Analysis to Determine Optimum Strain Gauge Locations for SENSEWHEEL

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Abstract

Manual wheelchair users rely on their upper extremity to self-propel their wheelchair, which have to stop and start repeatedly, across various terrains, in longitudinal, cross slope, and uneven surfaces. Many users suffer shoulder pain and injury in the long term because of unconscious overuse[1]. Training in pushing style has the potential to alleviate pain, with resulting NHS savings.

To provide a system for measuring the forces applied during propulsion, three identical load cells were interposed between the pushrim and drivewheel. This 'SENSEWHEEL' measures the three components of force Fx, Fy and Fz, and axial torque Tx applied at each load cell, fig 1. Strain gauges were located on a diaphragm forming one face of the load cell, for ease of construction and good sensitivity. The location of the gauges was optimized using COMSOL Multiphysics®.

The 0.75mm thick diaphragm has four pairs of gauges (one pair per quadrant) configured for half bridge strain measurement, fig 2. A universal joint connected each load cell shaft with the pushrim, thus applied shear forces were converted into bending of the diaphragm, to reduce the possible d.o.f. to 4. Each load cell measured 4 strains resulting from these 4 load components; the data from each were combined and telemetered by radio. Individual calibration of each load cell was carried out to relate each strain output to each load type applied via a cross-sensitivity matrix, and measured loads were then combined to find the resultant force system on the pushrim.

It was important to avoid points of inflection in the diaphragm, and optimum radii were found by applying a nominal 100N load along Fx (axial) and Fy (radial) axes, and plotting the resulting strains at 0.5mm incremental radial distances, for the 4 quadrants. The gauge angles were optimized as follows: COMSOL was set to output the two direct strains solid.eY, solid.eZ, and the shear strain in the plane of the diaphragm solid.eYZ. These strains were then combined offline using standard formulæ for co-planar strains in any given direction. Angles for each gauge in the half bridges were set separately. The half bridge output voltage was calculated for any given angle set, and the entire strain gauge arrangement was rotated in 5 degree increments whilst maintaining the same radial force, to simulate the behavior for any given radial load direction. It was important to show that for each applied load direction there was a significant strain response from at least one half bridge.

The optimum angle for all gauges was found to be 45deg w.r.t. each radial axis. This provided good sensitivity to, and separation of, force components. The first instrumented SENSEWHEEL has been constructed, calibrated, and used in a limited clinical trial. A wireless version is now being designed, using COMSOL Multiphysics®, for improved reliability and ease of construction. A musculoskeletal model is being used to infer the shoulder forces from these pushrim forces.

Reference

[1] Dee D Gutierrez et al., “The Relationship of Shoulder Pain Intensity to Quality of Life, Physical Activity, and Community Participation in Persons With Paraplegia,” The Journal of Spinal Cord Medicine, vol. 30, no. 3, p. 251, 2007.

Figures used in the abstract

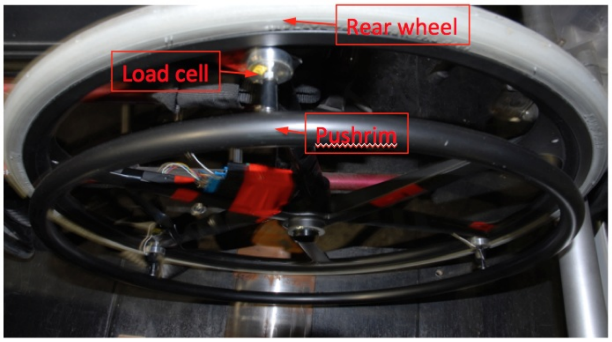

Figure 1: SENSE WHEEL.

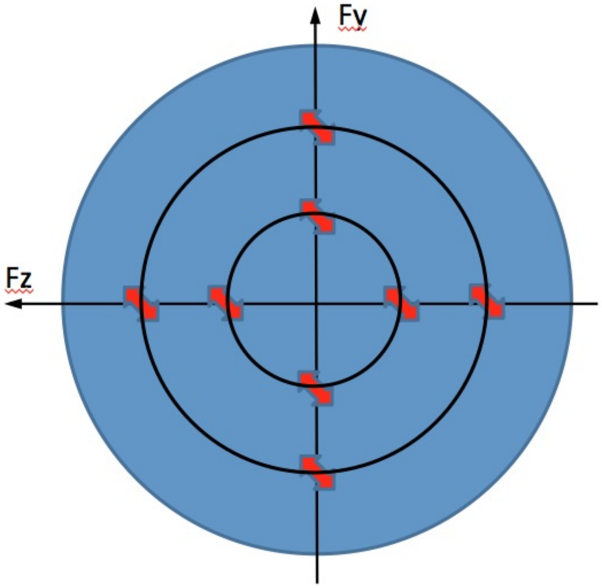

Figure 2 Positions of 8 strain gauges

Figure 2: Position of strain gauges.