J Solid State Electrochem (2004) 8: 932–933
DOI 10.1007/s10008-004-0560-7

MINI-REVIEW

Karel Micka

Contemporary trends in research and development of lead–acid batteries

Received: 2 September 2003 / Accepted: 6 April 2004 / Published online: 29 May 2004

The major market for lead–acid batteries is heading for a revolution. The familiar 12-V electrical system will, progressively during the next few years, be replaced by other electrical systems. Part of the automotive market will be taken over by so-called hybrid electric vehicles (HEVs) and the rate at which this shift is occurring is surprising even for some experts. Their advantage consists in that they use the electrical power for acceleration and, eventually, for driving short distances, whereas the internal combustion engine is used in other instances that do not require high power, e.g. charging the battery. Since the tentative introduction of HEVs to the market in 1999, the number of total sales has already exceeded 100,000. All of these vehicles, however, employ nickel metal hydride batteries since when they were designed the lead–acid batteries were unable to withstand the required operation for an adequate life time.

The remainder of the automotive market will involve conventional vehicles with internal combustion engines, but with a higher voltage electrical system, i.e., a 36-V battery and a 42-V alternator. This is because the demands put on electrical power in these vehicles have risen considerably in recent years. Electronic equipment is increasing in volume involving, as in the new BMW series 7, so-called telematics such as internet access, satellite radio, and in-car navigation, further computer-controlled air springs, electrically adjustable air conditioning, windows, side-view mirrors, power assisted steering, and many other features. All these new features will take electric loads beyond 2 kW, which exceeds the capability of the traditional alternator. The technical solution is to increase the voltage output of the alternator; 42 V has emerged as an acceptable figure. This means, in turn, re-designing the starting, lighting and ignition battery to give a terminal voltage of 36 V. This is no longer a discussion point. The introduction of the 36/42-V electrical system brings with it a reduction in fuel consumption, thanks to the possibility of regenerative braking and turning off the engine during stationary operation, and allows the automobile design engineer to perform many vehicle functions electrically that are presently performed mechanically. Toyota has put the first saloon car on the road with a 36-V battery and more than 20 other cars are at an advanced state of design with such an electrical system.

Toyota has chosen a lead–acid battery to be the car's source of electrical energy. With respect to price and energy, even in the luxury car market for the new style electrical system, the lead–acid battery has a good position in competition with concurrent battery chemistries. However, the new operation conditions for the 36-V lead–acid battery are unusually hard. The battery will face hundreds of thousands of shallow charge and discharge cycles. Electrical air conditioning and other electrical loads, when the engine is not running, could heavily discharge it and this could shorten its life if the battery is electrically undersized. It also needs a complex package of electronics to regulate and manage it and to give diagnostic information to the driver and service technicians. To date, only a few manufacturers have been able to offer a lead–acid battery that can satisfy the new requirements. Of course, lead–acid battery designers also have to do much work to ensure a satisfactory product. The new battery will be of the valve-regulated (VRLA) type. It will have to be equipped with sensors to advise how healthy it is and how much life it has left.

The lead–acid battery has made a lot of progress—largely as a consequence of the Advanced Lead–Acid Battery Consortium (ALABC) programs funded by the producers, which were set up to keep the lead–acid batteries in the race to provide power for (pure) electric vehicles. But the automobile industry is choosing a different path and batteries of higher voltage (e.g. 144 V) are promising in developing HEVs, besides the proposed 36/42-V electrical system for vehicles that re-

---

Presented at the 4th International Meeting Advanced Batteries and Accumulators, 15–19 June 2003, Brno, Czech Republic

K. Micka
J. Heyrovský Institute of Physical Chemistry,
182 23 Prague 8, Czech Republic
E-mail: karel.micka@jh-inst.cas.cz

main primarily powered by internal combustion engines. The motivation for the adoption of HEVs is the reduced fuel consumption (with associated reduction in air pollution) without the range limitation imposed by pure electric vehicles.

The operation conditions for both these applications require the VRLA battery to be held at a partial state of charge (PSoC) for most of its life and to supply and accept charge at unprecedented rates. This is because the battery will have to accept regenerative braking energy input. The remarkable advances achieved in VRLA battery technology for electric vehicles during the past decade will have to be continued in overcoming the difficulties due to high-rate PSoC service. This is because failure modes seen in the PSoC are quite different from those faced in electric vehicles, i.e. in deep-cycle operation. With VRLA batteries operating in the PSoC regime, a new problem arose, namely sulphation of the negative plates causing a new kind of premature capacity loss (PCL).

Of a number of possible approaches to this problem, perhaps the most interesting one uses additions of suitable sorts of carbon (not specified) into the negative paste [1, 2]. This idea was soon studied in more detail and it was found that additions of up to 2% of carbon black or powdered graphite to the negative active material indeed hinder the sulphation of the negative plates [3]. On the other hand, a rather trivial approach considers fine-pore separators with elevated tortuosity factors that inhibit the efficiency of the oxygen cycle by retarding the fluid transport. Thus, it becomes more difficult to create gas paths through the separator and more current can be used for charging the negative plates [4]. In this case, however, part of the oxygen evolved at the positive plates must inevitably escape into the atmosphere resulting in some water loss from the battery. Probably better from this point of view is the combination of the oxygen cycle with catalytic recombination [5], which also allows more current for charging the negative plates, but without the loss of oxygen. Also interesting is the application of charging pulses with the intention of minimizing the formation of "hard sulphate" during PSoC duty and stand conditions [6].

Last but not least, it should be noted that the performance of VRLA batteries operating in HEV duty can be improved by optimizing the lead grid used as current collector, since the discharging and especially the charging rates may attain unusually high values causing unequal current distribution over the plate surface. A possible approach to this problem was shown by computer calculations to be the appropriate choice of the position of the lugs welded to the lead grids [7, 8]. It has been shown experimentally [9] that when each plate is provided with a current tab welded both at the top and at the bottom of the plate, no significant temperature differences are formed within the battery even during rapid discharge, the cycle life increases, and the utilization of the active material is improved. Application of this invention in HEVs is envisaged [10]. Naturally, two or more ideas can be combined to achieve the best VRLA battery performance.

References

1. Nakamura K, Shiomi M, Takahashi K, Tsubota M (1996) J Power Sources 59:153
2. Shiomi M, Funato T, Nakamura K, Takahashi K, Tsubota M (1997) J Power Sources 64:147
3. Hollenkamp AF, Baldsing WGA, Lim OV, Newnham RH, Rand DAJ, Rosalie JM, Vella DG, Vu LH (2001) ALABC Project No. N 1.2, Annual Report, July 2000–June 2001
4. Nann E, Ruch J, Wagner B, Toniazzo V, Lambert U, Nelson RF (2001) ALABC Project No. S 1.2, Annual Report, June 2000–May 2001
5. Dyson I, Jones W, Griffin P, Whiteley P (2001) ALABC Project No. CAT 1.1, Annual Report, December 2000–December 2001
6. Lam LT, Phyland CG, Rand DAJ, Urban AJ (2002) ALABC Project No. C 2.0, Progress Report, August 2001–January 2002
7. Calábek M, Micka K, Bača P, Křivák P (2000) J Power Sources 85:145
8. Král P, Křivák P, Bača P, Calábek M, Micka K (2002) J Power Sources 105:35
9. Lam LT, Newnham RH, Ozgun H, Fleming FA (2000) J Power Sources 88:92
10. Newnham RH, Baldsing WGA, Hollenkamp AF, Lim OV, Phyland CG, Rand DAJ, Rosalie JM, Vella DG, Dickinson B, Loyns A, Karner D (2001) ALABC Project No. C/N 1.1, Semi-Annual Report, July–December 2001