Discussion Preparation for:
Power, Management and Monitoring

TECHNOLOGY AREA

Power, Monitoring and Management (PM&M) is one area that consumers, clinicians, researchers and manufacturers identified as requiring significant technological improvements. Power Monitoring means the ability to routinely and accurately determine the amount of power expended and remaining within a wheelchair battery. Power Management means the ability to correctly, safely, and efficiently discharge and recharge a wheelchair battery while maximizing cycle life.

THE NEED

Power wheelchairs are used predominantly by people with both lower and upper extremity impairments, such as those resulting from cerebral palsy, high-level spinal cord injury, or muscular dystrophy. There are over 93,000 power wheelchair users in the U.S. alone (Team Rehab, 1997). The "standard power wheelchair" accounted for $166 million in Medicare expenditures in 1997. We include power scooters in the discussion due to the overlap in power monitoring and management issues. Scooters are used by people of all ages but are particularly popular among older people (64,000 users) who acquire mobility impairments as they age.

The "power" in power wheelchairs is considered to be a limiting factor in performance. Some stakeholders desire an increase in the device's range of travel (i.e., charge capacity). Others may be satisfied with range but desire either reductions in size/weight of the power source, or better procedures for charging and monitoring battery power. Power management and monitoring must include attention to three primary components: (1) the battery, (2) the charger, and (3) the monitor or gauge of remaining battery capacity or range. Improvements are sought in each of these areas; however, this project recognizes the there are great difficulties inherent in the transfer of battery technology.

A common issue across all technology areas is that of cost and reimbursement pressures. While wheelchairs enjoy wide reimbursement coverage, problems remain for power wheelchairs. Payments remain low, barely or perhaps not covering the cost of more specialized, service-intensive wheelchairs. Current reimbursement policies have four key features to be aware of:

- Medically necessary (i.e., not a convenience item)
- Emphasis on cost rather then product attributes
- Service costs not well recognized
- Oriented toward short-term needs rather than long-term capabilities.

All opportunities for new technology development and insertion into this market must take these issues into consideration, recognizing that cost sensitivity is real and that payers are reluctant to trade-off increased up-front costs for possible long term benefits.

Many industries and federally-sponsored programs use and rely on battery power for equipment and subsystems in products for the consumer market, information technology, defense and aerospace. It seems likely that either appropriate technologies are already available to improve the monitoring and management functions important to wheelchair and scooter users, or that these other stakeholders would be willing to collaborate on developing improved power management and monitoring to serve their own needs as well – the dual-use rationale for technology transfer.

BASIS FOR DISCUSSION

Consumers would benefit from components that could:

- accurately track and calculate charge/recharge requirements,
- determine the actual state-of-charge at any time,
- calculate remaining time/distance available based on prior use,
- track the battery's performance degradation over time.

Given the mobility and dexterity limitations of many users of power wheelchairs and scooters, the power monitoring and management capabilities should be integrated or paired with the controller system, which is typically positioned for optimum access by the consumer.

The goal of the Forum is to select a high-priority problem and develop a problem statement that specifies requirements for a commercially viable solution. The following points are provided to help Forum attendees prepare their opinions and input on these important topics.

BATTERIES

Statement of the Problem

Stakeholders desire improvements in three important features of batteries: 1) energy density, 2) cost, and 3) cycle life. Energy density determines how much power can be stored in a given size and weight battery, with range (capacity) resulting from the battery's tradeoff between size and weight. Cost is determined by a combination of the raw materials, manufacturing requirements, and economies of scale. Cycle life is the number of charge/discharge cycles the battery can withstand before its performance degrades to a point of inoperability.

Current Solutions

Power wheelchairs presently are powered by deep discharge lead-acid (mostly gel-cell) batteries, with 24 volts the most common configuration. Typical battery life is 9-14 months or 365 cycles annually. Replacement may occur more often when 3rd party reimbursement permits it. Typical cost is $200 per battery. Lead-acid batteries are:

- Heavy (9-14 Kgs) - making replacement difficult for the user and limiting portability of spare batteries.
- Large - impacting wheelchair design due to the space required under the seat.
- Limited in current output - resulting in poorer performance in high torque situations.

A 1996 national survey of power wheelchair users indicated that batteries and tires were among the items most frequently needing repair or replacement (Lane, Usiak & Moffat, 1996).

Much battery research has gone into nickel metal hydride (NIMH) and lithium (Li) technologies. Alternative energy storage methods, such as flywheel energy storage, have been considered but remain merely an R&D interest at present. Battery technologies presently being developed for electric vehicles, currently being developed by the USABC (United States Advanced Battery Consortium), have a great potential for applications in electrically powered wheelchairs. is actively pursuing this.

Virtually every commercial wheelchair uses lead-acid batteries as they have been the most reliable, cost effective and practical battery on the market for decades. Newer battery technologies include NIMH which is a maintenance free battery with energy densities 2-3 times the lead-acid battery and Zn/Ni (Nickel –Zinc) batteries which have the highest energy density and lowest cost of any of the Ni-based battery. Li/FeS_2 provides power densities 6-7 times that of lead acid & are maintenance free. Lithium Ion batteries have high energy densities and are used in notebook computers. Lithium metal polymer technologies offer high energy density and extended run time. (Ni-Cd) Nickel Cadmium batteries have been used with wheelchairs primarily because of their long cycle life under high depths of discharge, but they cost about six times that of deep discharge lead-acid batteries (Bayles, et.al., 1994).

Issues to Consider

What is the relative importance of capacity (range), recharge time, cycle life, size, weight, and cost? How do these trade-offs vary among different types of wheeled mobility products and different populations of users?

- In what ways could wheelchair designs be improved by significant reductions in either battery size or weight or by alternative physical configurations of batteries?
- What are the prospects for transferring battery technology from other industry sectors? Would the industry consider a consortium approach to wheelchair battery development?
- What factors would payers evaluate in considering trade-offs, for example, a battery which is more expensive but offers a longer cycle life?
- Is there flexibility in reimbursement for better but more expensive battery technologies?

POWER MONITORS

Statement of the Problem

The state of charge of the battery in an electric wheelchair [or scooter] is of vital importance to the user. Despite the long-standing presence of multiple power monitoring gauges and battery charging systems, the existing systems are recognized as inadequate by wheelchair manufacturers, researchers, clinicians, consumers and care providers. A gauge that routinely and accurately tracks power discharge and remaining power, and then translates this into a measure of remaining capacity, would substantially improve the consumer's independence (Thacker, J.G., 1988). The Power monitoring should also track the state of battery's integrity so that the battery can be replaced before a critical failure.

Current Solutions

Current power indicators for lead acid batteries are based on simple voltmeters. Given the power discharge curve for lead acid batteries, voltmeter monitors are at best inaccurate, and at worst misleading, indicators of remaining battery capacity. These are commonly used because they are inexpensive and compact, and at least provide a general indicator of power.

The voltage levels being monitored can vary greatly with changes in the load placed on the battery, even thought the battery's actual state-of-charge is not changing greatly. When a battery is placed under a heavy load (e.g., while the wheelchair/scooter is being driven up an incline, through deep pile carpeting, or loose soil/gravel), the terminal voltage drops substantially until the load is removed. While under a heavy load and for some time afterward, the voltage monitor, will indicate a lower state-of-charge than actually exists. As a result, the voltage monitors produce variations in state-of-charge readings, due to the wide range of loads placed on the battery during typical daily use. Further, there is no means to translate remaining power into estimates of remaining range, so the user is forced to estimate the remaining range through trial and error (Thacker, J.G., 1988).

There may be more accurate options available. For example, the computer industry uses an SM Bus for monitoring the battery's status. Both the power monitoring and charging systems are paired with the battery technology.

The power monitor tracks the flow of current in to and out from the battery. The battery's full charge level is also tracked, so that the power monitor can assess battery degradation over time. This monitoring/charging system has the additional feature of being programmable, so that key parameters can be entered and the charging system can be accurately matched to battery performance specifications.

Regardless of the type of power monitor used, integrating the power monitoring device within the controller would reduce the number of components the user has to monitor and manage. It will improve reliability, make it more accessible, improve component sourcing for manufacturers, and reduce size.

Issues to Consider

- How would one specify the requirements for a technology that can accurately monitor the remaining power and more accurately measure the remaining range for lead-acid batteries?

- What diagnostic or self-testing capabilities can and/or should be incorporated for power monitoring of lead-acid batteries? How can microprocessors be used more effectively for this function?

- How is power and range information best conveyed to the user?

- How can we specify the technical requirements for power monitoring technology that is most appropriate for power wheelchairs and scooters?

- What capabilities would permit power monitoring devices to be compatible with changes in battery technologies?

- What are the barriers to integrating power monitoring into controllers?

CHARGING

Statement of the Problem

Improper charging of a battery reduces battery life, while more frequent replacements increase the total cost to the user or third-party payer. There is a need for a charger with built-in intelligence to determine battery status and optimum charge schedule. This would reduce a substantial problem identified by power wheelchair manufacturers and end users. Also, having the charger permanently on-board the wheelchair or scooter would eliminate many of the problems reported by users, provided care is being taken to avoid accidental shocks and other safety hazards. Most chargers are too large to incorporate into the chair/scooter, and the available smaller chargers are reportedly less reliable. Consumers prefer on-board charging systems but major providers such as the Department of Veterans Affairs do not support on board charging systems. User safety and provider liability are the concerns regarding on-board chargers, although manufacturers who provide on-board charger report negligible to non-existent hazard problems.

Current Solutions

When considering performance in general, if the charger does not recharge the battery completely, the recharge capability will degrade over time. That is, the number of remaining charge/discharge cycles remaining before failure will diminish. Failure is typically defined as an inability to maintain voltage, capacity and safety margins under the expected set of usage conditions. Five hundred (500) cycles is a realistic figure for battery life.

Research has determined that current chargers are inefficient and that these inefficiencies may damage the battery being charged. There is a disparity in charger performance, with some simply undercharging during an eight hour cycle, while others may actually damage the battery (Seeger, 1989). Research has also established a high degree of consumer dissatisfaction with existing battery chargers (Bauer, et al, 1998).

There are no onboard battery charging systems for powered wheelchairs, although they do exist for scooters. These onboard chargers have to be UL approved.

Previous discharge history is important when the battery is allowed to stand idle for long periods of time, or discharged at rates and capacities considerably different from normal use. A wheelchair battery does not usually become over-discharged since protective circuits in the wheelchair controller prevent this action. However, if the battery is left discharged after use it will spontaneously continue to discharge, especially at high temperature. In a week or so the battery may become so over-discharged that it will no longer be rechargeable (Kauzlarich, et.al, 1994).

Some batteries exhibit a memory effect that causes them to lose capacity for several subsequent discharge/charge cycles, if partially discharged on previous occasions. In these instances, several complete charge/discharge cycles are needed to restore the capacity of the battery. Nickel-zinc and nickel-cadmium batteries have a strong memory effect, whereas the leading lead-acid batteries show little memory effect.

Conversely, to maximize the life of deep discharge lead-acid batteries, the battery should not be over-charged or over-discharged. If the deep discharge battery is not fully discharged during use, its charge/discharge life will be extended. For example, the battery's life if doubled if the depth of discharge is reduced from 100% to 60%. Even though most batteries provide at least 90% of their full charged capacity after only 8 hours of charging, it is recommended that they always be charged fully by a charger that shuts off automatically when the battery is charged. Once a battery is fully charged, continued charging, even with a low current, can diminish service life(Thacker, 1994).

The previously cited problems with power monitoring make power management more difficult, because the consumer is almost never sure of the battery's state-of-charge. Even with an accurate state-of-charge measure, the consumer may lack sufficient information on the battery's capacity (which changes over time and through use), to choose the correct recharging point for optimum battery function and life(Panel Discussions,

1988) . Further, if the available charger does not recharge the battery to the correct level, the battery's service life will be degraded.

Issues to Consider

- What diagnostic or self-testing capabilities can and/or should be incorporated into battery chargers?
- What battery charging functions should be the responsibility of the technology and what functions should be the responsibility of the user?
- If intelligent battery chargers could extend battery life, how much of an improvement would be necessary to justify third party reimbursement for an intelligent charger?
- Is it desirable to integrate battery monitoring and battery charging capabilities? If so, how?
- Do on-board chargers make sense from both the user and manufacturer perspectives? The user *and* the manufacturer need to be protected (the first from shock and the second from liability).
- Do smaller battery chargers and/or battery-chargers matched to batteries, represent significant needs in the powered wheelchair scooter market?

REFERENCE LIST

Bauer, S.M., Lane, J.P., Stone, V.I. & Unnikrishnan, N. (1998). "The voice of the customer - part 2: Benchmarking battery chargers against the consumer's ideal product." Assistive Technology, 10, 51-60.

Bayles, G.A. (1994). "New power sources technologies for electric wheelchairs." RERC on Wheelchair Technology, Technical report #2, September, 1-16.

Bayles, G.A., Brienza, D.M, Palmer, K.M., & Ulerich, P.L. (1994). New Technology for Wheelchair Batteries. Proceedings of the RESNA'94 Annual Conference, Arlington, VA: RESNA Press, pp. 347-349.

Brubaker, C. (1988). "A survey of powered wheelchair problems and features." Wheelchair IV, Report of a conference on the state-of-the-art of powered Wheelchair Mobility. December 7-9, pp. 68-75.

Garrett, R.E., Hartridge, M., & Seeger, B. (1988). "Battery charger comparative evaluation." Veterans Administration Rehabilitation R&D progress reports, pp. 132-133.

Hartridge, M., & Seeger, B. (1989). "Costs and benefits associated with limiting deep discharge of wheelchair batteries." Veterans Administration Rehabilitation R&D progress reports, p. 129.

Lane, J.P., Usiak, D. & Moffat J.A. (1996). "Consumer criteria for assistive devices: operationalizing generic criteria for specific ABLEDATA categories." Proceedings of the RESNA '96 Annual Conference, Arlington, VA: RESNA Press, pp. 146-148.

Kauzlarich, J.J., & Thacker, J.G. (1994). "Wheelchair battery overdischarge and overcharge problems." Proceedings of the RESNA'94 Annual Conference. Arlington, VA: RESNA Press, pp. 344-346.

Panel Discussions (1988). Wheelchair IV, Report of a conference on the state-of-the-art of Powered Wheelchair Mobility. December 7-9, pp.114-135.

Thacker, J.G. (1988). "Batteries, wheels, tires, frames and drive trains." Wheelchair IV, Report of a conference on the state-of-the-art of Powered Wheelchair Mobility. December 7-9, pp. 45-54.

Thacker, J.G., Sprigle, S.H., & Morris, B.O. (1994). "Understanding the technology when selecting the wheelchairs." RESNA PRESS, 1994. pp. 58-75.