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Separator requirements for 36-/42-V lead–acid batteries

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Abstract

The balance of end-user requirements which result in multiple design options will ultimately define the configuration of 36-/42-V lead–acid batteries used in future vehicles. Analysis of the driving forces, i.e. high power output, space and weight minimization, and especially cost/benefit considerations, reveal a high probability for a 36-V flooded, prismatic, battery design. The main requirements on the separator will be superior oxidation stability and high puncture strength, i.e. to levels far beyond what are achievable today.

Keywords: 42-V; Development trends; Lead–acid battery; Oxidation stability; Puncture strength; Separator

1. Introduction

Today, exciting technological advances are taking place in the world. Recent developments have seen the advent of cellular telephones, personal computers and the Internet, together with their associated repercussions. These and many other inventions have benefited society as a whole. The battery industry also has opportunities to contribute, especially with respect to reducing the fuel consumption of cars.

2. The 42-V battery system

The concept of the 42-V battery system offers more opportunities than the conventional 14-V alternative. First, the 42-V battery system can improve fuel economy by the implementation of idle-stop operation, electrical power steering, regenerative braking, electric turbo boost, etc. Second, the 42-V system can be utilized to implement new safety features on automobiles such as traction control, heated front windows, collision avoidance devices, and blind-spot sensors. Third, the 42-V system can enhance the general quality of driving by allowing new comfort features to be added to the automobile, e.g. zone climate control (even in key-off operation), navigations aids, heated seats, additional electrical appliances, and electrochromic windows [1]. The key question is how to power these proposed new functions? This leads to the lead–acid battery and the modifications that are required to meet the new performance demands in vehicles.

3. Current status

Before determining how these new demands are going to be met, it is beneficial to consider the present situation, as this is the starting point for any modifications. First, almost all of the cars in the world today utilize 12-V, flooded, lead–acid batteries. In the late 1990s, hybrid and pure-electric vehicles became commercially available, but only achieved a very limited market penetration. For instance, in the USA, 213 million cars were registered in 2001. Of these vehicles, only 34,800 were classified as hybrid or pure-electric [2]. This means that such vehicles have managed to capture only 0.016% of the US market, and it appears that this trend is representative of other regions in the world. Why, therefore, have hybrid vehicles not achieved a larger market share? The explanation probably lies in the sentiments of Keim [3], namely, that market forces will 'standardize on the most cost-effective means to achieve the intended function'. Even though automobile manufacturers have heavily subsidized hybrid vehicles, they are still not the most cost-effective solution. Consumers have not perceived the value of hybrid or pure-electric vehicles. This should not be forgotten when considering the 42-V system. Keim [3] has further proposed that for the 42-V system to be successful, 'the cost of such system should only be US$ 180–300 plus the cost of the parts replaced'.

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4. Market requirements

The UN Department of Economic and Social Affairs reported [4] that the world population was 6.1 billion in 2000. In the same year, there were 450 million registered passenger cars world-wide [5]. This implies that less than 10% of the world has a passenger car for its form of transportation. Obviously, in many parts of the world, this percentage is much higher than in the less-developed countries. Nevertheless, the data suggest that more than 90% of the world's population does not presently own a car. If, for example, only 5% of these people in 10 years time are able to purchase a vehicle, this would translate into a 60% increase in vehicles, world-wide, over today's level. Or to put it another way, designing a vehicle for this market segment may be the greatest opportunity for market growth.

Market needs are wide and varying, but the majority segment will define what is generally available to the rest of the market, especially with respect to the major automotive components. The automobile manufacturers work towards standardization of major components in order to minimize stock-keeping units which, in turn, lowers purchasing prices for themselves and, ultimately, for the consumer. The degree of market penetration of the 42-V battery system will be dictated by the following: (i) the additional cost of the system; (ii) the perceived benefits of the new options; (iii) whether the new options can be achieved by other technologies besides the 42-V battery system; (iv) the mandates that will be set by governments. Local governments may mandate lower emissions for better fuel economy and higher safety standards. It must be remembered that the 42-V battery system will not be the focus of the legislation as it is only a means of meeting the desired results.

5. Past and future trends

As always, predicting the future is a difficult task. It is safe to assume, however, that the past trends will continue until major socio-economic changes occur such as wars and/or new technologies. It is clear that the need for higher power will grow for mid-size to luxury cars, as in the past. By simple analogy, the first cars did not require a battery but were started with a hand crank. Next came the 6-V battery, followed today by the 12-V battery. Since these changes were driven by the desire for more power, it is anticipated that this trend will continue.

Next, the need to reduce the weight and space requirement of the battery will continue to be a market demand. Simply put, the consumers desire the portable energy sources to be unobtrusive. Finally, in this mature product market, consumers have become accustomed to decreasing cost per unit, either in real or inflationary terms. Therefore, the expectations of consumers with respect to price have been set over years and the industry will have to continue to meet these expectations.

6. Battery solution

One possible solution to these changing market requirements will be a modified 12-V battery, or even two 12-V batteries, or a 36-V flooded lead–acid battery. The flooded lead–acid battery continues to offer the lowest cost over competing systems and this will continue to be an important criterion in the future. The battery or batteries will, however, have to contend with higher power requirements and probably a more frequent cycling duty—and in a smaller space.

7. Separator requirements

The question is how will the changing demands upon the battery translate into requirements on the separator? As stated, the consumers will continue to demand lower unit costs for the battery. In response to this market pressure, the battery manufacturers will have to find ways to run assembly equipment faster and gain better utilization of labor rates. These higher speeds increase the potential for separator punctures. Therefore, higher puncture resistance will be the key parameter to assist the battery manufacturer to control unit cost. It must be noted that increased puncture resistance of the separator can also assist in lowering costs that result from warranty returns.

Next, as the battery is required to provide more power in a smaller space, more heat will be generated between the plates, more oxygen will be evolved because of overcharging, and more shedding of active material will occur compared with the situation in existing batteries. If oxidation of the separator is considered in terms as Arrhenius put forth, then this reaction will occur faster at an elevated temperature and at a higher concentration of reactant, namely nascent oxygen. If these assumptions are true, then the polyethylene separator will be under a heavier oxidative attack than in present batteries. As a separator is oxidized, holes, cracks and splits will develop and may lead to premature loss of capacity, and even to complete failure of the battery. Therefore, separators with increased oxidation resistance are an important requirement to meet future market needs.

Foreseeing this trend, Daramic has been actively developing separators to meet the future market requirements and has launched a new family of products, namely Daramic® Duralife and Daramic® HPR. The development goal of these products is to increase puncture resistance by 50% and to increase the oxidation resistance by 100% over existing materials while maintaining all other properties on an equivalent level.

7.1. Improvements in puncture resistance

To appreciate the improvement achieved with Duralife and HPR separators, it is necessary to review the problem of puncture resistance. In order to simplify the discussion, a 200-μm (or 8 mil) backweb polyethylene separator is used

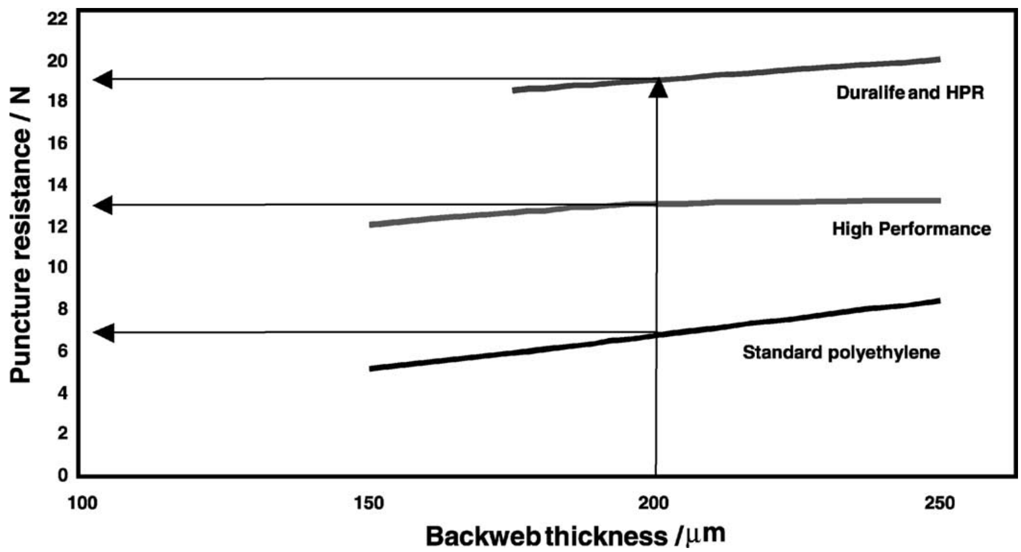

Fig. 1. Puncture resistance of separators as a function of backweb thickness.

as the standard. From the data shown in Fig. 1, the standard polyethylene separator without any modification will have a puncture resistance of 6–7 N. The first and easiest solution to increase the puncture resistance is simply to increase the thickness in the separator and/or sealing area to 250 µm or 10 mil. This will increase the puncture resistance to 7.5–8.5 N. Modifying the separator manufacturing process to handle long polymer chains in a more gentle manner yields substantially increased puncture resistance, as seen in the High Performance product, which has a value of 12–13 N [6]. Comparison of these results demonstrates the improvement in puncture resistance shown by Duralife and HPR materials which have typical values of 18–19 N.

7.2. Improvements in oxidation resistance

The primary tool for evaluating improvements in oxidation resistance is the industry standard hydrogen peroxide oxidation resistance test, called PEROX 80 [7]. In this accelerated test, separators are soaked in a heated mixture of sulfuric acid and hydrogen peroxide. These separators are removed from this oxidizing solution at various times, and the elasticity is then evaluated by measuring the elongation in the cross machine direction (CMD-elongation). The resulting value is compared with the initial value. The residual elongation at any time is a relative indication of the degree of polymer degradation. The more the polymer chains are degraded, the lower the mechanical properties, and the risk of holes, splits and cracks increases.

The first and easiest method for improving the oxidation resistance is to increase the backweb thickness of the separator. This offers, however, only a small improvement in oxidation resistance and has the negative consequences of increasing electrical resistance, displacing acid, and increasing separator costs. Another procedure employed in the industry is to add a non-woven laminate, e.g. glassmat, to the polyethylene separator. The glassmat is essentially inert to oxidative attack and is therefore placed in direct contact with the positive plate. This approach is very effective, but suffers from higher electrical resistance and substantially higher component costs because of the added expense of the glassmat.

Other methods are to modify the components of the separators, either in type or concentration, to prevent the oxidative attack of the polyethylene. For instance, increasing the residual oil in the separator or changing the various components of the oil can increase the oxidation resistance. Unfortunately, this change comes at the cost of decreasing porosity and increasing separator resistance, and may also lead to higher generation of black scum.

Another approach is simply to increase the polymer content. This, too, will decrease porosity, increase separator resistance, and increase separator cost. For the High Performance separator, it is considered that the concentrations of polymer and oil are optimized [6]. Nevertheless, the question remains: ‘how to gain further oxidation resistance?’ Some have suggested adding anti-oxidants to the separator. This approach does not appear to be practical for the following reasons: (i) the separator is a minor component by weight in the battery; (ii) anti-oxidants can only be added in small percentages to the separator; (iii) anti-oxidants are consumed as they come into contact with the oxidizing species, and thus the quantity of nascent oxygen produced in the battery would quickly overwhelm any anti-oxidation package in the separator.

Another solution to increasing the oxidation resistance is found in the Duralife separator. Using the PEROX 80 test, it can see from the data in Fig. 2 that the High Performance product has almost twice the oxidation resistance of standard polyethylene separators. The improved oxidation resistance is based on the gentle handling of the polymer molecules in an optimized process. With this material as a benchmark,

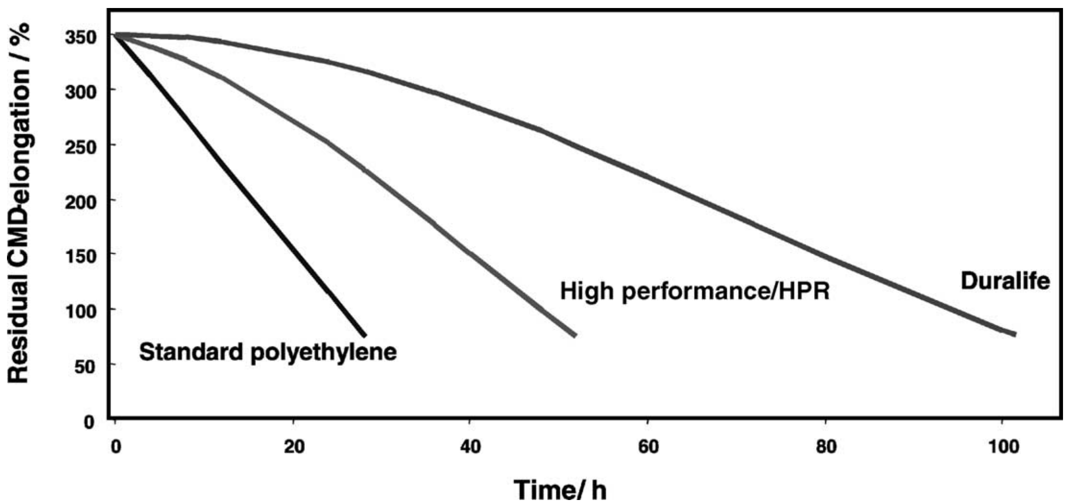

Fig. 2. Oxidation resistance of separators as a function of time.

Table 1
Typical separator properties

Characteristic	Daramic®	Daramic® HPR	Daramic® Duralife
Backweb thickness (μm)	200	200	200
Puncture resistance (N)	7.5	13	19
Electrical resistance (mΩ cm^2)	55	55	65
Porosity (%)	60	60	58
Elongation CMD (%)	350	350	350
Backweb oil (%)	11–12	11–12	11–12
Total oil (%)	14–17	14–17	14–17
Moisture content (%)	3	3	3
Dimensional stability (%)	−0.5	−0.5	−0.5

Daramic has made further enhancements to the manufacturing process and to the formula of the separators in order to achieve a new level of performance. From the PEROX 80 test, the resulting Duralife separator has double the oxidation resistance of the High Performance product, and thus more than triple that of standard polyethylene separators.

7.3. General separator properties

Besides having a high resistance to puncture shorts and oxidative attack, the other properties and associated functions of the separator must not be overlooked. The enhanced properties of Duralife and HPR separators are achieved by changes in both the formula and the manufacturing process. From the data in Table 1, however, only a slight drop in porosity can be detected together with an increase in electrical resistance. The latter is relatively small, viz. 10 mΩ cm^2, and within the detection limits. The Duralife product offers a 50% improvement in puncture resistance and 100% improvement in oxidation resistance over the existing High Performance product, while keeping all the other properties on an equivalent level. Thus, this separator is suitable for batteries to be used in harsh environments such as those which involve high operating temperatures, more frequent cycling, and higher power requirements.

8. Conclusions

The industry will continue to face pressures to increase the power, improve the cycling duty and reduce the size of automotive batteries, while keeping the cost close to that of present-day units. There is no doubt that the 42-V battery system offers many new advantages over the present 12-V system and will find applications in certain market segments as customers perceive its value. As the battery industry tries to meet these rigorous demands, new robust designs of separator will be required.

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