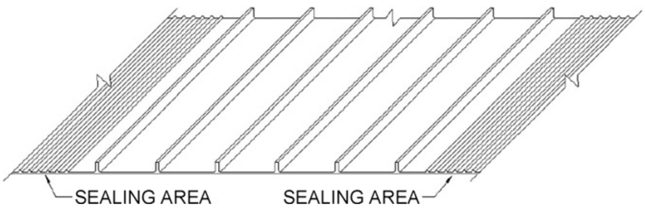


Fig. 2. Panel profile.

contacts the positive plate and another section, which is often called the sealing or land area (Fig. 2). In the land or sealing area, the ribs are often designed to improve sealing operation of the separator upon itself during the formation of an envelope that encases and separates one electrode from the opposing electrode.

When describing rib patterns, we often speak of the rib pitch. This is simply the distance between adjacent ribs, and is often designated by measuring rib center to rib center. The orientation of the ribs can occur from various combinations. The most common are the straight ribs, which run parallel to the end of the separator. The rib orientation can be sinusoidal [2], diagonal, cross-directional (perpendicular) to the rib [3], segmented [4] or a "fishbone" pattern (Fig. 3). Delving deeper, the shape of the individual rib can be defined by the height, width at the base, and the top and draft angles (Fig. 4).

The possible combinations of rib pitch, orientation and shapes could be endless. Now we will look at the primary markets served by the lead-acid battery, the overall demands of the respective applications, and how to optimize the separator design to meet the performance requirements.

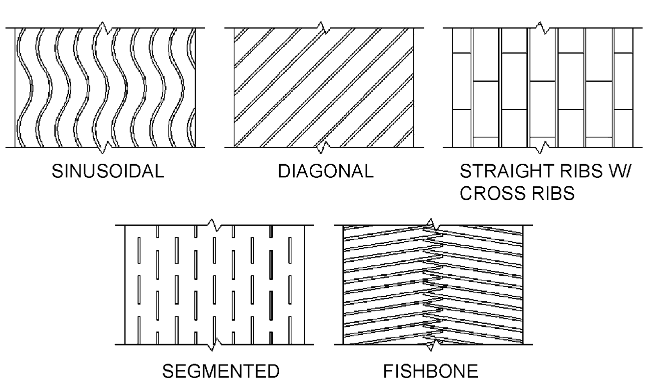


Fig. 3. Various rib orientation patterns.

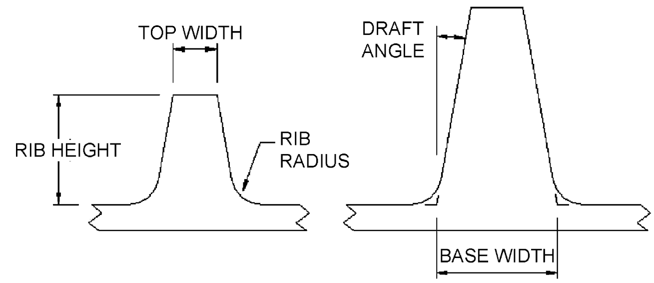


Fig. 4. Rib dimensions.

## 2. Automotive markets

Lead-acid batteries are used for starting, lighting and ignition [5] (SLI) in automotive applications to provide a large burst of power to energize the vehicle systems prior to engagement of the internal combustion engine. During the power burst delivery, the battery is typically subjected to a shallow discharge each time the engine is started. To deliver maximized power, ionic flux impedance of the separator, which is commonly called the "separator electrical resistance", should be minimized. In the configuration of a separator, the ribs are infinitely more resistant to ion flow (ionic flux) than the separator substrate. As more of the substrate surface area is taken up with ribs, separator resistance will increase and battery power decreases.

Ease-of-assembly with the separator is an important battery assembly parameter, and much work has been devoted to improving separator designs. The automotive industry has persistently pushed the standardization of battery types, and this has subsequently driven competition between battery manufacturers. One competitive tactic is to automate and strive for greater utilization of manufacturing equipment, which translates to increasing enveloper speeds and maximizing enveloper uptime and yield. Significant work has gone into separator designs targeted at maximum runnability, which can be negatively affected if the primary ribs are leaning, because the separator will track improperly through the enveloper, possibly causing skewed envelopes. Excessive winding tension or inadequate rib base dimensions for the height of the ribs can cause leaning ribs. To visualize this phenomenon, simply consider a very tall tree with shallow roots. The tree will fall down when a major force such as high wind is exerted, because the base of the tree is not large enough to support its large height. The same is true for ribs that are taller than their separator substrate base can support. The opportunity for ribs to lean has increased as the separator substrate thickness specifications have steadily decreased. To compensate for this tendency, especially in extreme conditions, such as plate spacing greater than 1.8 mm, the distance between opposing ribs has been split to form a "negative rib" (Fig. 5).

In addition to automating separator and plate assembly, battery manufacturers have automated the plate manufacturing process with expanded metal, punched plate or continuous cast plates. These plate processes can lead to sharp edges which can pierce the separator, thereby causing cell shorts. To maximize yield through the assembly process, battery manufacturers have

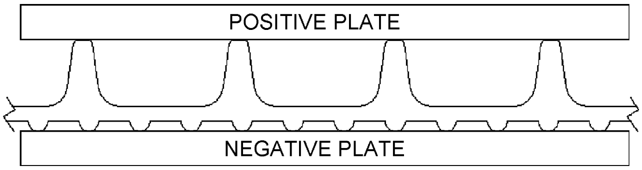


Fig. 5. Positive/negative rib profile.

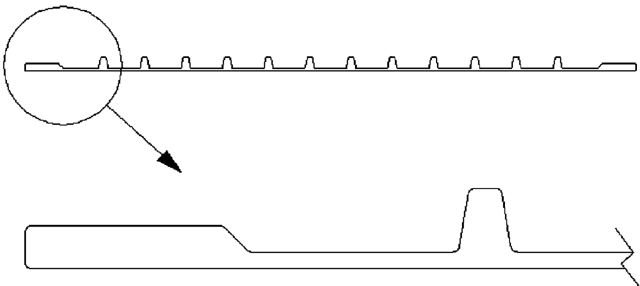

Fig. 6. Increased sealing area thickness.

requested greater puncture resistance especially in the land area. One of the earliest proposals for short protection was simply to increase thickness of the land area [6] by approximately 10% and this yielded a puncture improvement on the same level (Fig. 6). Over time, the idea to protect the land area against puncture shorts has been given much attention, as evidenced in the patent literature [7,8]. The approach for the separator profile design has been to prevent a catch point, or to deflect the sharp edge or corner away from the more vulnerable substrate (Fig. 7). Another option for minimizing puncture shorts, is to use a separator material with the ultimate polymer strength which maximizes puncture resistance throughout the entire separator, including the land area. This process is referred to as the HP process. Rearranging the mass in the sealing area has the potential of increasing the puncture resistance by 10% while utilizing the HP process can yield a 25–40% increase in puncture resistance depending on back-web thickness. Superior puncture resistance, coupled with electrical short-prevention rib designs does indeed yield the greatest protection throughout the battery assembly process.

For automotive batteries, we have thus far presented design criteria for improving runnability and minimizing puncture shorts to maximize automated equipment utilization. However, in Asia, due to the hot climates, and general use of antimony in the grids, reducing water loss is an important issue for end user.

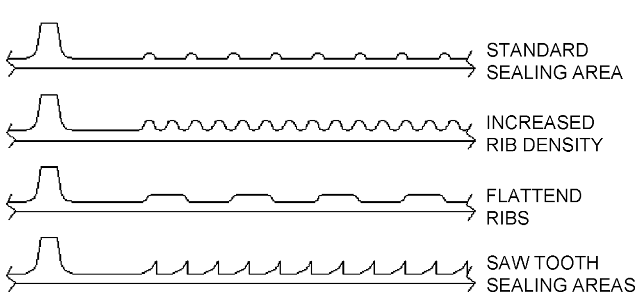


Fig. 7. Various land area modifications.

| Separator Type | Units | Positive Grid 1.6% Pb/Sb Alloy | Positive Grid Pb/Ca Alloy |
|---|---|---|---|
| Daramic Low Water Loss PE Separator | g $Ah^{-1}$ | 0.9 | 0.6 |
| Typical PE Separator | g $Ah^{-1}$ | 1.5 | 0.8 |
| | | | |
| 21 Days Overcharge 2.4 V/Cell at 40 °C | | | |

Fig. 8. Water loss comparison table.

Therefore, the battery manufacturer who can minimize water loss may have a distinct market advantage. Surprisingly, this is a place the separator can contribute to the solution with changes to the formula that are available in all profile types, such as are used in automotive, motorcycle, stationary and motive power batteries. Polyethylene separators with a special water loss additive can reduce water loss by 25% when non-antimony alloys such as calcium are used and by 40% when antimony is the alloy in the positive grid (Fig. 8).

## 3. Motive power applications

Frequent, deep discharging of batteries used in vehicles like fork trucks, submarines, coal-mining tractors, and golf carts is a critical design parameter for the general class of “motive power” applications. The batteries are discharged deeply on a regular basis, and the users are constantly trying to extend the cycling ability. Unfortunately, the cycle life ability of lead-acid batteries is not as good as other chemistries such as nickel metal hydride or lithium. As the lead-acid battery discharges, the lead and lead dioxide are converted to lead sulfate, which is substantially more voluminous. Simply put, the active material in the plates will swell during discharge. As the separator is positioned between these expanding plates, it provides an opposing force to resist the expansion forces. Upon recharging, lead sulfate must be brought into contact with particles that have been converted back into lead and lead dioxide. Therefore, a separator with more ribs or tighter rib spacing will be more effective with the recharge or conversion of the lead sulfate, especially for flat plate battery designs.

To counteract expansion of the lead sulfate, the tubular plate design offers some benefits over flat plate designs because the individual tubes of the gauntlets provide some resistive forces. Special considerations are required for the tubular design to take full advantage of the separator’s resistive forces. The electrode is no longer a flat surface with the tubular battery, and the ribs of the separator will therefore not function optimally if they slide between the shallow sections of the gauntlet – a likely occurrence due to vibrations over the life of the battery. Two approaches have been employed to prevent this problem. The first is to decrease the rib spacing so that a number of ribs contact the outer surface of the tubes (Fig. 9). The second approach, which can be combined with the tightened rib spacing, is to pitch the ribs slightly out of parallel to the surface of the tubes or to use a sinusoidal pattern (Fig. 10). Both the sinusoidal and diagonal ribs will continually cross the tubes of the gauntlet and never fall into shallow zone.

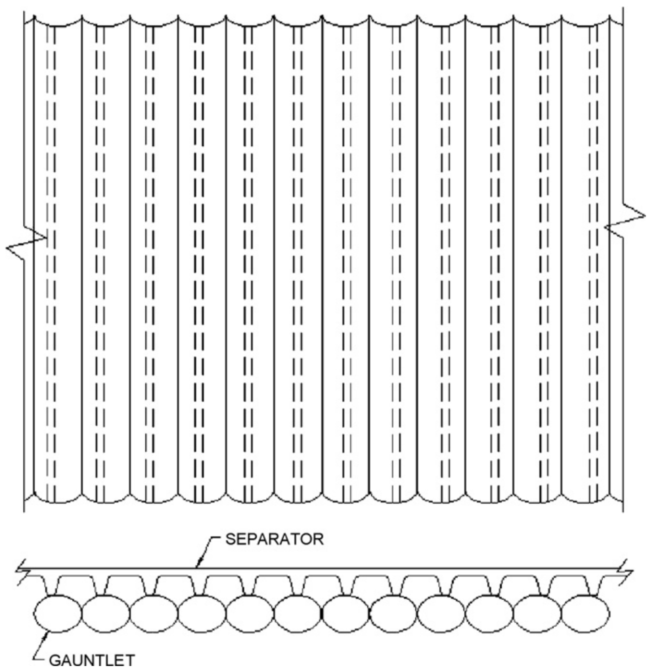


Fig. 9. Tubular plate and straight rib separator.

Rib designs can help extend the useful service life of a lead-acid battery that is heavily cycled by resisting the forces associated with shedding of the active material. In addition to meeting the cycle life requirements, the motive power battery must deliver the appropriate energy for the application. As the rib density is increased to prevent shedding and extend life, acid is displaced. As the acid is displaced from the space between the plates, the stated energy rating may not be realized due to acid limitations.

The objective for the Battery Design Engineer is to prevent shedding and subsequently extend cycle life while not compromising electrical capacity. One approach is to simply increase the rib density and then decrease the back-web thickness of the separator. Historically, the back-web thickness of the motive power battery separator was 600–650 μm. Removal of back-web mass could be achieved with the introduction of superior oxidation resistant separator materials like polyethylene. Today, the polyethylene separators have a back-web thickness as low as 500–450 μm, with some approaching the 400–350 μm range.

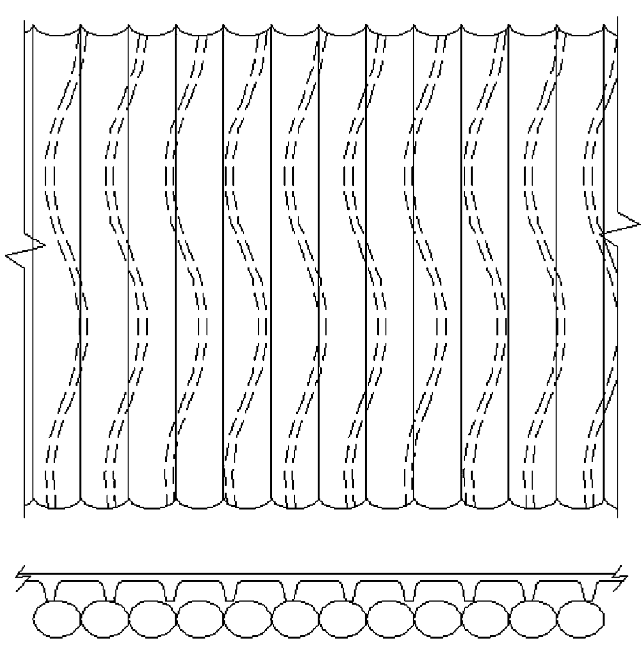

Fig. 10. Tubular plate and sinusoidal rib separator.

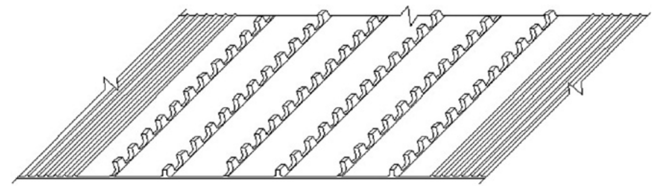

Fig. 11. Serrated rib profile.

The serrated rib separator profile design [9] (Fig. 11) is an innovative approach that allows the battery manufacturer to increase rib density without adding mass or displacing acid. With existing profiles, there is an obvious point of diminishing returns with narrowing the rib pitch. At some point, the active material will be appropriately supported, and the addition of ribs will not result in any appreciable cycle life extension. When the rib pitch is narrowed, support increases in the width direction of the plate. There is continuous support under the rib in the length-wise direction, thereby raising the question about necessity. The serrated rib profile design attempts to exploit this situation. Rib mass is removed in the length direction of the plate to achieve an unsupported distance equal to that in the width direction of the plate.

## 4. Stationary "power backup" applications

In addition to the automotive SLI and motive traction power applications, lead-acid batteries are used to provide temporary power in the event of electrical line service outages or relatively short interruptions of line current. These applications require the battery to have a relatively long service life with minimal maintenance, thereby often resulting in a flooded electrolyte design. Stationary batteries are normally floated or slightly overcharged during the majority of their life. There are certain implications for separator profile design for the infrequently discharged stationary battery system compared with the automotive and motive power batteries.

Increased rib density helps runnability and provides separation of the discharged active material from contacting the separator back-web in automotive batteries. For the motive power batteries, there is continued pressure to increase rib density to counteract shedding of the active material. The rib pitch can be increased for the stationary battery separator because those batteries are not often deeply discharged, and they are typically hand assembled. The ionic resistance of the separator becomes important because stationary batteries deliver a high amount of power in a short time period. This provides another driving force for wider rib spacing (decreased rib density) because fewer ribs lower the separator resistance, which subsequently increases the useful power output of the battery.

Power backup is often required in remote regions where the battery may be kept in a “less than hospitable” environment and often a battery with gelled electrolyte is chosen. Besides immobilizing the electrolyte, gel batteries are less susceptible to evaporative losses and stratification of the electrolyte. In lieu of these benefits, additional design parameters focused on the acid filling process, must be considered when selecting a separator profile for the gelled electrolyte battery. The immobility of electrolyte becomes a challenge in the filling process. Therefore, straight or diagonal rib profiles are preferred to sinusoidal profiles for ease of acid filling. To ensure acid availability at the negative plate, a profile with ribs facing both the negative and positive plates is often selected instead of the typical profile with ribs facing only the positive plate.

## 5. Summary

Selection and incorporation of the appropriate separator profile gives the Battery Design Engineer a method to achieve optimal performance. Profiles can be selected to lower the electrical resistance and subsequently deliver maximum power from the battery for automotive applications. Automated enveloper processing can be improved, and puncture shorts in the sealing area can be minimized. Applications such as motive power that require frequent, deep discharging will benefit by selecting profiles with increased rib pitch to prevent shedding of active material. For battery designs with limited acid volume, novel approaches like the serrated rib can be selected to eliminate the rib mass. For tubular batteries, the separator profile should be chosen to ensure proper support of the active material. A sinusoidal, diagonal or tightly spaced separator profile will provide this design function. Selection of an optimal separator profile also helps to meet the performance demands of stationary battery applications by decreasing electrical resistance and subsequently increasing power, minimizing problems associated with gel filling, and allowing sufficient space for gelled electrolyte to contact the negative electrode. Coupled with various profile options, additives for the separator can be employed to lower water loss and special separator processes can be used to improve separator puncture resistance and minimize the potential for shorting to achieve maximum battery performance.

The objective of the separator manufacturer is to be able to recommend and describe optimal profile options to the Battery Design Engineer, and to continually propose novel profiles through extensive R&D work. The ultimate goal is to anticipate the as-yet, unarticulated needs of the battery design, and then to develop new ways to further improve the profile design and performance characteristics. The separator is therefore much more than “just a spacer”!

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