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Low-cost thick-film force sensors for the 100 N force range

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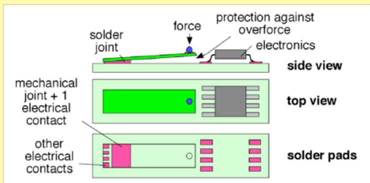
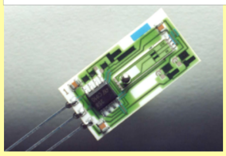
Thick-film piezoresistive force & pressure sensors

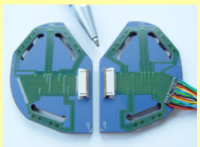
- Ruggedness, good stability and reliability
- Low cost, repeatable industrial fabrication process
- Cantilever force sensors good for low forces only
- Complex machined load cells expensive
- Up to now, no « simple » sensor for high forces



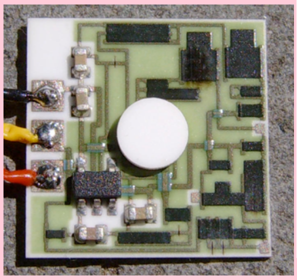
"MilliNewton" cantilever-type force sensor for 0.2…2 N range. Range is limited in practice by the cantilever and by the solder or glue joint to the sensor base.

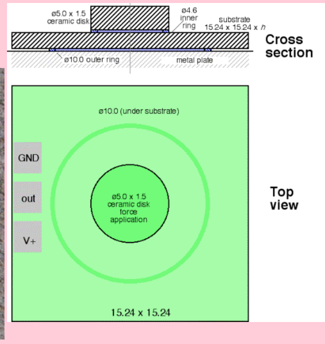


Steel + thick-film high range force sensor for total knee arthroplasty - ligament balancing



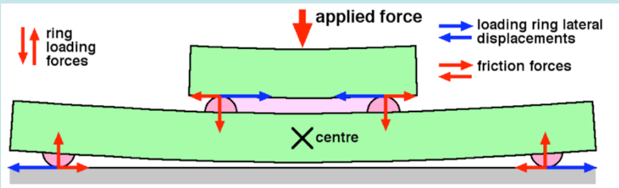
New "CentoNewton" 100 N force sensor





- Sensor based on the **ring-on-ring** bending test
- Higher achievable forces than cantilever or 4-point bending
- Sensing & electronics integrated on a **single substrate**
- Dielectric "loading rings" screen printed onto the substrate
- 2 piezoresistors in the centre (under ceramic disc)

Mechanical model & examples



Friction at loading points is a source of **hysterisis** - not a high-accuracy design !

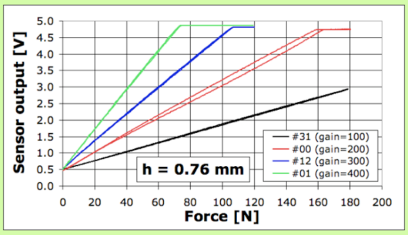
$$\sigma = \frac{3}{4\pi \cdot h^2} \cdot \left[2(1+\nu) \cdot \ln\left(\frac{d_{ext}}{d_{int}}\right) + (1-\nu) \cdot \left(\frac{d_{ext}^2 - d_{int}^2}{d_{disk}^2}\right) \right] \cdot F$$

$$d_{disk} = \frac{1+\sqrt{2}}{2} \cdot a \cong 1.207a$$

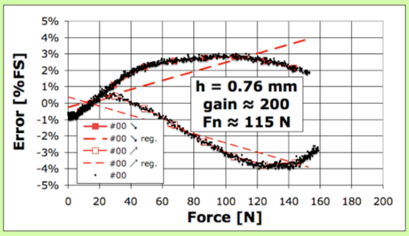
- σ nominal stress at centre
- ν Poisson's ratio of substrate (alumina)
- F applied force
- d_{int}, d_{ext} inner & outer ring diameter
- d_{disk} equivalent disk diameter for substrate size
- a sensor substrate edge size

Force F [N]	10	20	40	100	200	400
Substrate thickness h [mm]	0.25	0.30	0.50	0.80	1.00	1.50
Nominal stress σ [MPa]	80	111	80	78	100	89
Nominal response r [mV/V]	1.9	2.7	1.9	1.9	2.4	2.1

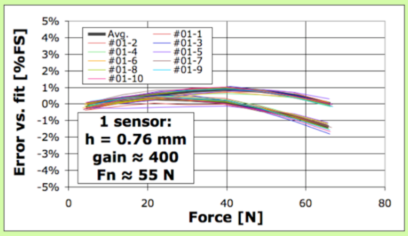
Results



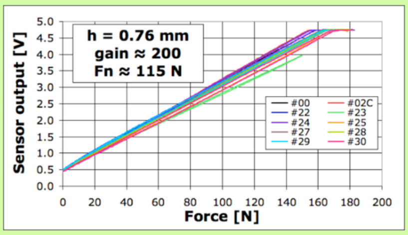
Response of sensors (same substrate thickness) with different amplifier gain settings. Note the significant hysterisis of sample #00.



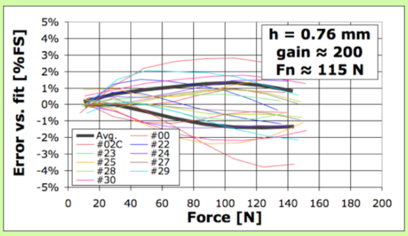
Detailed results for sample #00: noise, nonlinearity and hysterisis.



Repeated loading of a single sensor, showing good stability.



Response of nominally identical sensors. Sensitivity is relatively reproducible.



Error vs. fit of a sensor series, exhibiting hysterisis typical of that induced by friction (zero hysterisis at no load)

Conclusions

- Design & fabrication of a **low-cost force sensor for the 100 N range** has been successfully carried out.
- The force range this design can cover with standard materials is roughly 10…400 N.
- Sensor is **sturdy, compact and reliable**.
- **Friction** at loading rings is the most probable cause of **hysterisis**, and must be addressed to improve precision!