

**Discussion Preparation for:
Motors, Drive trains and External Drive Motor Systems**

TECHNOLOGY AREA

Motors, drive trains and external drive motor systems were identified by consumers, clinicians, researchers and manufacturers as having significant technical problems whose solutions could meet significant consumer needs and represent significant business opportunities within the wheelchair industry.

THE NEED

Power wheelchairs are used predominantly by people with both lower and upper extremity impairment 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. The “standard power wheelchair” accounted for \$166 million in Medicare expenditures in 1997. For the purposes of this program, scooters have also been included for consideration due to the many common technological needs. Scooters are most commonly used by people with the ability to walk short distances but who require assistance when shopping or interacting within the community -- wishing to remain active despite growing physical limitations. It is estimated that 64,000 scooters are currently in use in the United States.

The propulsion system of powered wheelchairs typically consists of a pair of motors, one for each drive wheel, and a drive train consisting of gears, belts and other mechanical elements that couples the motor’s shaft to the drive wheel shaft.

Most wheelchairs utilize two permanent magnet DC motors (PM motors), with two 12 volt batteries providing a 24 volt supply. PM motors have a linear torque-speed profile making them easy to control. A DC-DC converter drives each motor with a high frequency, square wave, pulse train that rapidly turns each motor on and off. Speed and torque generated by each motor is controlled by modulating the pulse width. Solid state relays are generally used to switch supply voltage polarity to change the running direction of PM motors.

Scooters have both three- and four-wheel configurations using direct or belt/chain drive systems. They use either one or two motors and are powered by a 12 or 24 Volt power supply. Most scooters are rear wheel drive for increased traction while the front wheel drive systems are

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lighter and as a result may have difficulty maintaining traction on inclines or rough terrain.

Free running under no load, PM motors can attain an efficiency of about 70%. Under loads typical for power wheelchairs, these motors are about 45% efficient. A drop in motor efficiency increases the current drawn from the battery and decreases battery life and efficiency.

The wheelchair's control module converts positional information from the joystick into power signals to the motors. Control modules are microprocessor based and have many adjustable parameters. Many control modules utilize feedback to sense whether the motor is responding properly to the joystick position. Such control systems adjust motor torque so as to maintain near constant speed while the load varies in response to changes in the terrain (incline, bumps) and surface (linoleum, carpeting, concrete, grass, sand).

Adjustable controller parameters include high/low speed range selection, maximum high speed, maximum low speed, maximum acceleration and turning speed, tremor dampening (low pass averaging of joystick position), maximum power delivered under high torque, and energy saver (reduces speed and increases range when the battery is low).

The drive train is a mechanical system that transfers rotational power from the motor to the drive wheels. There are two types of drive trains 1) direct transfer and 2) indirect transfer.

For a direct drive transfer system, the motor shaft is directly coupled to the drive wheel shaft (through gears for instance). Direct drive transfer requires a low speed, high torque motor and is mechanically efficient. However, the gears in the direct drive system are prone to wear and/or breakage and make them expensive to repair.

For an indirect drive transfer system, the motor is coupled to the drive wheel shaft through a system of gear train and flexible machine element (belts or chains). The gear train and belt typically serve to reduce the motor speed while proportionately increasing motor torque. They also act as a "shock absorber" when the drive wheels are stuck or under heavy load. Excessive stress on the system can cause an increase in noise and misalignment of the drive system. However, realignment is easily done

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and the cost of maintaining the system is relatively low if adjustments are made on a regular basis.

The size and weight of the gear train is proportional to its speed reduction ratio. There are two types of gear trains 1) involute geared and 2) worm geared.

Involute gear drives have a power transfer efficiency of 90-95% but are larger, heavier and noisier than worm gear drives. Involute gear drives are used on fixed frame power wheelchairs with both motors perpendicular to the orientation of the drive wheels.

Worm gear drives are relatively smaller, lighter and quieter than involute gear drives and approximately 70-80% efficient. With worm gear drives both motors are oriented parallel to the drive wheels. Worm gear drives are used on folding frame power wheelchairs. In addition, more space is generally available for respirators, power seating, and storage.

The chatter and swiping of gears, and friction associated with motor and idler bearings are potential sources of vibration and noise.

Wear and failure of components in the typical motor and drive system is a significant problem. Maintenance costs for a power wheelchair are estimated in excess of \$1000 over a five-year period. Motor and drive system repairs often cannot be completed by technicians “in the field” and must be returned to the manufacturer for service. Many users elect to operate their motor until failure and purchase a replacement motor as opposed to being both inconvenienced and paying high maintenance costs.

The torque delivered by motors and drive trains, places constraints on the environments (terrain and surfaces) that a power wheelchair user can access, work or recreate in. The speed and efficiency of motors and drive trains, constrains the travel distance and time between battery recharge.

The size and configuration of the battery, motors and drive trains constrains the physical dimensions of the wheelchair’s power base and impacts a user’s ability to access home, work, recreational and educational environments.

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Seat height impacts a users access to desks and tables (for instance). Vans generally require extensive modification to accommodate the seated height of a power wheelchair user.

BASIS FOR DISCUSSION

The goal of the Forum is to select a high-priority problem and begin to 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.

MOTORS

Statement of the Problem

Many new innovations in motor technology are occurring for power wheelchairs, electric vehicles, electric bikes and scooters. Many of these motor technologies are more efficient over a wider range of torque and speeds than PM motors which are the dominant motor technology for the power wheelchair industry. New motor technologies have not fully penetrated the power wheelchair market because of factors such as cost, size, weight, and voltage supply requirements. Further innovations are necessary to remove these market and technical barriers

Current Solutions

Most power wheelchairs and scooters currently utilize PM motors with iron magnets, brushes and indirect drive trains. Recent innovations within the power wheelchair and scooter industry includes the use of rare earth magnets; and brushless, gearless, direct drive motors.

Rare earth magnets support much higher magnetic fields than iron magnets. Motors utilizing rare-earth magnets are smaller and lighter than analogous motors with iron magnets. Alternatively, motors utilizing rare-earth magnets are more powerful than motors with iron magnets of a similar size. Brushless motors are more efficient than brush motors (brushes introduce electrical power loss). Brushes are also subject to wear and require regular inspection and replacement.

Gearing and belts in the indirect drive train are a source of mechanical power loss. Highly efficient, gearless, direct drive motors have recently appeared in the power wheelchair market. These motors can be mounted

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in close to the drive wheels and allow good access to the under seat compartment. However, these motors tend to be relatively large and expensive.

It is impossible to discuss even a fraction of the motor innovations which might have application to the power wheelchair industry. However, the following list includes some of the motor technologies that have been suggested.

- A brushless, gearless motor, entirely contained within the power wheelchair's drive wheel has recently been introduced by a European company.
- Pancake stepping motors efficiently generate high torque, even at high speeds. These motors are durable and reliable. "These motors are designed primarily for applications requiring accurate positioning, high torque and very thin, low profile packaging."
- Disc-armature DC motors have high power to weight ratio and efficiency. They are "ideal for battery traction applications where energy efficiency across the full speed range is of primary importance."
- Alternating current, three phase, squirrel cage induction motors (SCIM) are inexpensive, efficient, highly reliable and have a torque speed characteristic very adequate for vehicle propulsion. Commercially available induction motors typically require a 120 V or 240 V power supply. For this reason, these motors have not been considered suitable for power wheelchairs.

Issues to Consider

- What technical barriers prevent innovative motor technologies from penetrating the power wheelchair and scooter markets?
- What system requirements (battery, controller, performance, ...) of these innovative motor technologies represent significant technological barriers?
- What market barriers prevent innovative motor technologies from penetrating the power wheelchair and scooter markets?

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- What motor technologies exist in parallel industries (for example electric vehicles) which might be successfully transferred to the powered wheelchair industry, perhaps providing economies of scale?
- Which user populations would most benefit from improved motor technologies? In what ways would they benefit?

TRANSMISSIONS

Statement of the Problem

Innovative motor technology may eventually displace PM motors in power wheelchairs and scooters. However, PM motor technology is reliable, inexpensive and already incorporated into most power wheelchairs. A PM motor with an indirect transfer drive is inefficient in environments requiring significant low speed, high torque operation. Incorporating a transmission mechanism into the drive train would allow the PM motor to run efficiently for all speeds and torques and extend the serviceable lifetime of PM motor technology within the wheelchair and scooter industries.

Current Solutions

Patents have been granted for power wheelchairs which utilize transmissions in their drive trains. With the exception of one top-of-the-line power wheelchair which utilizes a transmission these power wheelchairs have generally not been successful in the marketplace.

Industry and technical experts suggested that the need for transmissions is quite great. These experts felt that transmissions have not succeeded primarily because of concerns for complexity, reliability, maintenance and cost.

Issues to Consider

- What technical barriers prevent transmissions from being designed and integrated into drive trains?
- How would the incorporation of transmissions into drive trains impact speed, torque and steering control?

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- What system requirements (configuration, fixed or folding frame, ...) are likely to impact transmission design?
- Is power efficiency loss through the transmission likely to be a significant problem?
- What business opportunities could be realized if a drive train incorporating a transmission was successfully designed?
- Which user populations would most benefit if a drive train incorporating a transmission was successfully designed? In what ways would they benefit?
- What transmission technologies exist in parallel industries which might be successfully transferred to the powered wheelchair industry, perhaps providing economies of scale?

EXTERNAL DRIVE MOTOR SYSTEMS

Statement of the Problem

Many consumers purchase manual wheelchairs but find over time that their physical abilities have decreased to a level where they cannot comfortably self-power the wheelchair. Shoulder and arm related disorders are often caused by the use of self-propelled manual wheelchairs and may add to the overall discomfort of self-ambulation. Motors and drive systems for retrofitting manual wheelchairs are currently manufactured and are the topic of many patent applications and successful USPTO filings. Product literature and patent information refer to these as “power assist” or “power conversion” systems.

Current Solutions

External motor sources are being applied to manual wheelchairs in an effort to reduce or relieve stress on the user during periods of physical fatigue, rough terrain or steep inclines. These systems can be applied or disengaged as required by the user. Removal of the system allows the user to fold the manual wheelchair with little or no additional inconvenience than folding their regular chair. The more common configuration uses dual motors that apply direct roller pressure to the rear drive wheels while other systems allow a combination of user applied

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propulsion that is monitored by the feedback circuitry of the control system. As the control system recognizes a reduction in velocity or acceleration it will augment power as required.

A few applications in front tiller designs have been attempted in the marketplace. Manufactures of this design use a front section similar to the front of a front-wheel drive scooter that attach to the cross bars on a manual wheelchair frame. This tiller system applies the power and acts as the steering mechanism, similar to how a scooter user would drive. These units provide control over speed, turns, and forward or reverse direction.

Issues to Consider

- What are the implications of external drive motor systems from the perspective of the user, reimbursement and safety?
- What technologies are required in the wheelchair design to accept external drive motor systems?
- What are the power requirements of external drive motor systems and what should be considered acceptable ranges for travel under normal circumstances?
- How does the end user know the range of the external drive motor system?
- What steering and braking issues are important in the use of these systems?
- What external drive technologies exist in parallel industries which might be successfully transferred to the wheelchair industry, perhaps providing economies of scale?

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