COMSOL Analysis to Determine Optimum Strain Gauge Locations for SENSEWHEEL

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Introduction:

Manual wheelchair users rely on their upper extremity for self propulsion, including the need 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 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.

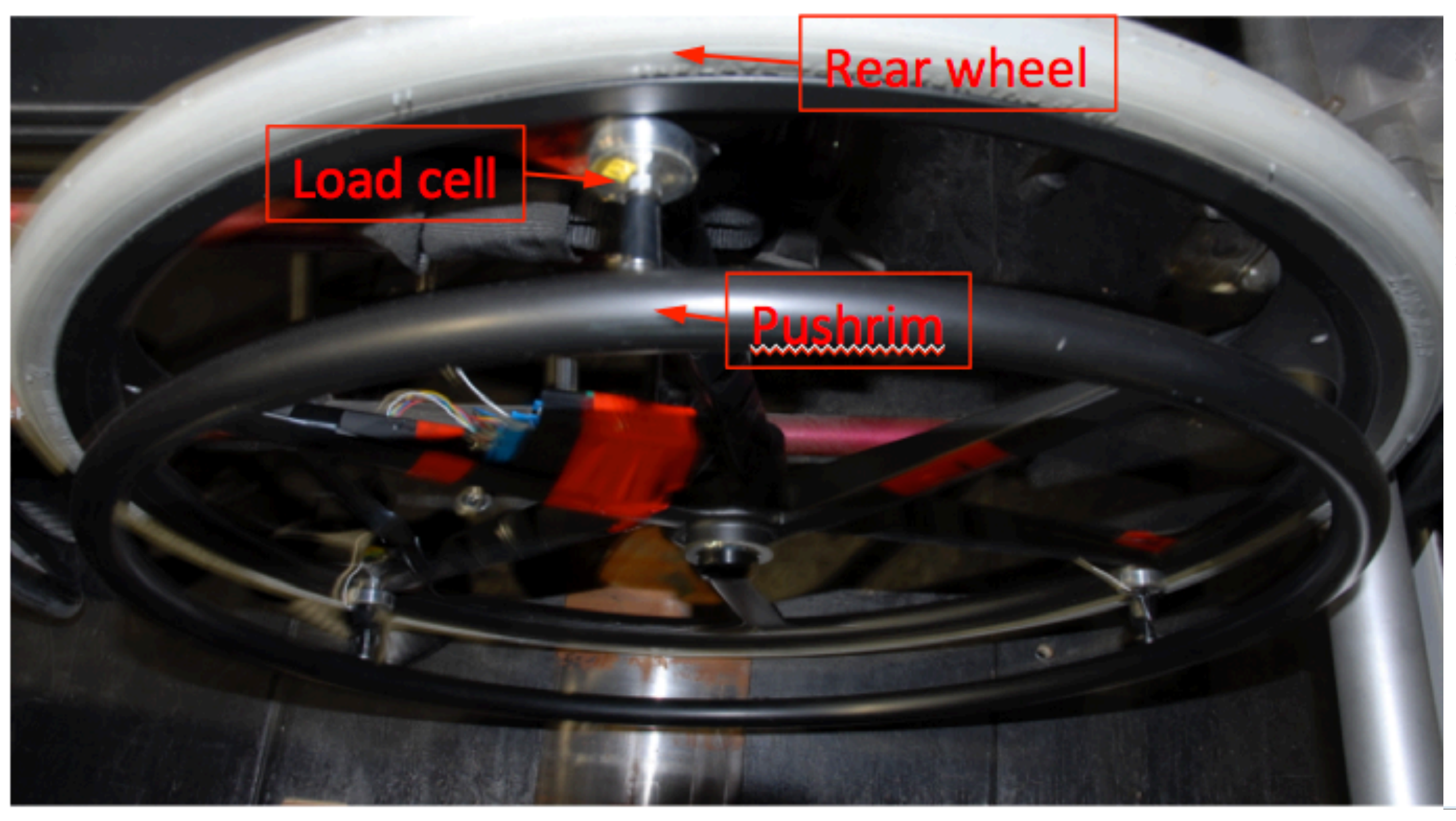

Figure 1. SENSEWHEEL mounted

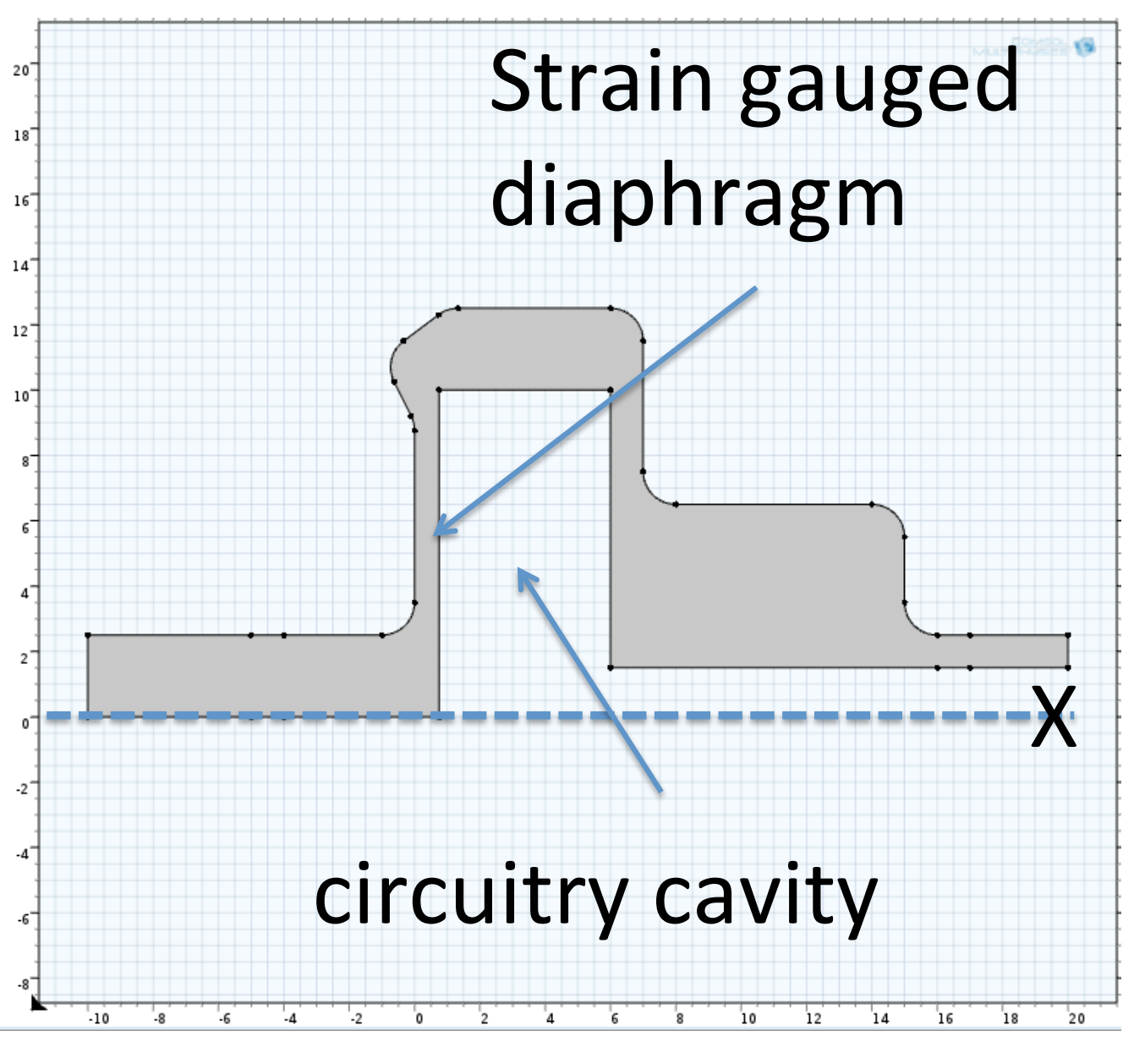

Figure 2. load cell section before revolving

Methods:

Three identical load cells were interposed between the pushrim and drive wheel. This 'SENSEWHEEL' (fig. 1) measures the three orthogonal forces Fx, Fy and Fz, and axial torque Tx, applied at each load cell. Strain gauges were located on a diaphragm forming one internal face of the load cell, for good strain sensitivity. The optimum location and orientation of the gauges was determined using COMSOL Multiphysics® with a 3D axis-symmetric finite element model generated from a 2D cross sectional model, fig. 2. The load cell was made as two halves, to be screwed together after assembly, modelled as one part. One end formed the diaphragm (0.75mm thick, 20mm diam.); a small cavity within the load cell housed a flexible printed circuit for ADC, microcontroller and accelerometer. Four pairs of gauges (one pair per quadrant) were configured for half bridge strain measurement, fig 3. 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 d.o.f. to 4 since a flat diaphragm is unsuitable for discriminating between shear forces and in-plane bending.

COMSOL was set to output direct strains solid.eY, solid.eZ, and shear strain solid.eYZ at 5 deg intervals around the circumference of radii (radii in 0.5mm increments to 10mm), in response to applied forces Fx, Fy, Fz, and torque Tx, fig. 4. These strains were then combined using standard formula for co-planar strains to simulate the half bridge strain measured by gauges on chosen radii at any given angle. It was important to show that for each applied load direction there was a significant strain response from at least one half bridge.

Results:

Half bridges strains on 4.5 and 8.5mm radii gave the best sensitivity to all loading types and avoided points of inflection on the diaphragm. To maximise the half bridge response it was found that gauges at 45 degrees offered the best discrimination, fig 5.

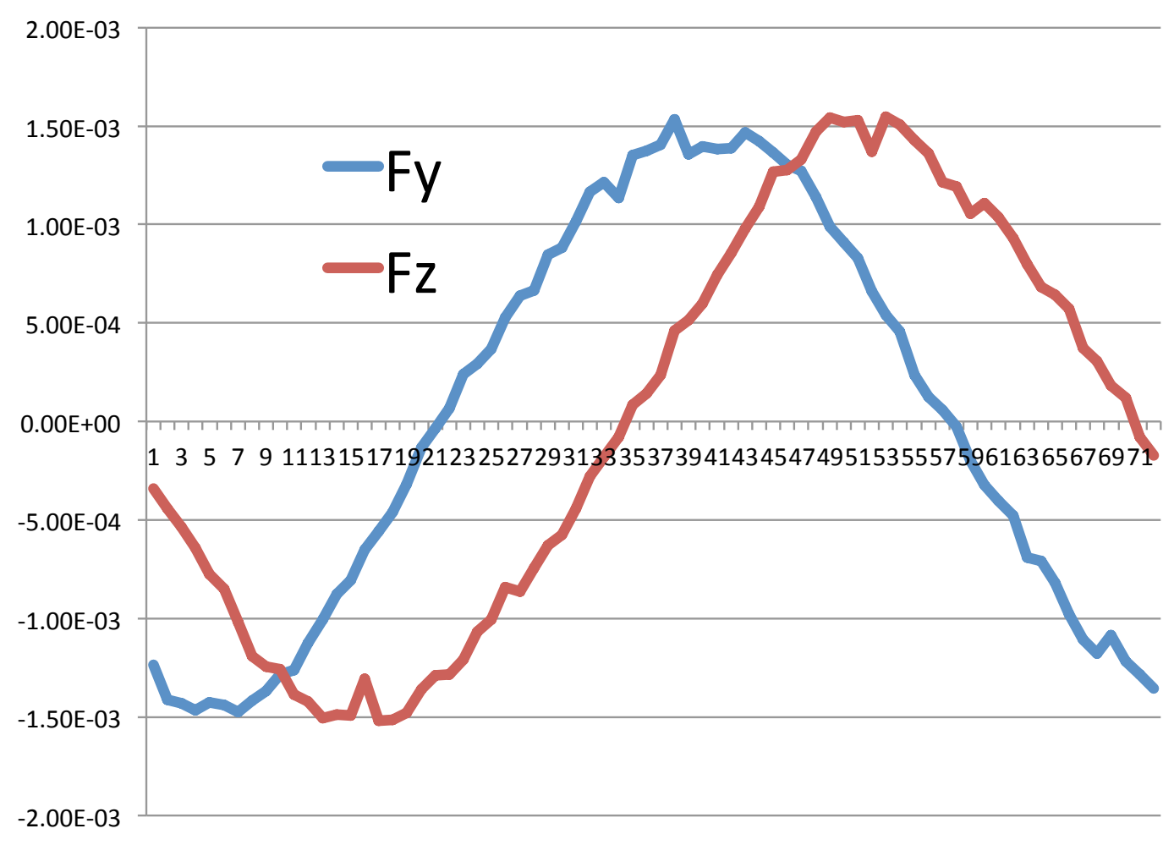

Fig 5. Half brg strains due to Fy, Fz from 45deg gauges at 4.5 & 8.5mm

The sensitivity effect of radial position of the outer gauge on the diaphragm is seen in fig. 6 for Fx and Fy. A choice of 8.5mm gave good sensitivity and avoided points of sharp strain change requiring very accurate gauge placement. The result, fig 3, has all gauges oriented in the same direction. This discriminates between Fx and Tx.

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.

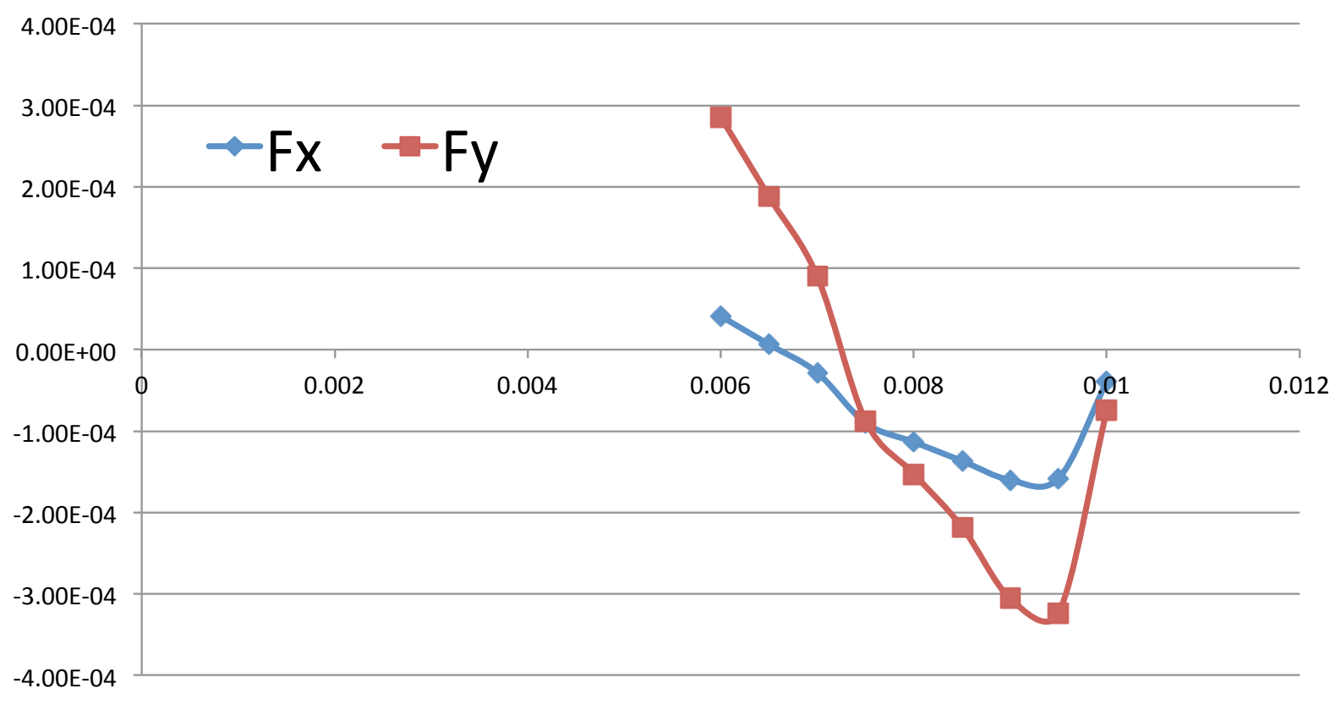

Fig 6. Sensitivity variation with radial position for Fx and Fy

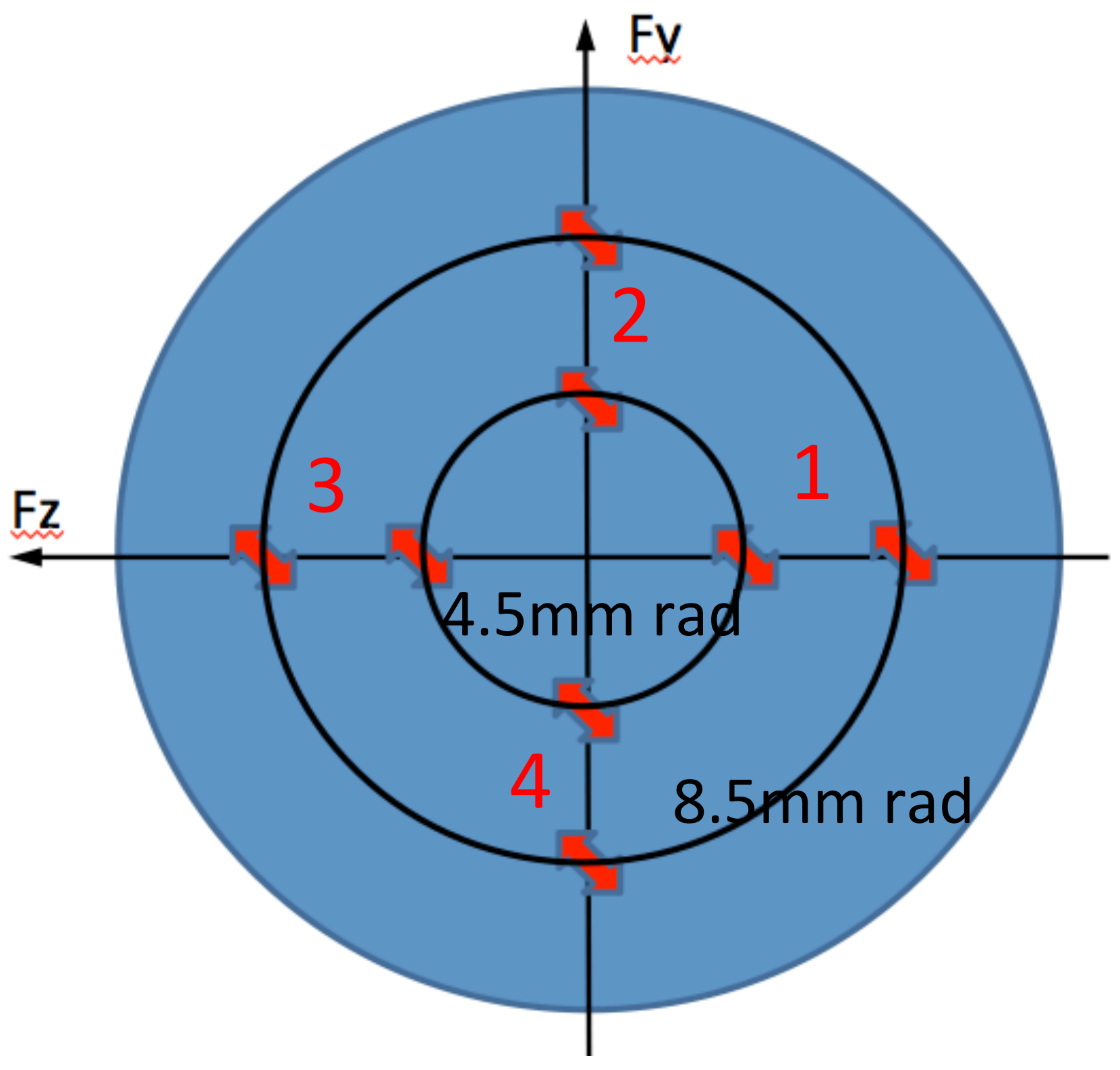

Figure 3. Gauge positions

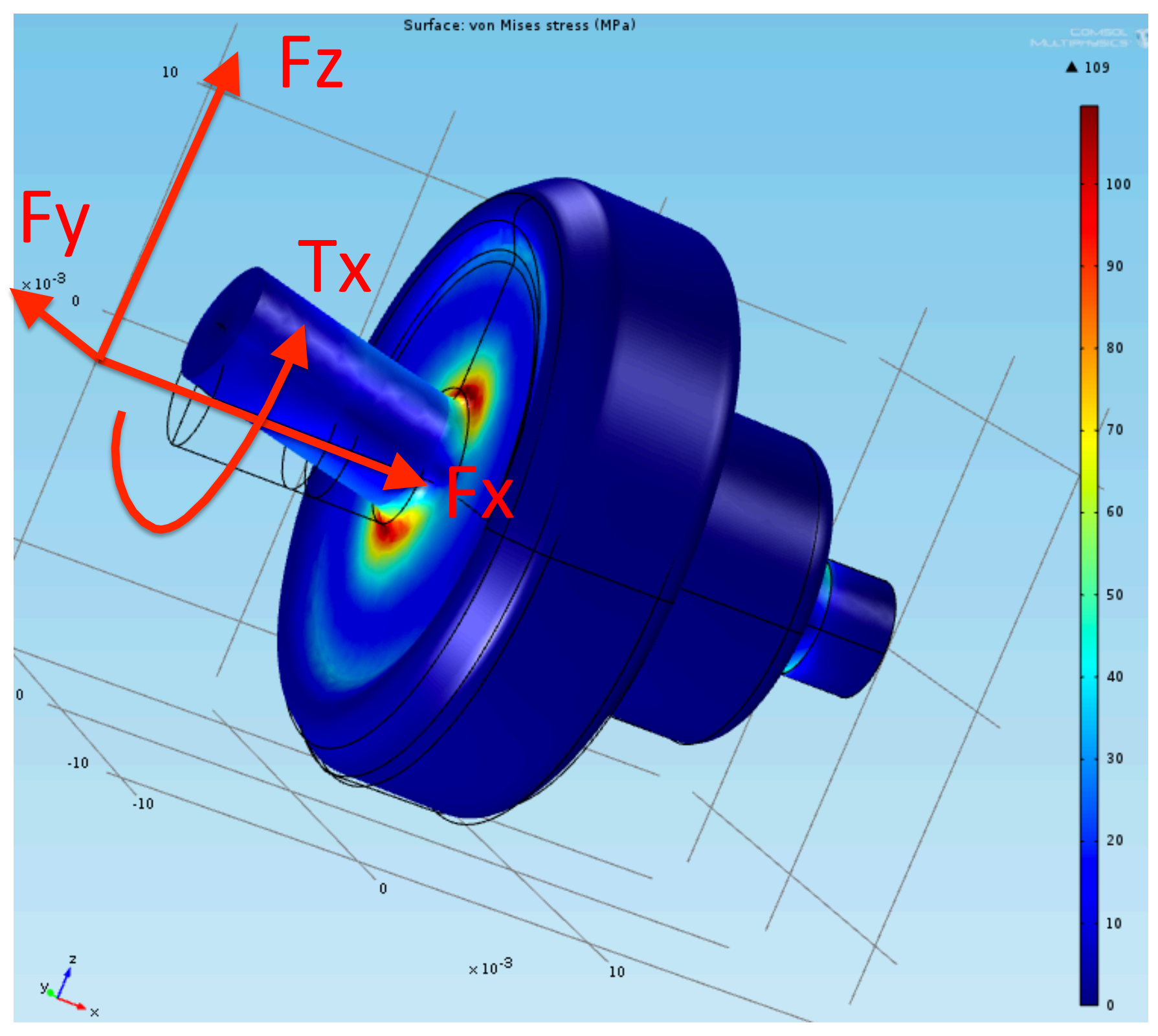

Figure 4. COMSOL output: Fz applied

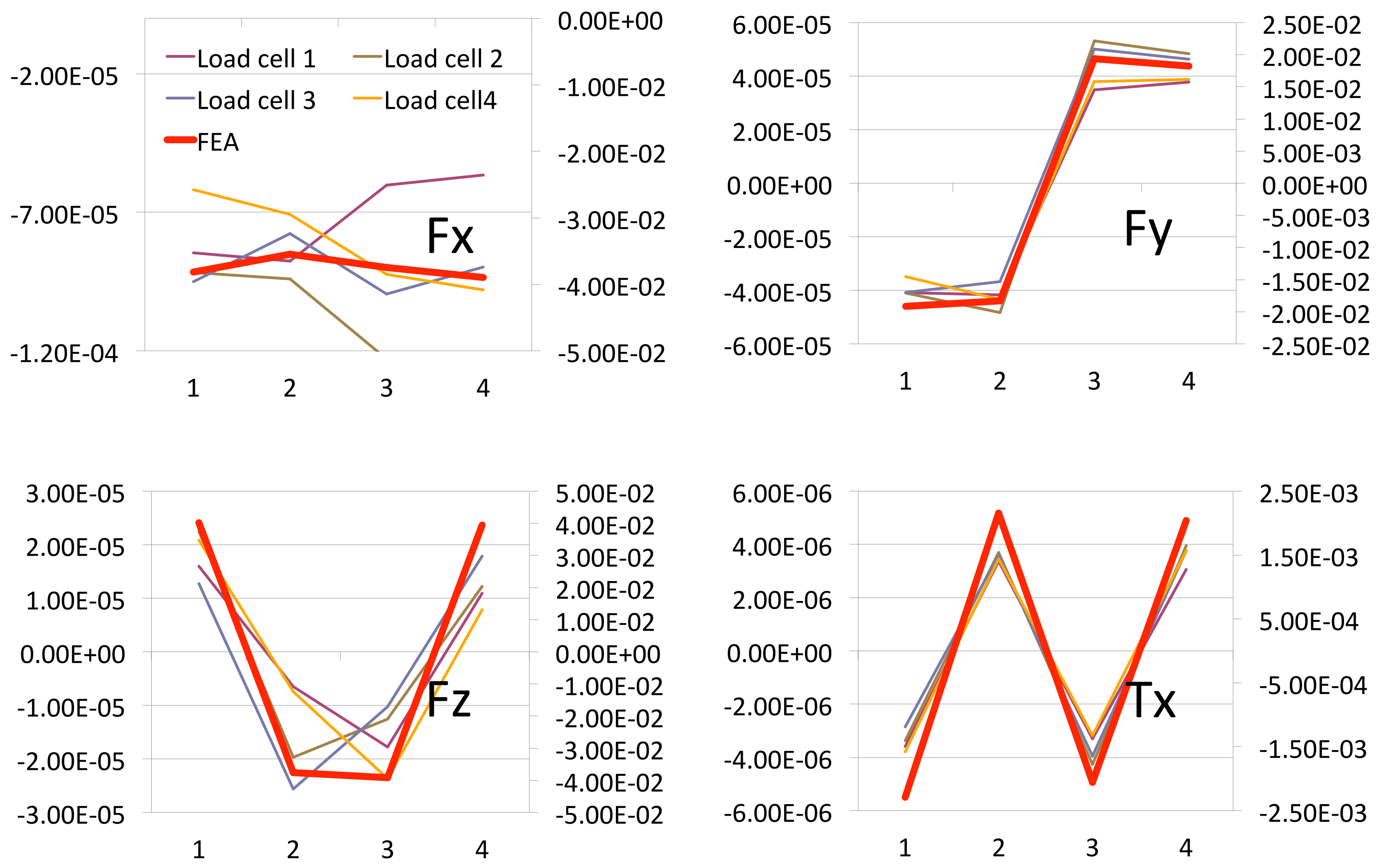

Figure 7. Comparison of FE and measured sensitivities

Conclusions:

The optimum angle for all gauges was found to be 45 deg w.r.t. each radial axis (signs alternating). This provided good sensitivity to, and separation of, force components, and calculated results with COMSOL were consistent with experimental results, fig. 7. The first instrumented SENSEWHEEL has been constructed, calibrated, and used in a limited clinical trial. A wireless version is now being designed, again using COMSOL Multiphysics®, for improved reliability and ease of construction. A musculoskeletal model, together with an instrumented shoulder implant, are being developed to infer the shoulder forces from these pushrim forces.

Reference:

1.Gutierrez et al. The Relationship of Shoulder Pain Intensity to Quality of Life, Physical Activity, and Community Participation in Persons With Paraplegia. J Spinal Cord Medicine, vol. 30, no3, p. 251, 2007.

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