COMSOL analysis of wheelchair pushrim six dof load cell for quantifying propulsion efficiency by SenseWheel

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Introduction: Manual wheelchair users rely on their upper extremities for self-propulsion of their wheelchair. This, over time, causes many users to suffer shoulder pain and injury, due to unconscious overuse [1]. Training in cost-efficient pushing style has the potential to alleviate pain, with resulting NHS savings. This can be assessed by measuring the 3D force acting at the pushrim. The SenseWheel is a lightweight force-sensing handrim, comprised of three identical load cells. The load cells are interposed between the pushrim and drive wheel. The initial design SenseWheel Mk 1 measured the three orthogonal forces Fx, Fy and Fz, and axial torque Tx, applied at each load cell [2]. It has been constructed, calibrated, and used in a limited clinical trial. SenseWheel Mk1 is: 1) light weight (less than 100g), 2) able to fit s different diameter wheel or hand rim and 3) Waterproof. This paper describes the development of an improved Mk2 version of Sensewheel which uses wireless 6DOF load cells to measure Fx, Fy, Fz, Tx, Ty, and Tz. This will simplify the coupling to the wheel and handrim. Each load cell will transmit its data via Bluetooth to a master tablet/SmartPhone carried by the user or held remotely.

Figure 1. SENSE WHEEL (Mk1)

Methods: COMSOL was used to redesign the 6DOF load cell, using 8 quarter-bridge strain gauges equi-spaced around the inner circumference of the widest part of the load cell for good strain sensitivity and selectivity (Figure 2). Each load cell is 40mm diameter at its widest, to accommodate coin cell, Bluetooth module and flexible printed circuit. The optimum orientation of the gauges was determined using COMSOL Multiphysics® with a 3D axis-symmetric finite element model generated from a 2D cross sectional model (Figure 3). The load cell was designed as two halves, to be screwed together after assembly, and this was modelled in COMSOL as one part. COMSOL was set to output direct strains (eX, eY, and eZ) as well as shear strains (eXY, eYZ, and eZX) in response to applied forces Fx, Fy, Fz, and torques Tx, Ty, and Tz. The strains were calculated(Figure 4) and converted to resultant strains at each strain gauge site. The resultant strains were used to investigate both the sensitivity of each gauge to each load type, and also the selectivity of each load type

The gauges of one semicircle of gauges were angled opposite the other semicircle to allow for separation between Fx and Mx, as previously used in an instrumented shoulder implant [3]. The correlation coefficient between force/moment pairs was then calculated to predict the optimum angle, which would give best separation between these load types.

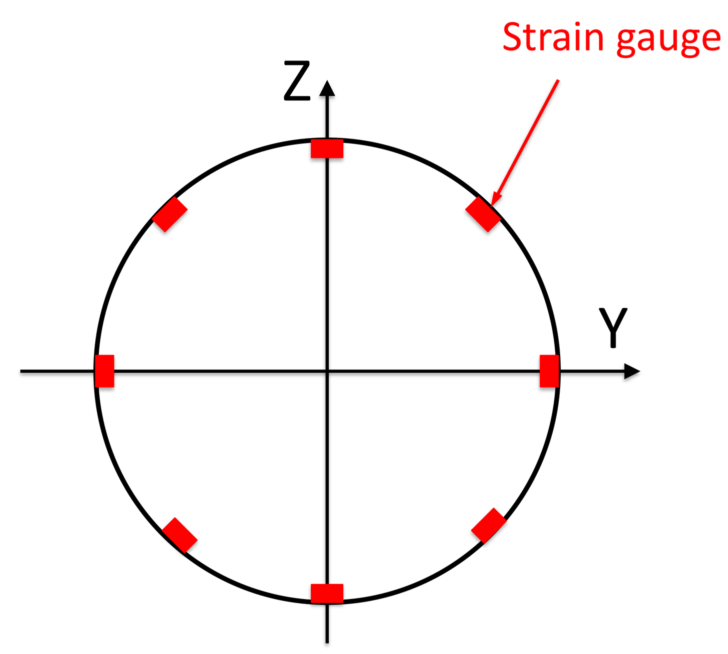

Figure 2. Strain gauge positions

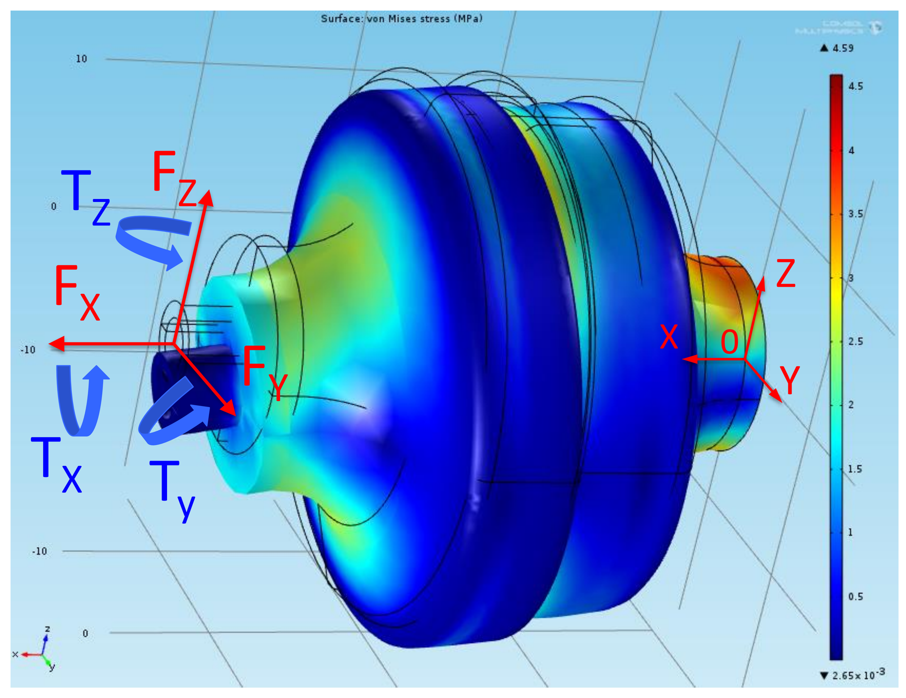

Figure 4. COMSOL Analysis

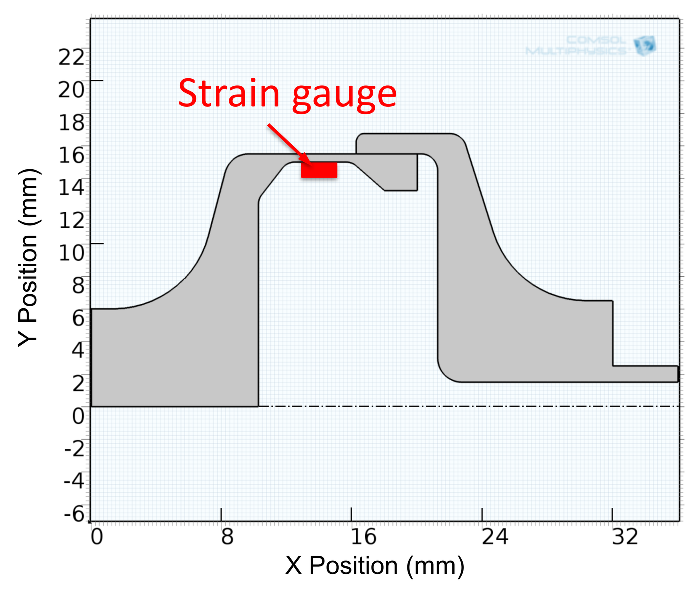

Figure 3. 2D Load cell model

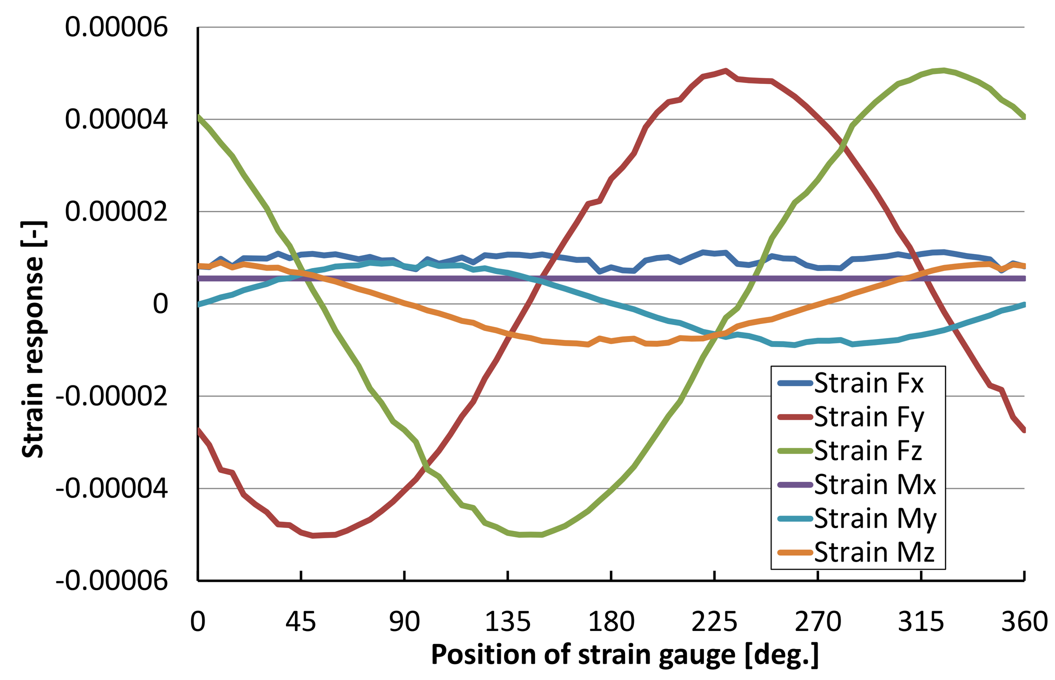

Figure 5. Calculated strain response

Results: The peak sensitivity of the strain output by radial position, for several strain gauge angles w.r.t. the longitudinal axis, and the correlation coefficient between same axis force/moment pairs, is shown in Figure 5. Figure 5 shows the strains at 5 deg increments around the circumference, for a gauge angle of 45deg, which gave a compromise between good strain sensitivity to each applied load, and adequate selectivity between load types. The designed load cells will now be manufactured, and following assembly each load cell will be calibrated to relate each strain output to each load type applied via a cross-sensitivity matrix, and measured loads are then combined to find the resultant force system on the pushrim.

Conclusions: The optimum angle for all gauges was found to be about 45 deg with respect to the longitudinal direction. This provided good sensitivity and separation of force components. Based on this COMSOL analysis, a wireless version of the SenseWheel will be developed, on a mobile platform. A musculoskeletal model is being developed to infer the shoulder forces, to be animated by these pushrim forces.

References:

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3. Taylor, S., Lambert, S., Bayley, I., Blunn, G. (2008). A telemetrised glenoid prosthesis for reverse- anatomy shoulder replacement. Journal of Biomechanics, 41 S448