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A new high-rate, fast-charge lead/acid battery

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Abstract

A new approach to the design of lead/acid batteries has been developed based upon the use of very thin, lead foil, current collectors and a unique method for facilitating high current-carrying capacity to and from external sources. The basic cell construction and the performance characteristics for this valve-regulated lead/acid design are described. Spiral-wound cells with electrode/cast-on-strap (COS) configuration exhibit extremely high power output with a very flat discharge voltage plateau at all normal currents. Conversely, equally fast recharges of 10 min, or less, to 100% capacity can be realized for the same reasons. Cycle life in deep-discharge applications does not appear to be compromised by the thin foil used, as normal behaviour is observed. Applications for this high-power technology include portable-power tools, UPS systems, electrically-heated catalytic converters, repetitive pulse-power applications, and electric and hybrid vehicles.

Keywords: Lead/acid batteries; Charging

1. Basic cell construction

The thin metal foil (TMF™) battery technology [1–4] has been developed over the past few years by, first, Bolder Battery, Inc. and, now Bolder Technologies Corporation. The concept represents a straightforward extrapolation of conventional lead/acid technology into a new non-conventional configuration. The original development of valve-regulated lead/acid (VRLA) cell/battery technology involved the use of thin perforated grids and multiple-tab current collection [5,6]. While being more efficient in terms of high-rate charge/discharge operation, this cell configuration still possesses limitations. Using the same spiral-wound approach as that of the original Gates design, Bolder has improved the high-rate performance by increasing the plate surface area and decreasing the plate-to-plate spacing (thus reducing dramatically the cell impedance). The 'grid' in the Bolder design is actually a solid, 0.002 in. (0.05 mm) thick, lead alloy foil with a 0.003 in. (0.08 mm) thick layer of active mass placed on both sides. The 0.21 mm plates are wound up into a spiral coil with a standard glass-microfibre separator in a head-to-tail configuration with an unpasted foil that protrudes from each end of the wind. These uncoated areas are each cast to a lead alloy 'puck' that serves as a bridge to the external cell terminals. This design produces a 16–19 times increase in the ratio of plate surface area to active material mass and a 20–80 times decrease in the path length for electron flow when compared with conventional flooded and VRLA batteries, as shown in Figs. 1 and 2, respectively. Fig. 3 depicts a cross section of the patented development cell. Bolder is currently developing a new cell design that will incorporate an all-plastic case in place of the plastic body/aluminum sleeve shown in Fig. 3. The new design also features a more reliable Bunsen-type valve in place of the O-ring valve.

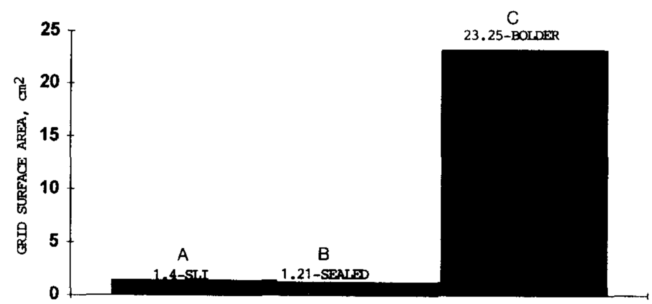

Fig. 1. Comparison of surface areas of grids (cm^2) per gram of active material: (A) SLI starter battery plate; (B) small valve-regulated (sealed) battery plate; (C) Bolder 1.2 Ah cell plate.

2. Performance characteristics

2.1. Discharge

The TMF™ cell has excellent charge/discharge characteristics. Fig. 4 gives typical voltage/time curves for

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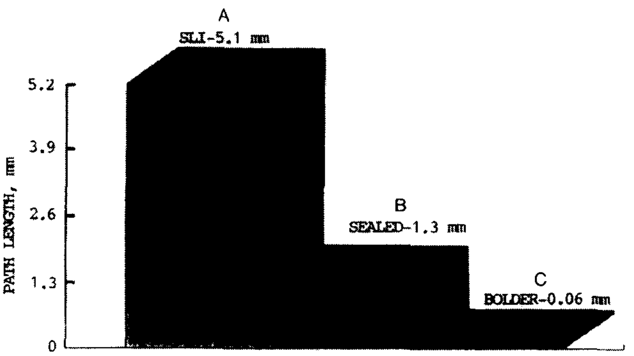

Fig. 2. Comparison of maximum path lengths through the active material to the grid/foil: (A) SLI starter battery plate; (B) small valve-regulated battery plate; (C) Bolder 1.2 Ah cell plate.

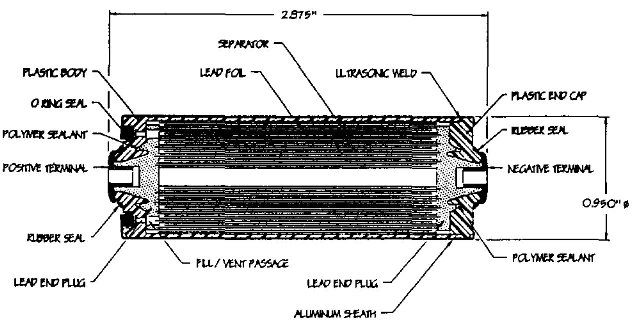

Fig. 3. Cross-sectional diagram of the patented Bolder Technologies cell.

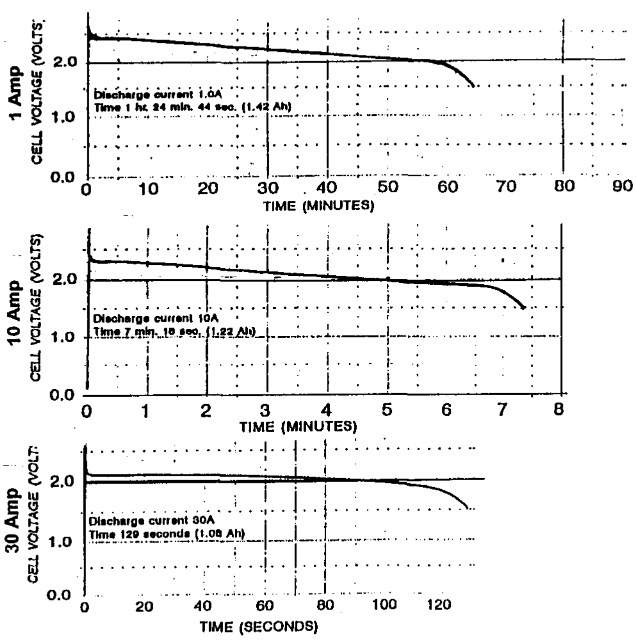

Fig. 4. Resistive discharge curves for the Bolder 1.2 Ah cell at three discharge rates, as shown at left.

discharge of a 1.2 Ah cell at approximately 1, 10 and 30 A. Note that the discharge curves are very flat in all cases and that the voltage stays above 2.0 V for the majority of each discharge curve. Fig. 5 shows a room-temperature Peukert plot for the 1.2 Ah cell and it can be seen that it is linear over a remarkable range of discharge currents. Typically, the cells yield over 75% of the low-current capacity at the 30 A rate to a 1.50 V cut-off. In the same vein, low-temperature performance is also outstanding.

The use of opposite-end current collection with a continuous contact between the COS pucks and the electrode foils results in a relatively uniform current distribution over the electrode surfaces. Combined with the high plate surface area, this provides a constant, low-resistance path for current flow across the full electrode surfaces, and thus minimizes cell polarization and increases the operating voltage. The relatively low current densities and proximity of the active material to the separator reservoir translates into reasonably good utilization levels of about 0.1 Ah g^{-1}, or about 45% of the theoretical capacity. The extremely high plate surface area and continuous-foil configuration result in very low discharge (and charge/overcharge) current densities, typically about 100 mA cm^{-2} even at a discharge rate of 30 A; for the thinner-plate designs under development, it is even lower. These factors negate the concept that the cycle life of the Bolder product may be very short due to the thinness of the foil and resultant brief corrosion lifetime. In fact, the cycle-life performance is comparable with other VRLA technologies at both low and high rates. Fig. 6 shows a cycle/capacity plot for a 1.2 Ah cell discharged to 100% at about the *C*/2.4 rate (0.5 A); the cycle life shown to 80 and 50% of initial capacity is typical of small VRLA products that are commercially available. As mentioned below, one of the prime applications for the Bolder technology is power tools, and on a 10 A/17 cycle per day discharge/charge regime, 400–600 cycles can be obtained with 100% DOD.

2.2. Recharge

The cell can be recharged by any of several regimes. These include constant voltage (CV), constant current (CC), tapered current, and various pulsing schedules. The high-rate discharge capabilities of the Bolder technology are mirrored by extremely good charge-acceptance. Fig. 7 shows a typical CV recharge of a 1.2 Ah cell at 2.65 V. A full recharge is accomplished in less than 7 min and the cell is 80% recharged in less than 3 min. Because of the cell's extremely low internal impedance and good form factor for heat dissipation, the skin temperature of the cell stays low during these fast recharges, as shown in Fig. 7. This ability of the TMF™ cell to accept and deliver current at very high rates allows great flexibility in applications that require high-current discharges followed by rapid recharges. This is a true 'power' cell and its development will make lead/acid technology superior to those of other electrochemical couples in the area of high-rate power delivery and uptake.

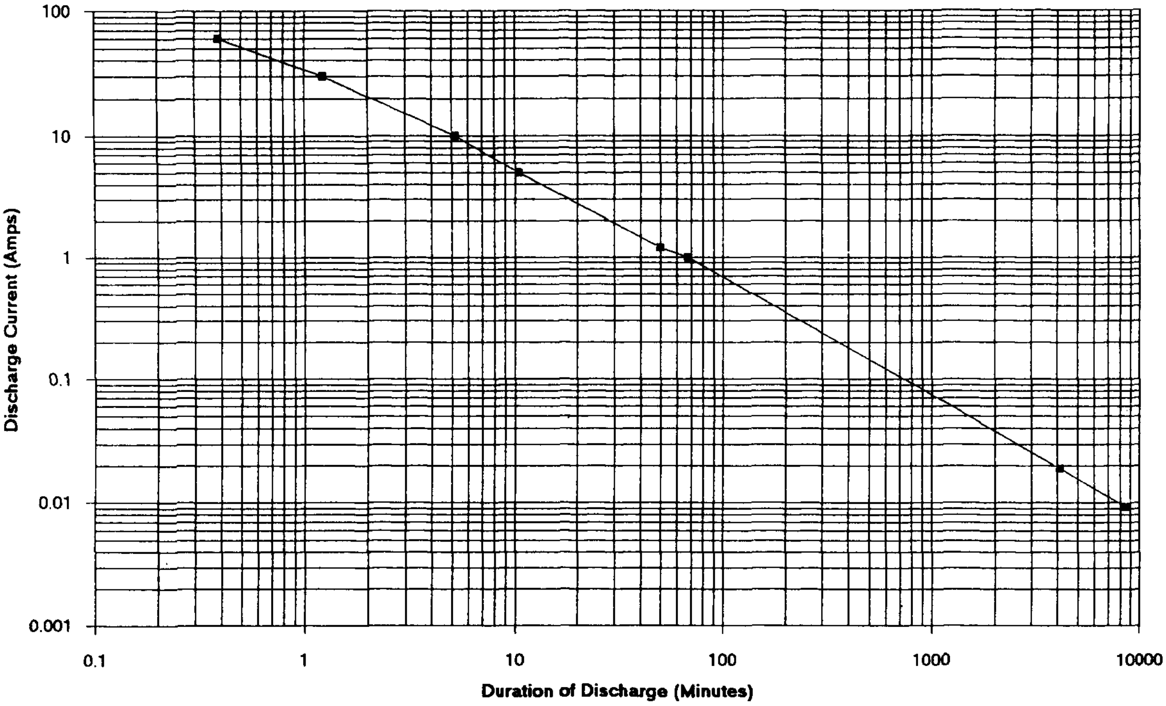

Fig. 5. Room-temperature (23 °C) Peukert curve for 1.2 Ah Bolder cell.

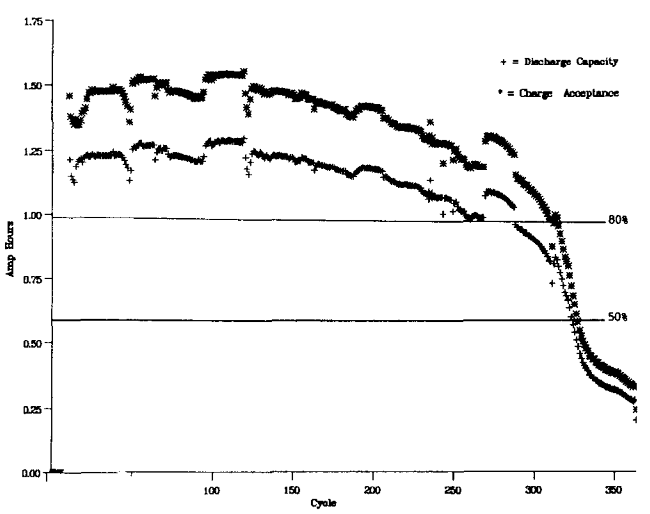

Fig. 6. Capacity/cycle plot for a 1.2 Ah Bolder cell discharged at an average current of 0.5 A (4 Ω load resistive discharge); 2.55 V CV recharge, 4 cycles per day. Cut-off voltage = 1.75 V.

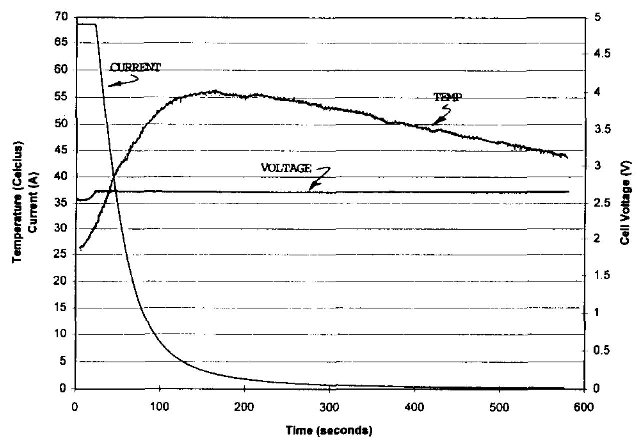

Fig. 7. Current and temperature response of a 1.2 Ah Bolder cell during a 2.65 V CV recharge.

All of the test results are based upon the Bolder 1.2 Ah 'commercial' cell first developed. It is anticipated that further significant improvements in performance will be realized as new cell configurations are optimized for specific application requirements. Work in progress is focused on developing: (i) thicker-plate technologies for better life and greater specific energy in deep-cycling applications; (ii) thinner plates for even stiffer voltages; (iii) ultra-high-power densities and novel alloys for improved handling and longer float and cycle-life performance.

3. Applications

Some of the applications areas that best fit these unique power capabilities are cordless power tools, UPS, engine starting, hybrid vehicles, and other high-power duty cycle requirements.

For power-tool applications, the superior high-rate capacity and voltage maintenance of this battery have been demonstrated. A standard test in the power-tool industry is to determine how many holes can be drilled in a 2 in. thick redwood board using a 0.75 in. auger bit. A simulation of this as a pulse-power test is shown in Fig. 8 for a 12 V Bolder battery and a 12 V standard Ni/Cd power-tool pack. The CC load is applied with

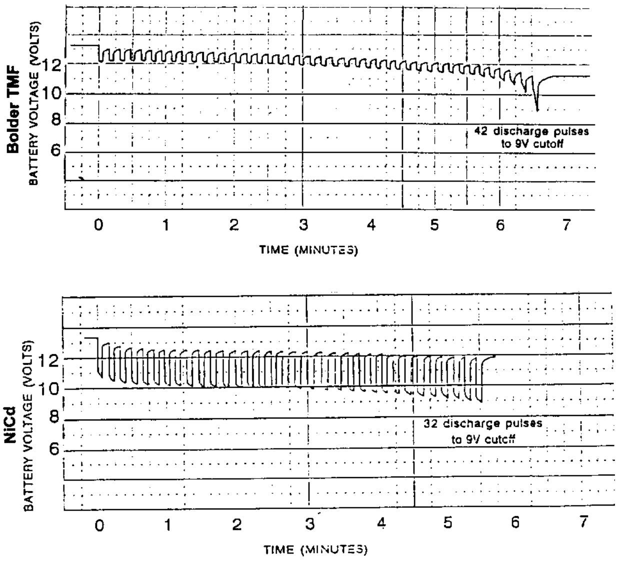

Fig. 8. Pulse-discharge cycling of a Bolder TMF 12 V battery and a commercial Ni/Cd 12 V battery. See text for details.

a 5 s 'on' and 4 s 'off' time duty cycle. The 'on' time is lengthened as the voltage falls off in order to maintain a constant energy output from the battery. As can be seen, the TMF™ battery gave 42 pulses, while maintaining the voltage above 12 V for the first 20 pulses. The Ni/Cd battery gave 32 pulses, in which all 32 were below 11 V. This performance behaviour, coupled with the inherent voltage differential, allows a 'one-for-two' exchange of Bolder cells for Ni/Cd cells in some applications. Very fast recharge also means fewer battery packs for professional construction workers or remote-control car enthusiasts.

For hybrid vehicles, regardless of whether the energy source is a petroleum-based heat engine, a fuel cell or a high-energy-density battery, there is a need for a very high-power-density energy-storage device, both for acceleration and for uptake of regenerative braking. The Bolder battery appears to be a good candidate. It has the potential to provide a better power:energy ratio at a lower cost and with greater safety than other alternatives such as fly-wheels, ultracapacitors and other types of batteries, as shown conceptually in Fig. 9. While the specific energy for the Bolder technology is no better than for other commercial lead/acid products – typically 30–40 Wh kg^{-1} – the specific power is outstanding. Instantaneous peak-power levels in excess of 5000 W kg^{-1} can be achieved easily for a few seconds. Moreover, using the USABC test procedure for sustained power level definition [7], impressive levels are achieved throughout discharge. On this test, the cell delivers power of at least 800 W kg^{-1} for over 70% of its discharge lifetime and it continues to deliver over 400 W kg^{-1} at 90% of its useful duration, as shown in Fig. 10. This is superior performance to that of any other known chemical battery system in the advanced

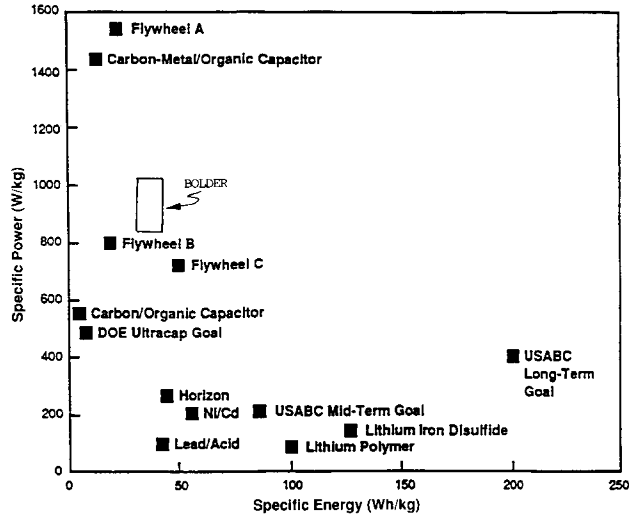

Fig. 9. Power:energy comparisons for various energy-storage technologies that are under investigation for hybrid vehicles.

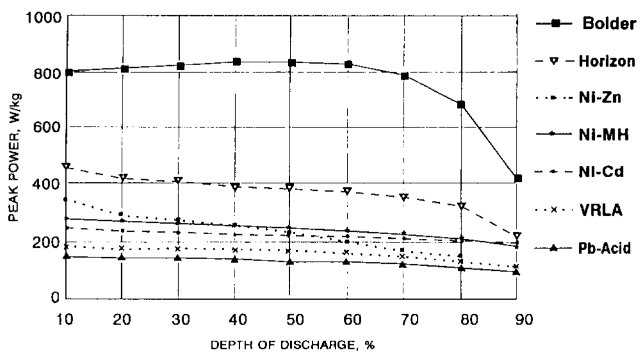

Fig. 10. USABC peak-power testing of various chemical battery technologies.

stages of development, as illustrated by the comparative data in Fig. 10 that are taken from published reports [8,9].

The ability of the Bolder battery to deliver extremely high levels of power and to be rapidly recharged makes it an ideal candidate for applications such as those cited above. These characteristics, coupled with the low cost, profitable recycleability and ease of manufacture associated with lead/acid products, suggest this as an 'enabling' technology whose development will facilitate the creation of new applications and markets based upon the product's ability to provide high levels of power in extremely short times (1 μs or less) and with almost constant voltage regulation.

4. The future

Currently, Bolder Technologies Corporation is producing 1.2 and 1.5 Ah single cells that incorporate its TMF™ technology. It is capable of scale-up to larger cell capacities and, in fact, a 10 Ah, proof-of-concept cell has been fabricated and tested with very positive results. Modelling work is being carried out on sizes up to 50 Ah and a development project is just beginning to take the technology to the 30 Ah range for hybrid and electric vehicles, as well as other applications that require higher-capacity unit cells.

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