Task: PM-1 Improved Electric and Electromechanical Systems

Approach and Background

The research approach taken was to address each of the major electromechanical components of the powered wheelchair independently within Tasks PM-1-3. Task PM-4 was intended to integrate the component results into a complete 'idealized' system. Task PM-1 investigates each of the major drive system components (batteries, controller, motors, and power train) as interrelated sub-tasks.

The four sub-tasks of PM-1 are as follows:

PM-1a Electromechanical System Simulation

PM-1b New Technology for Wheelchair Batteries

PM-1c Improved Power Controllers

PM-1d Improved Wheelchair Motor Drives

The initial two years of the Task PM-1 involved a major subcontract with Westinghouse Corporation. Unfortunately, Westinghouse has undergone significant downsizing and restructuring which has lead to a reduction in resources (staff and laboratories) that were initially available to this task. Progress was impeded by this unforeseeable event as new resources had to be identified and new team members brought up to speed during Year III. By the end of Year III, most collaborative work with Westinghouse had been terminated and other resources identified.

PM-1a Computer Simulation of Electromechanical Systems

Investigators: Douglas Hobson, Dave Brienza, Fazal Mahmood, Jonathan Evans

Rationale

Designers of powered wheelchairs have few tools to assist in the design and development of new powered wheelchairs. This task focuses on the development of a computer simulation tool that can aid designers during the decision-making process regarding the selection of various electromechanical components. The primary strategy is to optimize the design towards the lowest energy consumption. Other variables, such as tipping stability, can also be optimized.

The initial thrust of this task was to model the components of the wheelchair using a proprietary simulation tool (HEAVY) developed by Westinghouse, Inc. When it became evident that the Westinghouse tool was not appropriate for wheelchair simulation and considerable new code would be required, the task was scaled back to focus on a more limited design tool for industry. This direction was taken at the advice of our Advisory Board at its May 1995 meeting.

Goals

To develop a computer-based design tool to facilitate the design of powered wheelchairs for use by wheelchair designers.

Methods Summary

A computer program called HEAVY, originally developed by Westinghouse Inc. when it was involved in battery powered car research, was used as the conceptual model for the simulation program. Many algorithms had to be modified and others added to make the model applicable to wheelchairs. The original program was Fortran based therefore not readily useable by desktop computers. Prior work done at the University of Virginia-RERC on rolling resistance, wind drag and power consumption was used to make the model more applicable to wheelchairs. Comments were solicited from industry designers regarding the desirable outcomes of the model. Once the simulation model was completed, validation by actual wheelchair testing using a prescribed test course was done to check the accuracy of the simulation model. Refinements to the simulation tool was done over time by continued validation testing using different types of wheelchairs.

Outcomes Summary

Conversion to C++ code for the simulation program was completed. The simulation program now includes program code to carry out the simulations as illustrated in the following flow diagram. First stage validation of the simulation was completed. This was done using an on-board data measurement/collection system while driving two production wheelchairs through a prescribed test course. Energy consumption was measured and compared to the simulation results.

In order to verify the accuracy of the energy consumption model, two powered chairs were monitored while they completed the test track outlined in the ISO standards (ISO 7176/6) for determining the energy consumption and range of powered wheelchairs. Our test course covered 200 feet with the dimensions of the rectangular track measuring 50 feet on each side. Throughout the test, the voltage and current were recorded using a lap top computer, which acquired readings 200 times per second. The results of the validation were then used to compare the results obtained when running an identical course in the computer simulation model.

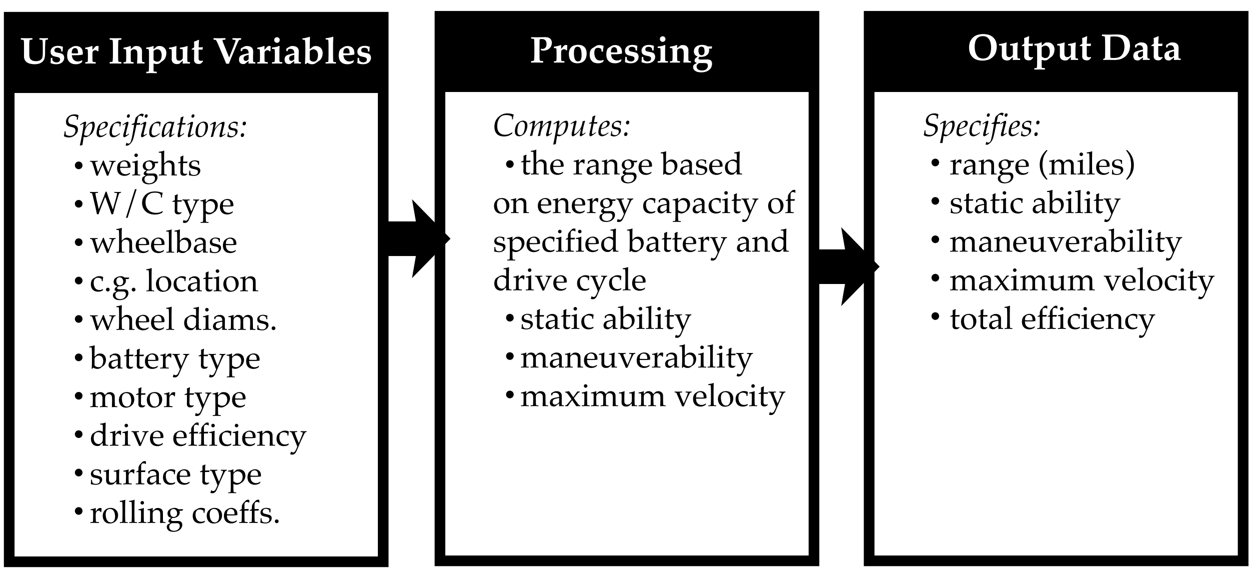

Figure 1 - Flow diagram of simulation process

Since we were unable to obtain the specific motor and battery characteristics for the wheelchairs that were tested, the program used data obtained for motors and batteries with similar characteristics. However, due to the power capacity of the Invacare chair tested, the characteristics were thought to be sufficiently different to effect the results of the simulation program. Therefore, only the results from the Quickie P-190 are were used.

For the Quickie P-190, the measured average speed over the ISO test track was 5.67 ft/ second. The distance traveled was 2000 ft. and the energy consumed was 22.7 watt-hours. By using the ISO guidelines for determining the range of the chair, the range for the P-190 was determined to be 6.67 miles.

For the simulation, the motor data that was used was the Fracmo M453-W30 24-volt DC motor. The battery data was based on the MK 22NF Gel Battery. Using the speed of 5.67 ft/sec. as input data, the program then calculated the drag, the gear-box losses and the air drag to determine the torque required to overcome these losses at the specified motor RPM. The drag losses calculated for P-190 was 35.5 pounds. The wheel diameter is 12.5 inches; therefore, the torque required to overcome these losses is 221.9 in./ lb. Use the look-up tables for the motor characteristics, the available energy of the battery is monitored at each 1-second interval in order to determine the range. From the simulation, the energy used while driving through the virtual ISO test course was 52.86 watt-hours, yielding a total range of 3.86 miles.

The results of the simulation program vs. the validation test show that the computer model computes a range 42% less than the actual measured results. This difference makes the use of the simulation program impractical at its present stage. More work is required to determine the source of error.

It seems that the method used for determining the drag may be incorrect. From studying how the air, motor, and rolling drag are calculated, it appears that the rolling resistance equations yield a larger value than expected (32 lbs.). Accurate battery and motor characteristics are also necessary for precise comparative validation. Also, the effects of caster drag, even on a firm rectangular test course, are not adequately addressed by the simulation model. If these deficiencies can be corrected, it appears that the computer model can be a useful tool in studying the effects that different batteries, motors, mass and frame and wheel configurations have on the range and energy efficiency of powered wheelchairs.

Recommended Future Research and Development

The C^{++} code for the simulation program functions as intended. Additional experimental work must now be done to refine the algorithms in order to reduce the disparity between actual and simulated values. Initial C++ code work was also done on the modeling for static stability. However, now that the newly revised versions of the ISO standards for static (Part 1) and dynamic stability (Part 2) tests have been completed, these simulations could be added to the battery of tests. All information on the above algorithms, program code and energy consumption testing will be maintained on file, at least until January 2003. This information can be made available to any persons seriously contemplating additional development of this simulation tool.

Publications

Alva, P and Hobson, DA, Computer simulation of powered wheelchair electro-mechanical systems, *Proceedings of the RESNA '96 Annual Conference*, Salt Lake City, UT, June 1996

Hobson DA (in preparation)

PM-1B Power Wheelchair Batteries

Investigators: David Brienza, Douglas Hobson, Mostafa Khondukar

Collaborators: Rick Blanyer, Steve Addington (Electrosource, Inc.)

Rationale

The key component in any electrically powered vehicle is the battery—the heaviest, most expensive, and least reliable system component. The need for improved battery technology is clear. Current technologies used and the configurations made available are far less than optimal for wheelchair applications. For example, the basic configuration of lead-acid batteries [Bode, 1977] limits frame design, space for respirators, etc. Virtually every commercial electric vehicle, including wheelchairs, uses a lead-acid battery. For many years, lead-acid has been the most reliable, cost-effective, and practical battery available. It exists in its present form due to the billions of dollars worth of research and development aimed at improving both the battery and the mass production process. These efforts, which were fueled and funded almost entirely by the automobile industry, have led to the optimization of a lead-acid battery with respect to economics and the task of starting a car engine. For application in wheelchairs [Kauzlarich, 1990; Petersen, 1986; Lavanchy, 1992], the lead-acid battery is much less than ideal. It is heavier, more costly, and less reliable than desired, which is not a surprising situation considering the fact that the lead-acid battery was not originally engineered and developed for motive power applications.

Project Goals

Our objectives for this task were:

- Review current and developing battery technology and evaluate its efficacy for use in powered wheelchair systems,
- Identify one or more candidate battery technologies, acquire prototypes and evaluate performance relative to wheelchair applications, and
- Disseminate findings and facilitate technology transfer to wheelchair manufacturers.

Methods and Outcomes Summary

A comprehensive review of emerging battery technology was completed and published as an RERC Technical Report No. 2 (Bayles, 1995) and presented at a national RESNA Conference (Bayles et al., 1994). As a result of that effort, one candidate battery technology was selected to evaluate for possible application in powered wheelchairs. That technology—the Horizon® battery—is an advanced lead-acid technology developed by Electrosource, Inc. of Austin, Texas. The Horizon battery is shown along side a standard 22NF lead-acid battery in Fig. 2. Although other technologies were considered, the Horizon® was selected as the best battery available for evaluation. The potential advantages are improved energy density, improved specific energy and a low profile design. A test plan including bench testing and dynamometer testing was developed. The load cycle used for testing is a variable discharge cycle and is intended to be representative of typical indoor and outdoor wheelchair driving. Bench testing has been completed. Compared to commercially available 22NF gel electrolyte, lead-acid batteries, the Horizon® battery demonstrated a 74% increase in specific energy (40.6 Wh/kg vs. 23.3 Wh/kg).

A meeting was organized, including technical and marketing staff from Electrosource, representatives from three major wheelchair manufacturers, a representative from one scooter manufacturer, and the RERC staff was organized. At the meeting an introduction to the new technology and preliminary test results were shared. The research staff has no knowledge of any further communication between Electrosource and the wheelchair manufacturers.

Recommended Future Research and Development

Development of new battery technology has been progressing more slowly than was anticipated in 1993. However, we expect that significant improvements will be achieved. For this reason, wheelchair industry representatives are advised to stay informed and in the development loop so that the specific requirements of the power wheelchair may be accommodated in the packaging of any new and significant battery technology.

Figure 2 - Horizon (right) and standard 22NF (left) lead-acid batteries

Publications

Bayles, G. New Power Source Technologies for Electric Wheelchairs, Technical Report #2, RERC, University of Pittsburgh, Pittsburgh, PA 1995.

Bayles, G., Ulerich, P., Palmer, K., and Brienza, D.M., New Battery Technology for Powered Wheelchairs, *Proceedings of the 17th Annual RESNA Conference*, Nashville, TN, June 1994.

References

Bode, H., Lead-Acid Batteries, John Wiley & Sons, NY, 1977.

Kauzlarich, JJ. Wheelchair batteries II: Capacity, sizing, and life, *J Rehab Res and Devel*, 1990; 27(2):163-70.

Lavanchy, C. Comparative evaluation of major brands of lead-acid batteries, *Proceedings of the 1992 RESNA International Conference*, 1992;pp.541-43.

Peterson. HA. Development of test procedures for batteries in electric wheelchairs, *Report No. 86022*, Energy Research Laboratory, Niels Bohrs Alle 25, 5230 Odense M, Denmark.

PM-1c Power Wheelchair Controllers

Investigators: David Brienza and Wonchul Nho

Collaborators: Theodore Heinrich (Westinghouse Inc.)

Rationale and Goals

Very little innovation has occurred in the methodology used to control the power from the batteries to the motors, which is the job of the power controller. The objective of this development task was to adapt an alternating current (AC) motor controller technology developed for an electric automobile for use in a wheeled mobility device.

Methods and Outcomes Summary

An AC power controller using the vector control technique was designed. An existing design produced by the Westinghouse Corporation for electric vehicles (EV) was modified and updated to fit specifications developed for powered wheelchairs. The vector controller consists of two portions, software and hardware. Our initial work on this task concentrated on the hardware dedicated to the high current output stage of the controller, the motor drive. The role of the motor drive is to convert stored energy in the batteries to electrical power for the motors according to the magnitude of a control signal generated by the controller section of the device. A block diagram of a typical electric wheelchair power train is shown in Figure 3 below. The design for the power controller has been completed. The new design of the motor drive has been enhanced as compared to the original EV design. The power switching integrated circuits were upgraded using IGBT devices and important performance gains were achieved with the addition of a dead-time generator.

The design of the dead-time generator in the motor drive has involved the theoretical determination of three important parameters: carrier ratio, modulation index, and time-delay. Depending on the values and combinations of values of these parameters, harmonic and wave form distortions can be significant or negligible. The effect of the significant distortions is a reduction in efficiency and a momentary loss of control. Distortions in the voltage-wave form have been investigated through simulation. Distortions were determined as a function of carrier ratio, modulation index, and time-delay. Optimal values that minimize the distortion for both fundamental and harmonic components of the voltage-wave form in the output of the motor drive were selected for three representative operating conditions. The results of the simulation indicate that the modulation index must be near unity, carrier frequency is good at 15 kHz and a time delay of 10 msec is adequate. The application of these optimal values should allow for significant improvement in the output wave form of the motor drive.

Original plans for this task included the fabrication and testing of a prototype controller; these plans were not executed.

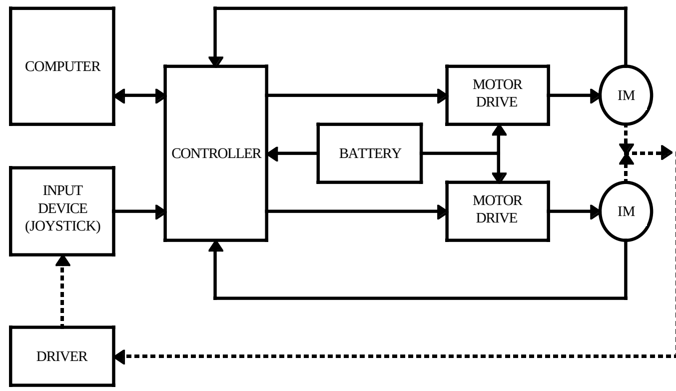

Figure 3 - Schematic of the prototype controller

Publications

Nho WC, Brienza DM and Boston R. The development of and AC motor drive in power wheelchair Proceedings of 15th Annual RESNA Conference, Salt Lake City, Utah, June 7-12, 1996.

PM-1D Improved Wheelchair Motor Drives

Investigators: Douglas Hobson, David Brienza

Collaborator: Jules Legal

Rationale

Advancement of powered wheelchair options is restricted by the availability of motor drive configurations. This task explored motor developments and specifically, motor/drive combinations that will open new opportunities for alternate wheelchair designs.

This task initially focused on the potential use of AC motors and the improvement of DC motors. However, it quickly became evident that the size of the wheelchair market limits the development of new motor technology specifically for use in the wheelchair industry. Therefore, the focus was redirected to identify existing technologies that can be "re-packaged" in such a manner to offer new drive options, such as a steerable in-hub motors and gear train combinations.

Project Goals

1. To improve the availability of alternate wheelchair motors/drive systems through forming working partnerships with Federal labs and/or motor/gear drive developers and manufacturers,
2. To work with wheelchair manufacturers in evaluating the feasibility of introducing new motor/train concepts and devices into new wheelchair designs.

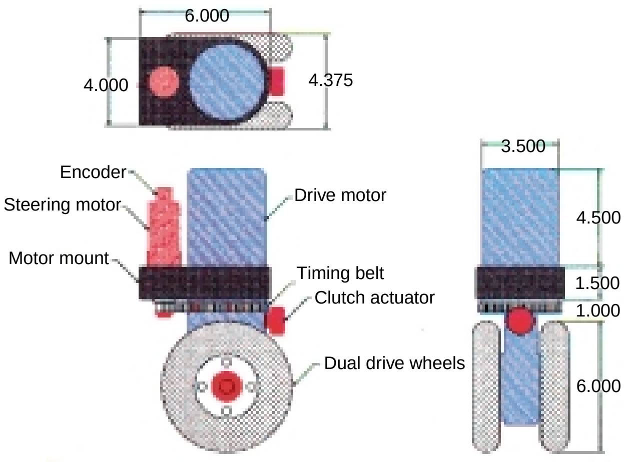

Figure 4 - Schematic of powered steering for front wheel drive wheelchair

Outcomes Summary

Information and supplier literature was collected on available motors and gear drives, such as the Fracmo line. Direct communication was established with Fracmo, which was followed by a joint meeting with the Pitt-Westinghouse team in November 1994. As a result, several prototype motor drives were obtained and used in tasks PM-2 and PM-6. A conceptual design was prepared and sent to a list of manufacturers with the goal to identifying a firm that wished to pursue a joint development project. The same specifications were distributed throughout the NASA technology transfer network in an effort to identify new sources of motor/drive technology. Finally, the following conceptual drawings were prepared, complete with more detailed views and specifications on the operational characteristics required. These drawings and their contained specifications will be used for future communications with prospective motor/drive manufacturers.

Rearch and Development

As will be discussed in Project PM-6 below, the commitment of a motor development and manufacturing company will be necessary before any new significant motor drive options will be made available to the wheelchair industry. As part of the PM-6 continuation plans, SBIR funding will be sought to allow active participation by a motor company and a wheelchair manufacturer in this effort to provide alternate drive systems for indoor power wheelchairs.