

Real-Time Active Loading of Piezoelectric Ultrasonic Motors for Simulating Space Robotics Applications

James B. Dabney

Abstract—Piezoelectric ultrasonic motors (PUM) offer dramatic improvements in a variety of space-based robotics applications if the problem of real-time torque control can be solved. This research enhanced the UHCL PUM laboratory apparatus by the integration of a magnetic particle brake to enable real-time control of an active torque load. The implementation of real-time active torque load control permits the modeling of a variety of space-based robotics applications. It enables expansion of the performance database to include steady-state load behavior.

SPACE-BASED ROBOTS TYPICALLY require light-weight actuators exhibiting high precision and simplicity. Piezoelectric ultrasonic motors (PUM) are well-suited to these requirements. PUM can achieve high precision as a result of low speed, the absence of gears and transmissions, and freedom from backlash. They are quite simple mechanically, consisting of a single moving part that provides the same functions as a motor, transmission, and brake in a conventional motor-driven system.¹

A typical piezoelectric ultrasonic motor (Piezo Systems/Shinsei USR 30, Fig. 1)² consists of a toothed piezoelectric disk (stator) in contact with a metal disk (rotor). Time-varying electric fields applied to the piezoelectric stator induce a traveling wave which is mechanically rectified, causing the rotor to rotate (Fig. 2)³. This mechanism produces relatively high torque at low rotor angular velocities, eliminating the need for gearing. The friction between rotor and stator provides a passive holding torque typically larger than the rotating torque, eliminating the need for mechanical brakes or active holding torque. These motors can be built in such a way that they neither produce nor are affected by magnetic fields, making them useful in highly magnetic environments and applications in which magnetic fields are harmful.

The state-of-the-art of PUM control only partially exploits the potential of the motor for important applications. Good results have been achieved for applications requiring only speed regulation. Existing controller technology is adequate for positioning applications traditionally served by stepper motors. Current



Dr. James B. Dabney



Figure 1. Piezo Systems Ultrasonic Motor (Shinsei USR30)

PUM control technology does not address the many important potential PUM applications requiring precise torque control.

Goals of the Project

The ultimate goal of the PUM research being conducted in the UHCL Systems Engineering Laboratory is the development of a PUM driver/controller unit that implements model-based real-time torque control algorithms.

Research supported by ISSO this year entailed modifying the PUM apparatus by the addition of a magnetic particle brake and integration of the brake driver into apparatus control circuitry and software. This enhancement to the apparatus permits improved characterization of motor performance to include steady-state behavior and facilitates the modeling of a variety of realistic loading scenarios.

Results

A Placid Systems magnetic particle brake was integrated into the apparatus as illustrated in Fig. 3. The brake was inserted in the apparatus between the flywheel and the laser encoder. The brake is mounted to the mechanical breadboard with a machined hanger bracket and drives the encoder by means of a flexible coupling.

The magnetic particle brake produces a braking torque proportional to the drive current and nearly independent of motor speed. The brake is driven by a Placid Systems magnetic particle brake driver (Fig. 4) which is, in turn, controlled via the

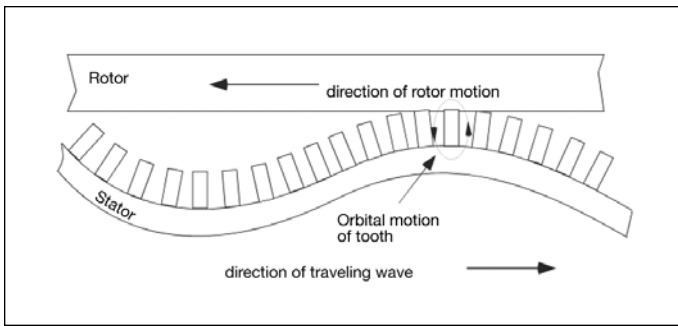


Figure 2. Traveling Wave Formation

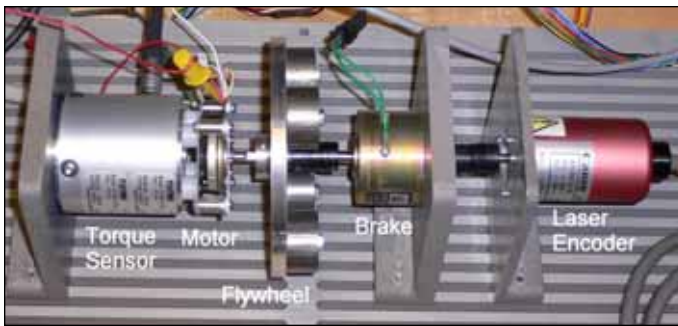


Figure 3. Motor and Encoder Assembly



Figure 4. Magnetic Particle Brake Driver

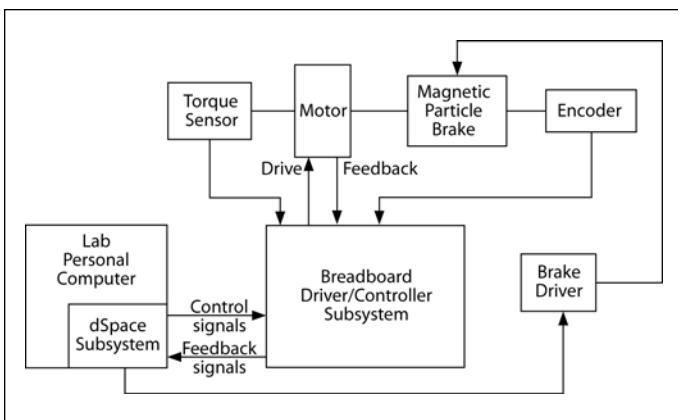


Figure 5. Apparatus Schematic

dSpace system in the laboratory personal computer. The driver produces brake drive current proportional to input signal voltage, permitting real-time control of the load torque.

A system block diagram including the magnetic particle brake and driver is shown in Fig. 5. The Simulink⁴ real-time control software was modified to provide the brake control signal. A simple proportional-integral (PI) controller was implemented in the Simulink software to permit real-time control of motor speed by adjusting load torque. A dSpace graphical user interface (GUI) was implemented (Fig. 6). That permits the operator to select motor speed control using the PI controller or brake torque control.

Using the dSpace GUI, researchers conducted preliminary experiments to verify operation of controller software and the magnetic particle brake subsystem. A typical test case involves selecting a motor speed, initiating motor operation, and then varying the drive signal frequency to force the PI controller to vary brake torque so as to maintain the desired motor speed. A plot is shown in Fig. 7 of motor speed as drive signal frequency is varied. For this test case, commanded motor speed was approximately 41 RPM. At the initial drive signal frequency of 51.2 KHz, the motor speed was less than the commanded speed with no load; therefore, the brake command voltage remained at zero. As the drive signal frequency was reduced, the motor speed increased to near the target speed, causing the controller to command brake torque to reduce motor speed. The preliminary PI controller response indicates the need for refinement of the controller, but the experiment demonstrates clearly that torque regulation is effective.

The next phase of the project will entail improved characterization of motor performance employing the torque controller. Using the improved characterization of motor performance, model-based control algorithms will be implemented in the Simulink software and demonstrated using the active load and torque sensor. The enhanced apparatus will also be used to investigate implementation of a single degree-of-freedom haptic interface.

Acknowledgments

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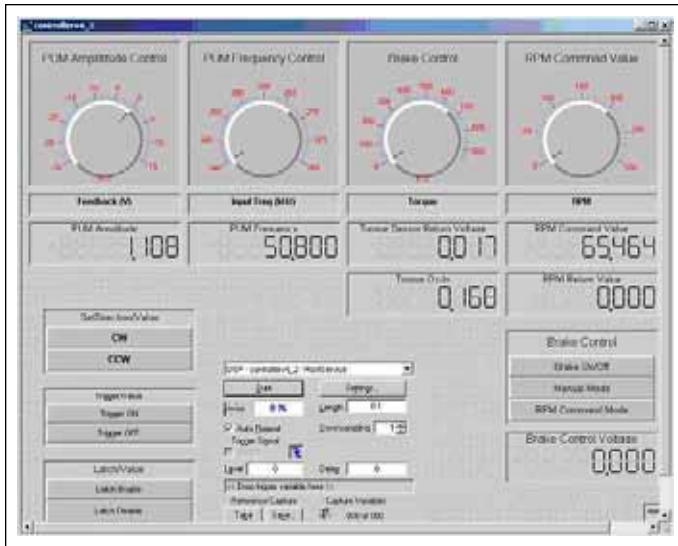


Figure 6. dSpace Interface with Load Torque Control

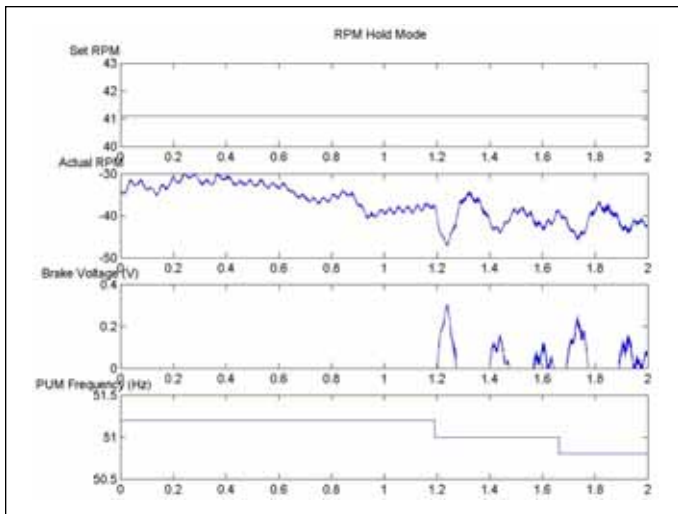


Figure 7. Measured Torque Compared to Computed Torque

⁵C. Wagner, J. Arceneaux, and A. Vyvial, “Model-Based Torque Control of Piezoelectric Ultrasonic Motors,” Capstone Project Report, UHCL Systems Engineering Laboratory, 2005.

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Funding

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