

# **Advanced Lead Acid Battery Technology Used in UPS Applications**

**Shawn Peng  
Vice President of Technology  
Leoch International Technology, Ltd.  
Foothill Ranch, CA**

## **Abstract**

This paper will review the global market of uninterruptible power system (UPS) batteries and present the new requirements of extremely high power and low cost solutions. The different plate making technologies of lead acid batteries, related to UPS application, will be reviewed, which include gravity casted grid plates, expanded metal grid plates, thin plate pure lead plates, and full border 3D punched plates. Optimized solutions will be used to reach high rate discharging and fast charging practices. The comparison among these technologies will be discussed, which could be used by end UPS customers as a battery selection reference.

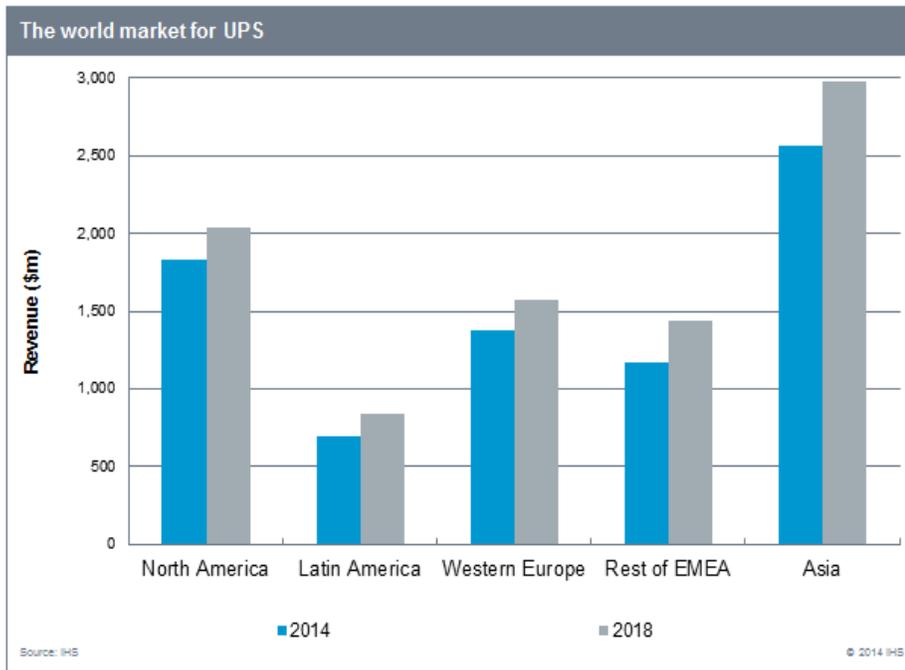
## **Global UPS Battery Market**

### **The global market of UPS batteries**

The global industrial UPS market is driven by many factors, the major ones being the increasing population and the progress of civilization, which lead to high energy consumption at present. End-users are increasingly adopting UPS systems as the backup power for many purposes, such as data storage systems, cloud computing, and personal/public electronic systems, to fulfil the requirements of more diversification of daily needs. The fluctuating cost of raw materials is one of the major challenges confronting the market. The prices of raw materials, such as steel, copper, and lead are undergoing fluctuation that affects the market. These materials are widely used in all ranges of UPS systems.

The global industrial UPS market is expected to grow at a steady rate (CAGR - Compound Annual Growth Rate) of 5.55%, during the forecast period 2013-2018. Major OE (original equipment) players such as Eaton Corp., Emerson Electric, and Schneider Electric are trying to increase the market share significantly. Many large vendors and emerging contenders in the market are employing merger and acquisition strategies to enhance their market presence.

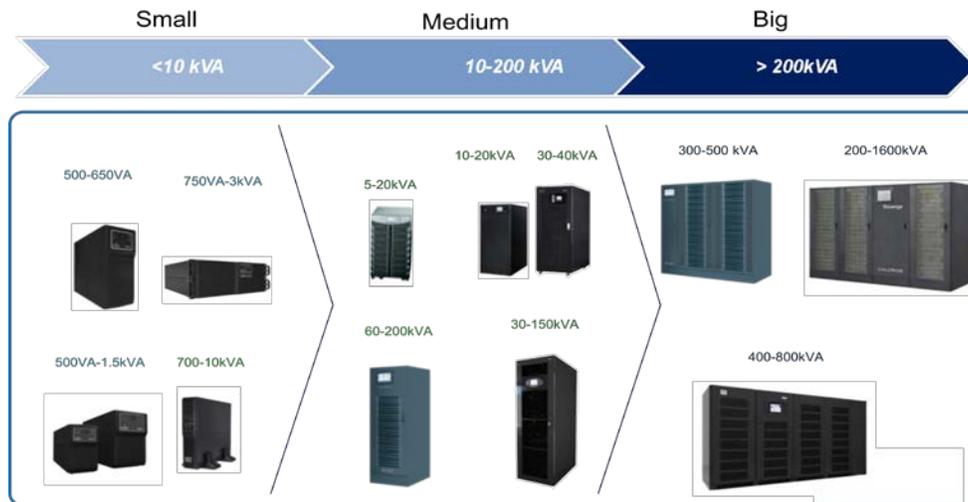
Figure 1 illustrates the UPS market size comparison between 2014 and 2018 in different regions. The total size of the global market has been predicted to increase over 16% in this period. The Asian and North American markets are, so far, the biggest markets, comprising more than 55% of the total market.



**Figure 1. The global UPS market.<sup>1</sup>**

Note: EMEA means Europe, the Middle East and Africa.

This market covers three UPS product segments: Small-sized UPS systems (<10 KVA), medium-sized UPS systems (10 KVA-200KVA), and large-sized UPS systems (above 200 KVA).



**Figure 2. UPS system size classification.**

Not only does the size of the UPS market keep growing, but, also, new characteristics are being built into this industry, such as Green UPS, as an emerging concept. A Green UPS system consumes less power per unit than traditional UPS and delivers an optimized power supply to enterprise infrastructure. It has lowered operational and maintenance costs more than any other type of UPS equipment. The introduction of ‘green’ will result in the higher adoption of these more efficient and environmentally friendly UPS systems among enterprises. But affordability is the key to making fast UPS market growth a reality in the next decade.

Another resource, TechNavio’s analysts, forecast that the global uninterruptible power supply (UPS) market will reach US\$9.84 billion by 2015. Asia-Pacific currently accounts for the largest share in the global UPS market due to expanding infrastructure coupled with growing commercial, retail and hospitality markets. UPS battery demand comes mainly from UPS OEMs. Figure 3 shows that the top five players cover 56% of the UPS battery market needs.

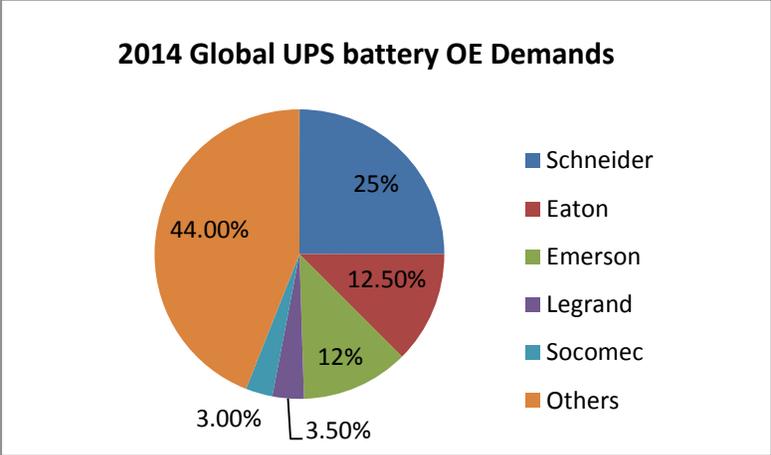


Figure 3. 2014 Global UPS battery OEM shares.

Growth of unorganized players, especially in the low rating UPS segment, is emerging as a major challenge for the organized players operating in the global UPS market. The unorganized sector continues to maintain its stronghold despite large-scale efforts by leading players to launch high-value, entry level UPS solutions. This is mainly due to growing UPS sales in small office/home office (SOHO) and small and medium sized business (SMB) markets, which are largely driven by consumer-vendor relationships, thus benefitting unorganized players in the long-term.

Table 1. 2013 Global UPS battery market share by region. (Total ~5Billion USD)

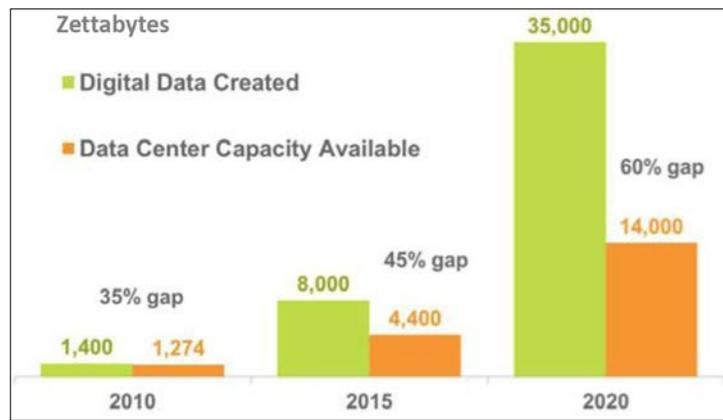
Region	Market (B \$)	Share
America	1.6	32%
China	1.4	28%
India	1	20%
APJ*	0.4	8%
EMEA	0.6	12%

Note: \*APJ means Asian Pacific and Japan.

Small size UPS batteries are less than or equal to 18Ah size, whereas large size are normally larger than 18Ah capacity.

**Future requirements**

The big portion of UPS application growth is coming from data center expansion and cloud computing, which need extremely large data storage capacity now and in the near future. Demand will grow exponentially fast in the next five to ten years. We must keep the storage capacity expanding quickly enough to keep up with this trend.



**Figure 4. Data generation vs. storage comparison from 2010 to 2020.<sup>2</sup>**

Over 90% of all the data in the world has been generated in the period of 2012-2014.<sup>3</sup> From Figure 4, we can see data increased by 5.7 times from 2010 to 2015, then is forecast to expand two times larger till 2020. Meanwhile, with data center capacity remaining behind real world needs, the gap will expand from 35% (2010) to 60% by 2020. Finding the space to build more data centers very quickly, reaching higher level of security/efficiency with multi-backup systems (memory storage/ power supply), and efficiently saving energy for operation (green concept) will be the main challenges we need to face.

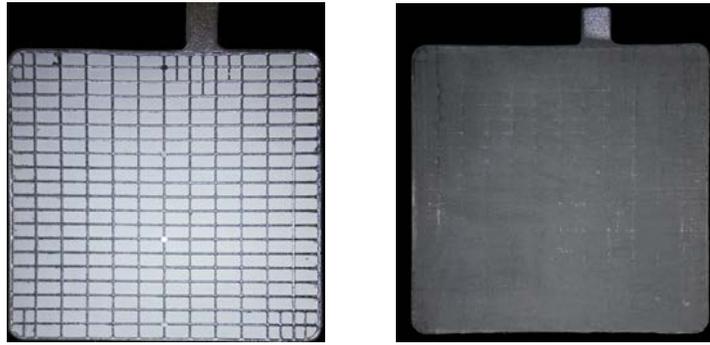
A huge investment is needed, as well as the space required, in a short period of time from 2013. For UPS battery systems, data centers and the UPS industry are looking for better battery solutions that can deliver higher power density, higher cost/performance ratio, smaller footprint or lower weight, faster charging capability, and better consistency among the batteries in strings, along with being safer during the operation. Much shorter discharging time with higher discharging power are needed. The typical 15 minute backup time moves down to five minutes and even to one minute in advanced systems. In some single generator cases, 30 second backup can be reached, which is similar to the automotive battery 30 second cranking requirements, except under the low temperature condition of -18°C or 0°F.

UPS battery design philosophy needs to change due to this extremely high discharging power output. What type of battery technology can support it, with respect to performance and cost? Our answer is lead acid batteries with new, punched thin plate technology.

## **The Lead Acid Battery Technology Today and Tomorrow**

### **Plate technology review**

The popular plate making technologies of UPS lead acid batteries we are using or are going to use are gravity casted grid plate, expanded metal mesh plate, and punched thin plate (pure lead thin plate and strong PbCa alloy punched plate). We are keen to use valve regulated lead acid (VRLA) batteries with absorbed glass mat (AGM) separators to achieve high power. These are non spillable and maintenance free type batteries. Figures 5 through 8 show different grid plate technologies.



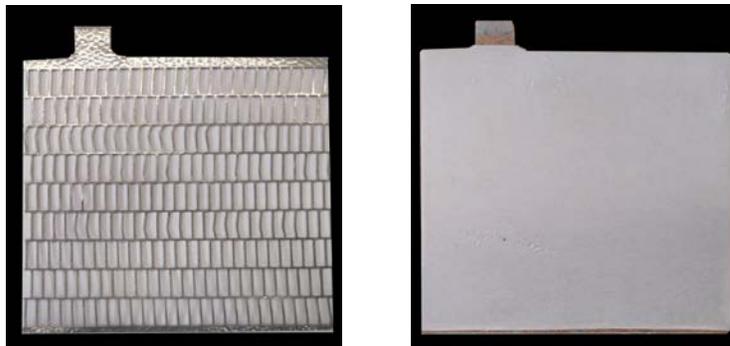
**Figure 5. Gravity casted grid and plate.**

This type of grid is casted by book moulds. The individual plate has been made. The cross section of the wires cannot be too small, in order to ensure the hot lead alloy will flow smoothly inside the moulds. The liquid alloy feeds from the lead pot normally in the horizontal direction shown in Figure 5. We can see that the general design produces more horizontal wires than vertical wires. Also, the operator needs to cork the mould from time to time, which will occasionally lead to a variation of the grid thickness.



**Figure 6. Expanded metal grid and plate.**

Expanded metal grid is a type of continuous grid making technology. It was first used in automotive batteries (flooded electrolyte type). Since the plates do not have side border frames, they have been enveloped in PE (polyethylene) bags to prevent a short circuit problem during assembly and application. Later, with better machinery and better process control, Japanese companies started using this technology to make UPS batteries because it can produce very thin plates with good consistency and fast production speed.



**Figure 7. Punched pure lead alloy (PbSn) grid and plate.**

A pure lead, thin grid plate is shown in Figure 7. The plate is very thin and punched. It belongs to continuous plate making technology. The alloy grid can give very long life due to a very slow corrosion rate under float charging conditions. However, this is a quite soft plate, and it is very challenging to make the plate and assembly with high production speed. Pure lead, thin plate batteries are expensive when compared to gravity casted and expanded metal types.

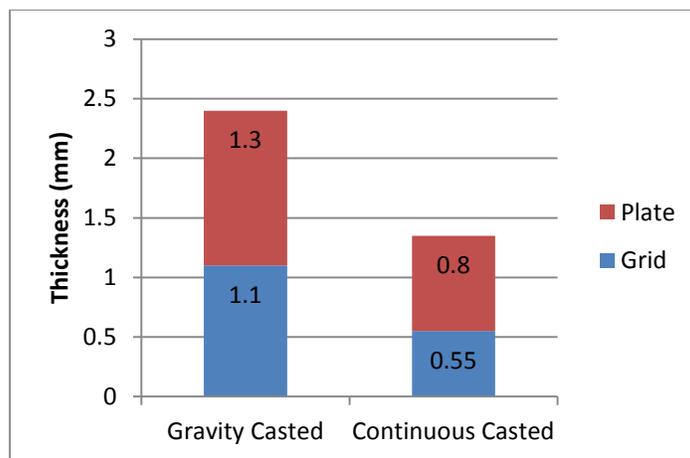


**Figure 8. Punched full border frame grid (PbCaSn alloy) and plate.**

Figure 8 shows punched thin plate with full border frames, which is very thin and strong. Fast production speeds can be achieved easily.

**Advanced technology combined with continuous plate making process, negative carbon additives and special separators**

In order to achieve the high power density, we need to find another way to make thinner plates in order to have enough effective contact area between positive and negative plates that can lead to high discharging current or high power but keep the current density (current value per square millimeter) in a suitable range. High utilization of PAM (positive active material) and NAM (negative active material) may not be good to extend the cycle life of lead acid batteries, but is not so critical for UPS application in general float charging conditions as a backup power source. Conventional gravity casted grids can give 1.2 mm-1.3 mm minimum thickness, plus 0.3-0.4mm over pasting, which will give plate thickness around 1.5mm to 1.7mm as minimum. With the continuous plate making technology, we can reach 0.6mm-0.7mm minimum grid thickness and 0.8 -0.9 mm plate thickness.

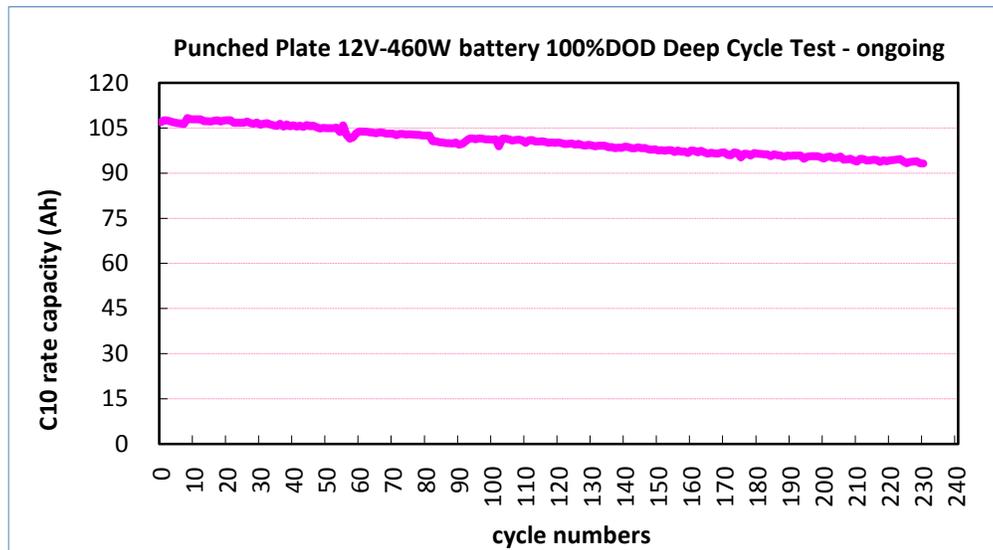


**Figure 9. Grid and plate thickness comparison between gravity casted and continuous casted/pasted plate types.**

Battery designers need to make careful balances among positive plate, negative plate, and acid amount to reach the best results to achieve high power and reasonable life (floating and shallow cycle in different circumstances) as well. With thinner plate design, we can increase the battery high rate discharging power by 15% to 25% and keep the weight of lead used to very similar or lower levels. Table 2 shows recently reached figures.

**Table 2. An example of punch grid (Pb/Ca/Sn alloy) plate model and gravity casted plate model, VRLA – AGM types.**

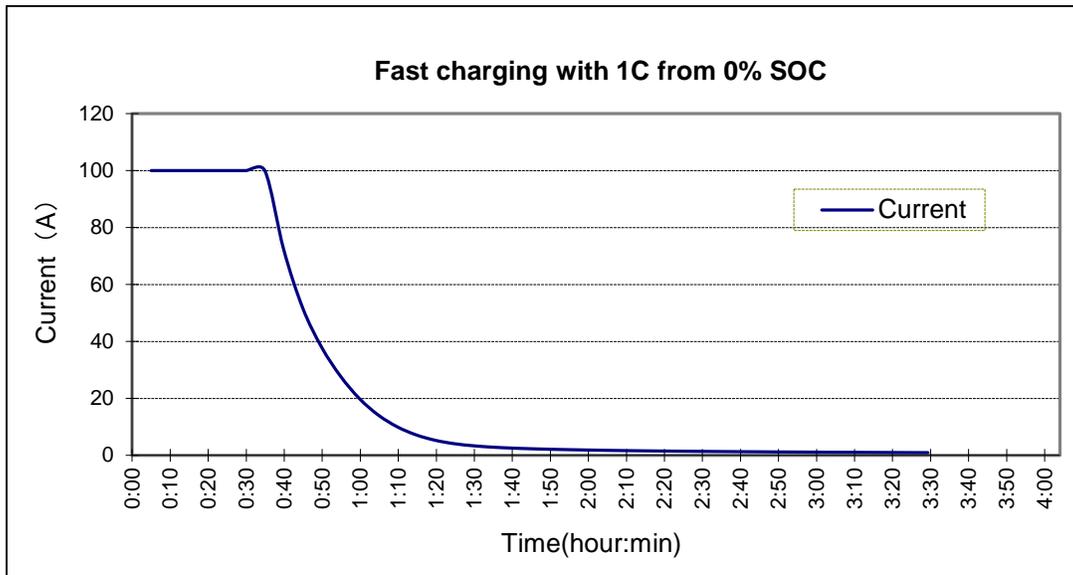
No.	Item		Requirements	Punching Technology	Gravity Casted Technology
				12V-460W (100Ah size)	12V-400W UPS (100Ah size)
1	Total Weight (kg)		N/A	31.4	35.3
2	Internal Resistance (mΩ)		N/A	2.6	4.1
3	C <sub>10</sub>	25°C, 10A, 1.80V/cell	T≥10h	105	102
4	Constant Power Discharge	25°C 460W/cell 1.67V/cell	T≥15min	0: 15: 10	0: 12: 30



**Figure 10. 100% DoD cycle performance of a 12V-460W battery – ongoing.**

From charging and discharging behaviors, we target 300 to 350 cycles with 100% DoD, which will show 25% to 30% more deep cycle numbers than general purpose, lead acid batteries or traditional UPS AGM batteries and be closer to deep cycle battery performance, but with much higher discharging power.

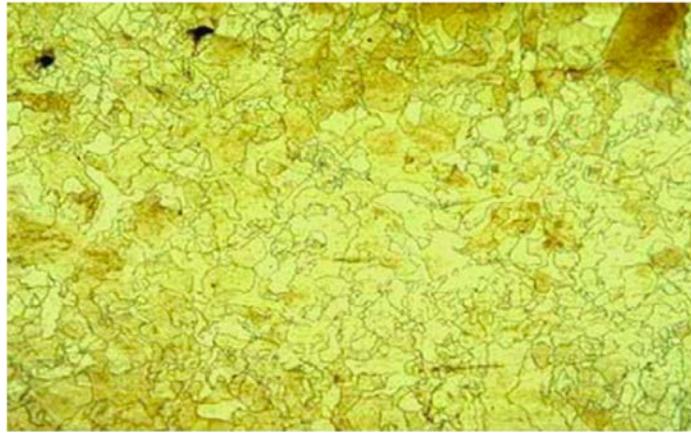
Consequently, this type of lead acid battery can be charged faster than normal, gravity casted grid batteries. Our study shows 1C charging (*with constant voltage regulation*) would be possible to significantly shorten the charging time **from 14 hours to 2.5 hours** with boost charging method, and **50 minutes** to reach 90% SoC level from 0% SoC level. Further study on this high rate charging on the life impact is undergoing.



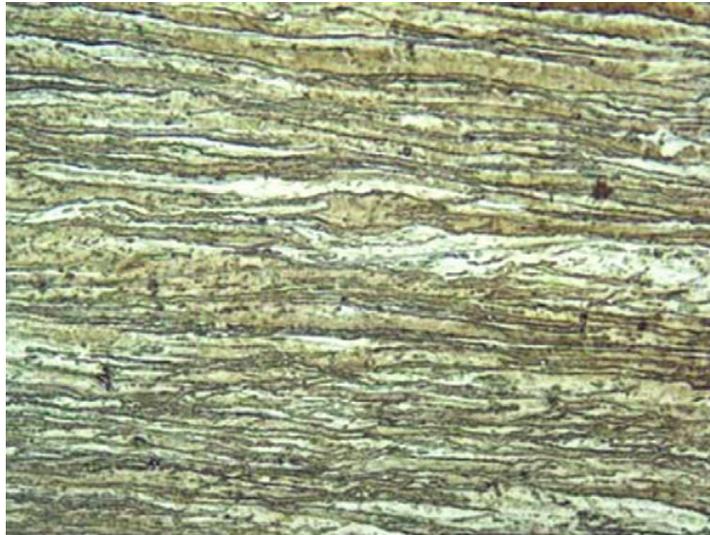
**Figure 11. 1C Fast charging curve of 100Ah punched frame plates' AGM batteries.**

In order to reach high power, long deep cycle life, and reasonable float charging life, fast charging request (in some special situations) for UPS application, our study shows that VRLA AGM technology, with Pb/Ca/Sn alloy punched grid (full border frame with 3D structure), gives the best optimized results, which can mean fast production speed, high production process consistency with low defect rates, less internal resistance, less water consumption rate, and lower internal temperature during floating charging condition. Correct selection of expanders in negative will help the product reach a few percent higher power output. Carbon is necessary, but we need to be very careful with the types and amount used to ensure not having too much water consumption that could lead to dry cell and a potential risk of thermal runaway.

Since the grid strip is thin, it may give short standby life due to the lead alloy grid corrosion that is one of the failure modes under float charging condition. By using the rolled strip, we can obtain the very fine grain structure that makes the grid far more resistant to corrosion. This property can compensate the shortcoming due to the smaller wires cross section and show the same level of floating life, compared to normal AGM UPS lead acid batteries with gravity casted plates. A continuously cast, thick, lead alloy strip ( approx. 13mm) is continuously rolled into a narrow thin strip (0.6 – 1.0 mm). The large size alloy grains have been squeezed, deformed and reformed into a fine grain structure oriented to the rolling direction, which provides extremely strong, creep resistant properties. Also, this will prevent the penetration type corrosion of the grid and help battery life. The sufficient tin additive in alloy can lower the grid corrosion rate and give higher conductivity to the corrosion layer. This is very similar to high antimony alloys, which give batteries the high cycle performance.

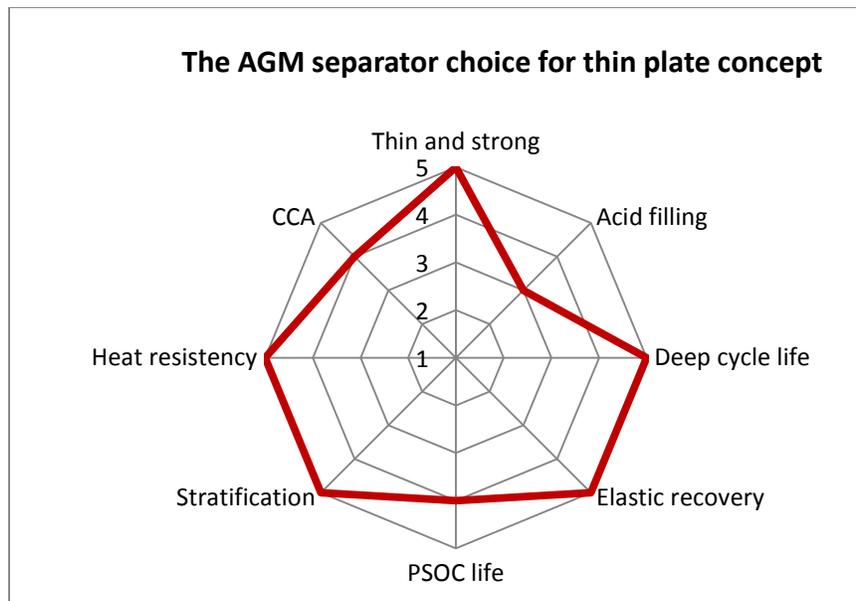


**Figure 12. Pb/Sn/Ca alloy grains for gravity casted grid plate VRLA AGM batteries. Magnification 160X.<sup>4</sup>**



**Figure 13. The oriented fine grain structure of a rolled Pb/Ca/Sn alloy grid. Magnification 200X.<sup>4</sup>**

Another factor is the selection of the new generation of AGM separator to fit the thin plate – more plate design requires a much thinner AGM separator be used. The thickness can reach 0.7, 0.8 mm after compression. This will lead to extreme challenges for acid filling and prevention of short circuit problems during assembly processes. The following figure shows the factors we need to consider when setting up the correct separator properties. The strength, acid filling resistance, deep cycle life, stratification, and elastic recovery properties are of main concern, along with internal resistance as the consequence of the combination effect.



**Figure 14. AGM separator selection for very thin VRLA batteries.**

## Discussion

### Greener technology

Greener technology can mean less pollution, less energy being used for production, less labor and higher productivity. Continuous plate making technology, with high production speeds, has been used in the automotive battery industry for years. Now, we introduce this technology into the UPS battery. With much stronger lead calcium alloy rolled grid strips, we can make the product much faster (three to four times faster than pure lead soft strip production) and produce a 10% to 20% lighter battery, yet deliver the same or higher rate discharging performance or save 10% to 20% on the space required for battery installation. The advantage will be even more when UPS application backup time is reduced from 15 minutes to five minutes or, even shorter, to one minute.

Efficient productivity can save over 20 operators from the gravity casted grid process to the advanced fast punching grid strip production process, which can deliver 400 to 500 plates per minute. (The older one is 12-16 pcs per minute.) For strip casting process, one big, closed, lead alloy pot system (three 20 ton size pots) will replace approximately 30 gravity casted machine's lead pots and make environmental control more efficient and effective. Continuous pasting gives cleaner working conditions than the traditional, individual plate pasting process that has paste between plates falling off the pasting system and needing to be put back into the pasting machine in time to keep plate property consistent, or recycled if not collected in a timely, repeatable manner. After plate pasting and curing, no tank formation is needed; therefore, no burden of acid neutralizing and recycling is needed. Since the punched plates have better dimensional consistency, the jar formation process will replace the tank formation process, which leads to far fewer requirements for acid recycling. All these will move VRLA AGM batteries to the next level, combining with new active material formulas and new types of AGM separators, which allow the advanced lead acid batteries to fulfill the new generation UPS application requirements: smaller, lighter, more powerful, and greener.

## References

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