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Findings of the rechargeable battery study sponsored by NATIBO (North American technology and industrial base organization)

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Abstract

This paper summarizes and updates the findings of the North American technology and industrial base organization (NATIBO) study entitled "Rechargeable Battery/Systems for Communication/Electronic Application". The mission of the NATIBO organization is to promote a cost effective and healthy technology and industrial base that is responsive to the national and economical security needs of the United States and Canada.

Keywords: Standardization; Military batteries

1. Introduction

For the purpose of this paper, it is assumed that the reader is familiar with the rechargeable battery/charger technologies; therefore this paper will only skim the surface of this material. The main focus will be on the conclusions, recommendations and on the consequences to changing from primary to rechargeable technologies.

2. Objectives

The main objective of this study was to compare the current trends in the commercial rechargeable battery and battery charger markets and relate these to the requirements of the military. It also assessed which battery and battery charging technologies would be required/desired for military communications and electronics (C/E) equipment and to analyze the North American technology and industrial base capability to produce the type and quantities of rechargeable batteries required by the Department of Defense, USA (DoD) and Department of National Defense, Canada (DND).

3. Scope

The rechargeable batteries and battery chargers studied were only those used in the communications and electronics (C/E) industry and similar applications. Battery chemistries addressed were sealed lead–acid, Ni/Cd, Ni/MH, lithium-ion (Li-ion), and lithium polymer. Batteries used for starting, lighting or ignition, and propulsion were not studied. Types of chargers studied included integrated, stand-alone, and multi-port, and their charging methods. The study focused on those representative companies who currently provide, or are expected to provide in the near future, rechargeable batteries and chargers to the DoD/DND.

4. Methodology

The rechargeable battery/charger industrial base study required a clear, concise, and well-defined methodology to survey government, industry, and academia effectively and compile military, commercial, political, marketplace, and academic perspectives. The data collected and analyzed for this study were drawn from previously published reports, conference proceedings, journal articles, Internet home pages, and other on-line sources, as well as from discussions with US and Canadian representatives from industry, government, and academia.

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The study group's goal was to meet with or contact a representative sample of rechargeable battery/charger researchers, rechargeable battery/charger suppliers, end users, proponents and policy makers. Factors taken into consideration in selecting sites to visit or contact included volume of production and business with DoD and DND, battery chemistries produced, chargers manufactured, state of the technology, applications, and new technology development. Site visits were conducted in the US and in Canada.

Data collection guidelines were developed and used to facilitate obtaining data from all points of contact either through telephone interviews and/or site visits.

5. Background

NATIBO completed a sector study assessment of the overall battery industrial base in August 1994. Since then the production base for non-rechargeable batteries unique to the military has eroded due to reduced peacetime demands and high operating and support (O&S) costs. These costs have driven the US Department of Defense (DoD) and Canadian Department of National Defense (DND) to increase significantly the use of rechargeable batteries, during operations other than war.

In Canada, the Canadian Forces have used rechargeable batteries for a number of years as a reliable, cost effective, source of power. The Canadian Forces have also determined that they will increase the use of rechargeable batteries to power their portable communications equipment for many of the same reasons outlined by DoD. At present, the Canadian Forces are using rechargeable Ni/Cd batteries to power their equipment. By contrast, the DoD is deploying the Ni/MH system and pursuing the rechargeable lithium technologies. The Canadian decision is based on concerns regarding the reliability and service life of Ni/MH batteries. In all likelihood, the Canadian Forces will wait to procure rechargeable lithium batteries and associated chargers as these technologies mature, foregoing the use of Ni/MH batteries altogether.

6. A technology overview and comparison of battery systems

In the military, parameters other than cost — such as weight, capacity, and the number of batteries to complete a mission — have an impact on the battery technology selection process. Currently, the baseline to which all rechargeable batteries are compared is the BA-5590/U Li/SO_2 battery. The BA-5590/U battery is used in over 50 different pieces of US Army equipment, including the single channel ground and airborne radio system (SINCGARS) tactical radio. Table 1 compares the parameters of specific rechargeable batteries to the non-rechargeable BA-5590/U.

Table 2 is a comparison showing how the major rechargeable battery technologies compare to the baseline non-rechargeable Li/SO_2 technology. In all cases, the capacity is less and the weight is greater.

However, the cost per cycle of all the rechargeable batteries (in the order of US$ 2 to US$ 3, given that one may not get the total cycle life) is substantially less than the single-use baseline battery cost of approximately US$ 68.00 per unit.

7. Technology overview of charging methods

7.1. Constant current charging

Constant current charging is the simplest method of charging, delivering a single-value low level current to the discharged battery. The current is set at a fixed rate that is usually selected at 10% of the maximum Ah rated capacity of the battery. Constant current charging is best suited for use on lead–acid and Ni/Cd batteries. The type of charger is usually small, lightweight, and relatively inexpensive.

Table 1
Comparison of battery parameters[a]

Chemistry/military designation	Nominal voltage of cell V	Energy (Whbdm^{-3})	Operating temperature range (°C)	Cycle life[b]	Weight as compared to BA-5590/U	Capacity in Ah as compared to BA-5590/U[c]	Disposal
Li/SO_2 BA-5590/U	3.0	415	−55 to +70	1	1.0	1.0 (7.2 Ah)[d]	Hazard
Sealed lead–acid BB-490/U	2.0	90	−20 to +55	250–500	2.04	0.30	Hazard/recycle
Sealed Ni/Cd BB-590/U	1.2	80–105	−30 to +40	300–700	1.8	0.39	Hazard/recycle
Ni/MH BB-390/U	1.2	175	−20 to +40	1000	1.73	0.75	Non hazard
Li-ion BB-XX90/U	2.9	200	−30 to +55	>1000	1.32	0.78	Non hazard
Lithium polymer BB-XX90/U	3.2	350	−20 to +55	Unknown	1.45	0.89	Non hazard

[a] Specific energies, operating temperatures, and cycle lives were taken from: D. Linden (Ed.), Handbook of Batteries, 2nd Edition, McGraw-Hill, New York.

[b] The number of cycles (the discharge and subsequent or preceding charge) under specified conditions, which are available from a rechargeable battery before it fails to meet specified criteria as to performance.

[c] Capacities based on BA-5590/U Li/SO_2.

[d] In series configuration to give nominal 30 V output.

Table 2
Comparison of mission requirements and cost

Chemistry/military designation	Weight in kg (lb.)	Batteries per mission[a]	Mission weight in kg (lb.)	Battery unit price (dollar)[b]	Cost/mission[c,d] (dollar)
Li/SO_2 BA-5590/U	1 (2.2)	1	1 (2.2)	68.00	68.00
Sealed lead–acid BB-490/U	2 (4.5)	4	8 (18.0)	155.00	2.76
Sealed Ni/Cd BB-590/U	1.8 (4.0)	4	7.2 (16.0)	153.00	2.73
Ni/MH BB-390/U	1.7 (3.8)	2	3.4 (7.6)	293.00	2.61
Li-ion BB-XX90/U	1.3 (2.9)	2	2.6 (5.8)	e	e
Lithium polymer/BB-XX90/U	1.4 (3.2)	1	1.4 (3.2)	e	e

[a] Based on a 24 h mission using the SINCGARS.
[b] BB-490/U and BB-590/U prices from Mathews Associates; BB-390/U and BA-5590/U prices from US Army CECOM.
[c] Based on price paid by user and 224 cycles.
[d] Cost of charging equipment and charging not included in this estimate.
[e] Not yet in military inventory.

7.2. Constant potential charging

Constant potential charging allows the charger's maximum current to flow into the battery until its voltage reaches a preset limit. This system allows for higher charging currents, thus returning the battery quicker to a full state of charge. This system works well with batteries that exhibit a voltage rise at the end of charge, such as the lead–acid battery. Constant potential charging is detrimental to Ni/Cd batteries, which exhibit a drop in voltage when the battery goes into overcharge and begins to heat up, causing the voltage to drop. Some other chemistries, especially Li-ion, are not able to absorb additional energy once fully charged and must be removed from the charging source. ‘‘Float charging’’ is not recommended for these latter chemistries.

7.3. Constant current/constant potential charging

Constant current/constant potential charging is a combination of the two methods above. The system is designed to limit the maximum charger current until the battery voltage reaches a set limit. Then, the voltage control takes over; allowing the current to taper to a minimum value as the battery voltage nears full charge. The combination of constant current and constant potential allows for fast charging without the problems of gassing and overheating due to charging at high rates. This method is especially useful for sealed lead–acid batteries. It is particularly detrimental to Ni/Cd batteries that begin to heat up near the end of charge, causing the voltage to drop. This results in an increase in charge current at a time when the battery does not need high currents for charging.

7.4. Pulse charging

Pulse charging applies a series of charge/discharge or charge/rest cycles until the battery is fully charged. The charge current pulse is larger that the normal charging value and may be followed by a rest period rather than a discharge cycle. Using this method, a battery can be fully recharged, with less gassing and heating, over a shorter time period that could be realized by any of the above methods. This method of charging has been used on Ni/Cd batteries to restore capacity lost due to ‘‘memory effect’’.

7.5. Smart charging

Smart charging adjusts the voltage and current supplied to the battery based on the monitoring of critical battery parameters (temperature, cell balancing). Charger operation can be optimized by using a micro-controller to carefully monitor and adjust the charging rate, the time, and, in some cases, the voltage. This optimization is used to increase charging efficiency, reduce charging time, or extend cell life. Use of smart charging is critical to rechargeable lithium chemistries to prevent the activation of the battery's internal safety features, which, if activated, render the battery useless. The charge rates and times are optimized to the specific battery chemistry and internal conditions during charging. This system does require special circuitry. The chargers that utilize this method tend to be larger and more expensive. They usually require high levels of power to support the rapid recharge that the system may select based on the battery's state of charge.

8. Applications for rechargeable batteries and chargers

8.1. Commercial rechargeable batteries

Rechargeable batteries are normally found in one of three generic formats. The oldest format is individual standard-size commercial batteries (such as ‘‘AA’’, ‘‘C’’, and ‘‘D’’-size batteries). These batteries were normally marketed independent of the charger, which itself was a basic version of the multi-port system. Many consumers find it cost effective to buy individual rechargeable batteries and their associated chargers to power common items like flashlights, radios, and electronic toys and games.

The second format is product-specific battery packs. This format is where standard cells are combined to form a battery pack that is removable from the using equipment. These applications normally have a separate, stand-alone, dedicated charger. Examples of this would be cellular phones and pagers.

The third format is those commercial devices where the rechargeable battery and charger are integrated into the actual device. For example, many laptop computers employ this technique, as did some of the older portable power tools. Another example is cordless telephones, which are constantly on charge when placed in their base-station receptacles. This is convenient when one component of the total system is normally connected to household or commercial electrical power outlets.

The commercial market for rechargeable batteries is vast and expanding. It includes portable communications such as cordless telephones, cellular telephones, pagers and two-way radios, portable computers. It also includes portable entertainment such as radios, tape players, CD players, televisions, toys, and games. Portable tools is another, which includes drills, screwdrivers, sanders, saws, personal grooming tools such as shavers and toothbrushes, kitchen tools like mixers, blenders, and carving knives. Another segment is portable lighting, which includes flashlights and lanterns, also portable medical devices including hearing aids, heart products (pacemakers and defibrillators), and a variety of portable scientific and testing devices.

The improvements in rechargeable battery technology are driven by this rapid growth of the portable electronics market. Virtually all portable electronic product developments seek increased functionality (marketing features) at reduced weight. As these electronic devices become more miniaturized, the battery becomes a larger fraction of the overall volume and weight of the item. Therefore, the incentive for future advances in battery technology is to provide greater stored power with reduced volume and weight.

8.2. Rechargeable batteries for defence

DoD and DND have very demanding requirements for rechargeable batteries when compared to those of the commercial market. In addition to mission critical applications, high current requirements and long hours of continuous operation, the military has temperature and environmental (such as vibration and shock) requirements that exceed those of most civilian applications.

The US and Canadian Militaries have many generic C/E applications including

- Communications, navigation, and identification.
- Computers.
- Remote sensors, range finders, and laser target designators.
- Night vision devices.
- Mine detectors.

When selecting a battery chemistry to meet the requirements of either commercial or military applications, certain engineering and logistics factors must be considered. These include

- Cost (the unit price for commercial applications and life-cycle cost for the military applications are the driving influences).
- Weight.
- Safety (especially overheating during recharging).
- Operational requirements.
- Shelf life (including loss of charge over time).
- Operating environment.
- Human factors engineering.
- Disposal.

Future defence challenges include

- Laser flash protection.
- Microclimate conditioning systems.
- Chemical detection.
- Mine detection.
- Medical sensors.
- Helmet mounted displays.
- Mobility sensors.
- Voice communications (individual).
- Combat identification.
- Image transfer systems.
- Individual positioning/navigation systems.
- Thermal weapons sights.
- Forward observer/forward air controller communications.
- Aiming lights.
- Small arms fire control.
- Data network connectivity for situation awareness, command and control, and target handover.

Providing power to all of these systems will place heavy demands upon the battery packs, and innovative solutions will be demanded.

9. Options for facilitating more widespread use of rechargeable battery technologies

9.1. Reduced operating and servicing costs

As the defence budgets of the US and Canada continue to decrease, DoD and DND must look for cost savings in all areas. The US Army has already shown that the use of rechargeable batteries can reduce operating cost for training exercises. The attraction of reducing costs should help increase the future use of rechargeable batteries in all types of military applications and equipment.

9.2. Usage of commercial batteries

By taking advantage of what the commercial sector has done with rechargeable batteries and chargers, DoD and

DND can avoid the expense of R&D for military-unique cells and cell technology. By using the commercial industrial base, the US and Canada can avoid the development of an industrial base for rechargeable batteries that would be unique to the military.

9.3. Increased battery cycle life

As shown in Table 2 (comparison of mission requirements and cost), rechargeable batteries can have enormous cost savings because they can be used and reused over several different missions because of their ability to be recharged.

9.4. Reduction of battery weight

C/E applications of rechargeable batteries will increase in the future as battery weight decreases. The Land Warrior/Soldier Systems programs depend on sources of power that the individual can carry easily. If the weight of the power supplies were less, effort would be better-utilized in carrying additional combat capability.

9.5. Smart technologies

The use smart technologies will enable a more efficient use of rechargeable batteries. Batteries will be charged faster and safer to the optimum level without degrading the battery or shortening its life. The increase in efficiency will lower life cycles cost and improve the effectiveness of the batteries.

9.6. Low power electronics and power management

The use of low power electronics and of power management will increase the mission time supported by batteries thus increasing the attractiveness of rechargeable batteries.

10. Barriers against more widespread use of rechargeable batteries

10.1. Power source logistics

As rechargeable batteries and chargers are introduced into military units, a new logistics tail will develop. Currently, non-rechargeable batteries are consumed — similar to ammunition. Rechargeable batteries will not be treated as consumables, but will require a back-up supply line that allows them to be continuously rotated for charging. Also required will be an area where the batteries can be recharged, a power source for the chargers, manpower for recharging, and transportation.

10.2. Applications unique to the military

The applicability and use of rechargeable batteries in high risk airborne and reconnaissance missions where support is low is both untested and unproven.

10.3. The commercial trend towards small cells

The military will substitute rechargeable batteries for the current non-rechargeable batteries. The use of large cells is more efficient than connecting many more small cells. Besides the complexity of connecting small cells, heat generated by the small cells becomes a problem, which can affect battery life and performance if not managed properly. As commercial products (cell phones, PDAs, etc.) becomes smaller, the need increases for smaller, lighter rechargeable batteries. Commercial producers will respond by facilitating production capabilities for small cells — not large cells. Any niche market that the military creates will cause the costs of these rechargeable batteries to increase.

10.4. High initial cost

As shown in Clause 6, the initial cost of a rechargeable battery is higher than the comparable non-rechargeable battery. However, the total life cycle cost of the rechargeable battery is lower than the non-rechargeable. With current resources scarce, the decision to expend them in anticipation of future savings is difficult.

10.5. Acceptance by the soldier

Some units within the US Army are reluctant to switch to rechargeable batteries due to perceived reduced performance when compared to non-rechargeables. Not only do these units have to deal with a new battery, but also with the charger that accompanies it. The logistics to assure that portable power is available is an additional task that must be performed with no increase in resources.

10.6. Performance at extremes of temperature

The military requirement for C/E equipment to operate at extreme temperature conditions (-40 to $+65^{\circ}$C/150°F) eliminates the use of nearly all currently available rechargeable chemistries.

10.7. Shelf life

Rechargeable batteries may require charging during storage to compensate for their inherent self discharge.

11. Conclusions

11.1. There is a deterioration of the Li/SO_2 industrial base

The use of rechargeable batteries in most operational scenarios short of full combat will have the effect of reducing the consumption of non-rechargeable batteries in peacetime. This reduction could be rather large. The result could further erode an already weak military-unique non-rechargeable battery production base for Li/SO_2 primary batteries.

11.2. Power source logistics are not being thoroughly addressed

There are a number of logistical considerations that need to be thoroughly examined such as movement of batteries, manpower dedicated to charging the batteries and the provision of power to the chargers. In addition, rechargeable batteries require charging during storage to compensate for their inherent self-discharge.

11.3. The commercial trend to smaller cells is against the requirements for military applications

Industry that is making for the commercial and consumer market is moving towards smaller cell sizes in response to the trend for smaller and more energy efficient commercial electronics (i.e. cellular phones and beepers). However, the battery configurations for existing military applications are predetermined. If the military services use these commercially available cell sizes, it will require putting more, smaller, cells into the battery configuration in order to achieve their capacity requirements. This would cause other design issues, such as increased internal heating (or heat management), increased weight and additional inter-cell wiring. There also would be a loss in the total available capacity that could be packaged into the battery.

11.4. Batteries and chargers are not being considered as a single system

In the past, the military procured rechargeable batteries and their chargers separately. This approach was considered feasible due to a relatively limited use of rechargeable batteries. However, as the use of rechargeable batteries increases and where the new technologies are sensitive to a specific charge algorithm, this approach is no longer valid.

11.5. The specific capacities of batteries are approaching their realistic limits

As highlighted in Clause 6, the rechargeable battery technology is beginning to level out in terms of the available capacity from the various chemistries. Although advances will still be made in improving the performance of rechargeable batteries — in the short term, in lithium polymer and in the longer term, in solid state batteries — no "silver bullets" are seen on the horizon. This necessitates the increased emphasis on power management techniques and the use of low power electronics.

11.6. The use of rechargeable batteries reduces the operating and servicing costs for military applications

Rechargeable batteries offer significant reductions in battery-related O&S costs. Even after costs associated with the procurement of chargers and the additional resources required to operate and power the chargers are accounted for; the savings both in procurement dollars and disposal costs have the potential to be significant.

11.7. DoD and DND are increasing the use of rechargeable batteries for combat electronics applications

Faced with increasing costs associated with the use of non-rechargeable batteries and decreasing budgets, DoD and DND accelerated the use of rechargeable batteries in C/E applications. The Canadian Forces have used rechargeable batteries for a number of years as a reliable, cost effective, source of power. Within DoD, the US Army has been aggressively pursuing the use of rechargeable batteries to reduce battery-related O&S costs.

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