SAND2006-6523P

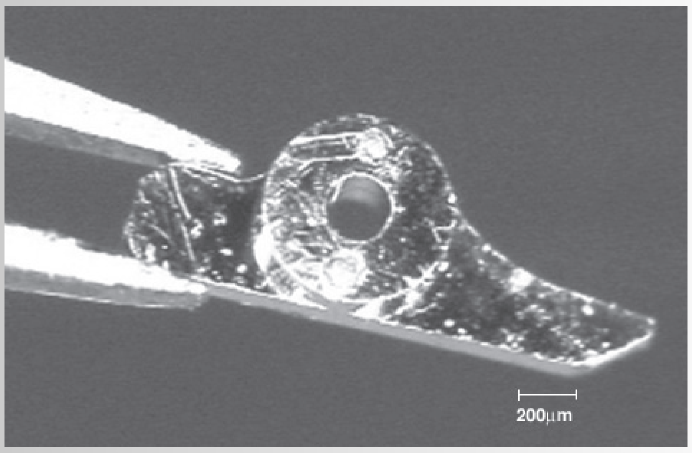
Experiments in Sub-Millimeter Interference Fits

James F. (Red) Jones, James M. Bailar, Dannelle P. Sierra, and William L. Evans II

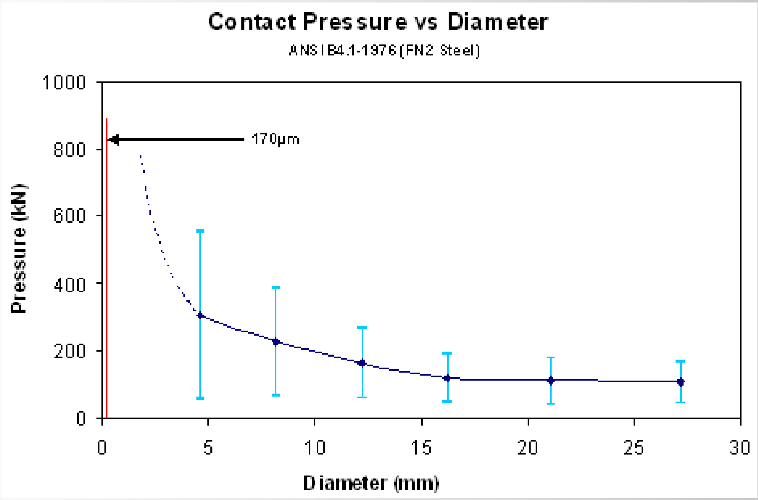
Intelligent Systems and Robotics Center
Sandia National Laboratories
Albuquerque, New Mexico USA
redjone@sandia.gov

Abstract

Interference fits are a common assembly technique for mechanical devices. Unfortunately, no standards and little published data exist for fits having sub-millimeter diameters.



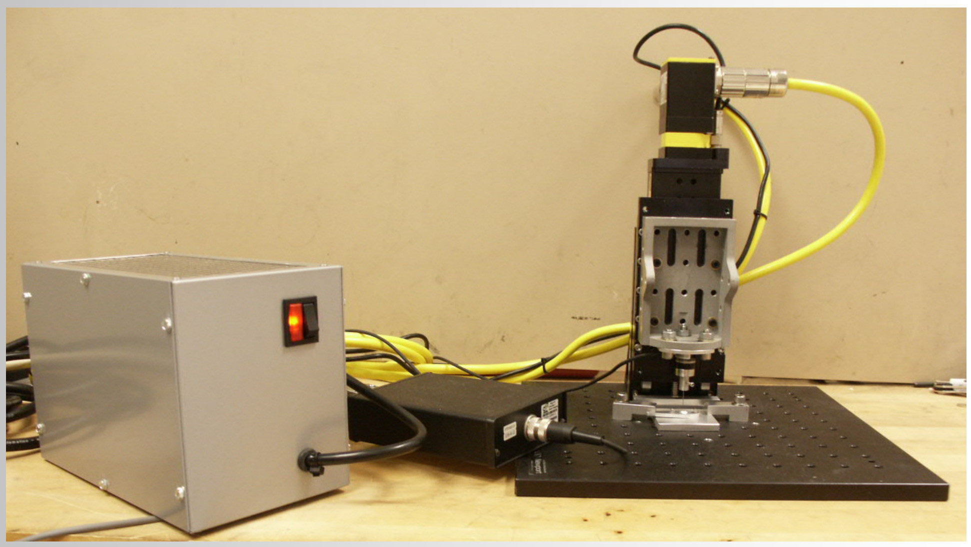
Pawl/washer assembly created using two 170 µm diameter interference fit shafts



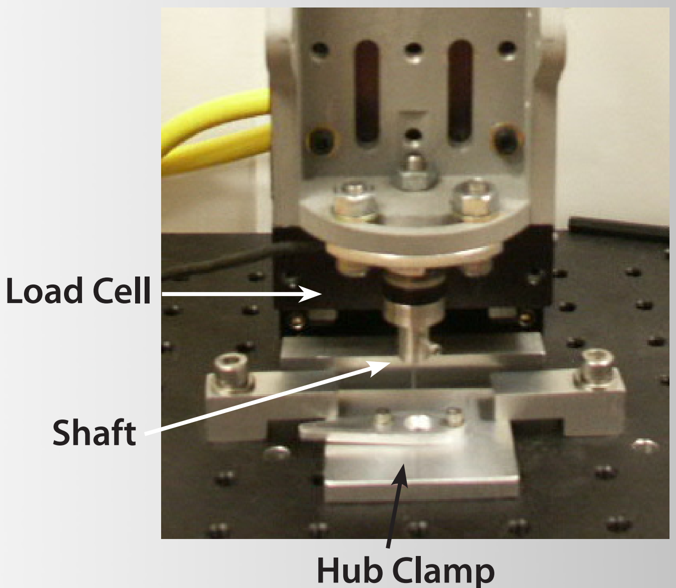
Allowable nominal contact pressure for 170 µm interference fit

- ISO286 -2 "Tables of standard tolerance grades and limit deviations for holes and shafts" specifically excludes nominal diameters under 1 mm
- USAS B4.1-1967 (R1974) reaffirmed 1994 "Preferred Limits and Fits for Cylindrical Parts" specification is questionable for nominal diameters less than one millimeter
- Standards evolved through the consensus of experts based on practical experience, not on theory
- Developing a scientific basis for establishing the parameters for sub-millimeter scale interference fits would be more expedient than accumulating sufficient practical experience to achieve consensus

Experimental Apparatus



Experimental apparatus consists of a Parker-Daedal precision ball-screw stage, an ATI Nano-17 load cell, and custom fixturing. The experiment is controlled by a PC with a NI DAC (not shown).



Close-up showing the load cell and fixturing

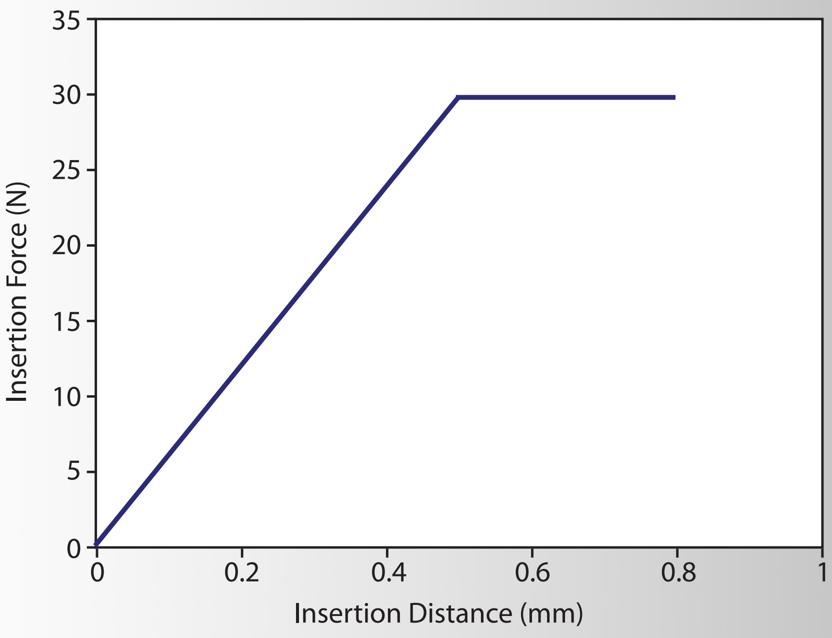
Classical Analytical Model

Can be shown to be:

$$F = \tfrac{1}{2} \mu \pi E(d_s - d_h)L$$

Where:

- F – axial insertion force
- μ – coefficient of friction
- E – elastic modulus
- d_s – shaft diameter
- d_h – hole diameter
- L – length of engagement

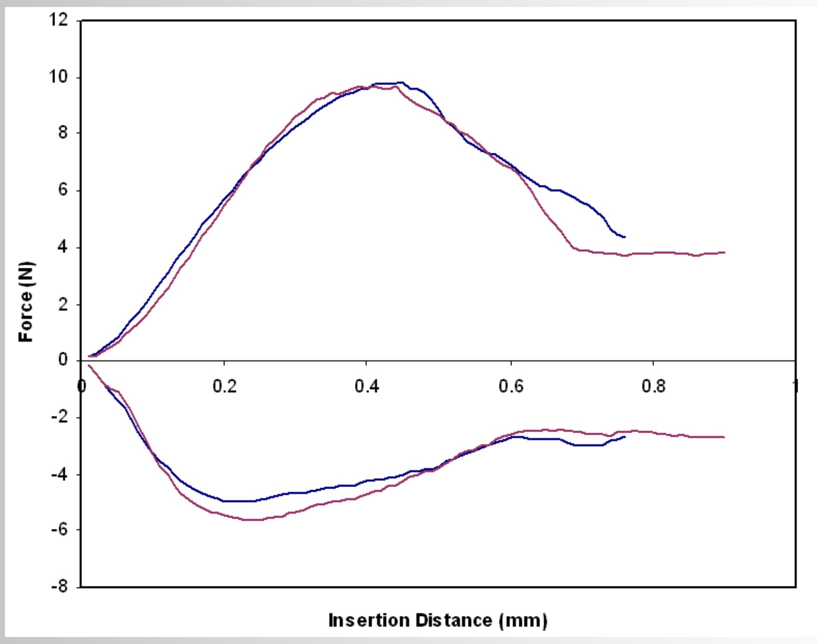


Predicted insertion force for a steel shaft being inserted into a 0.5 mm thick hub (190GPa) with 1µm of interference between the parts

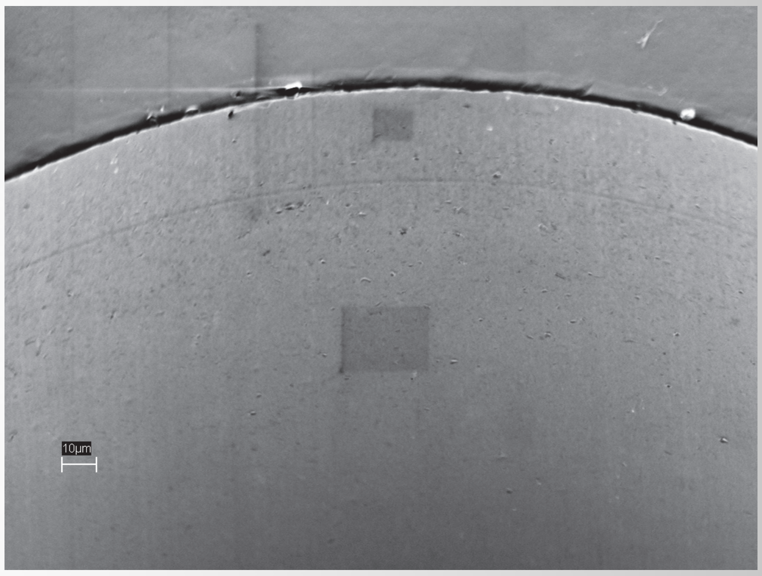
National Nuclear Security Administration

Experimental Results

LIGA

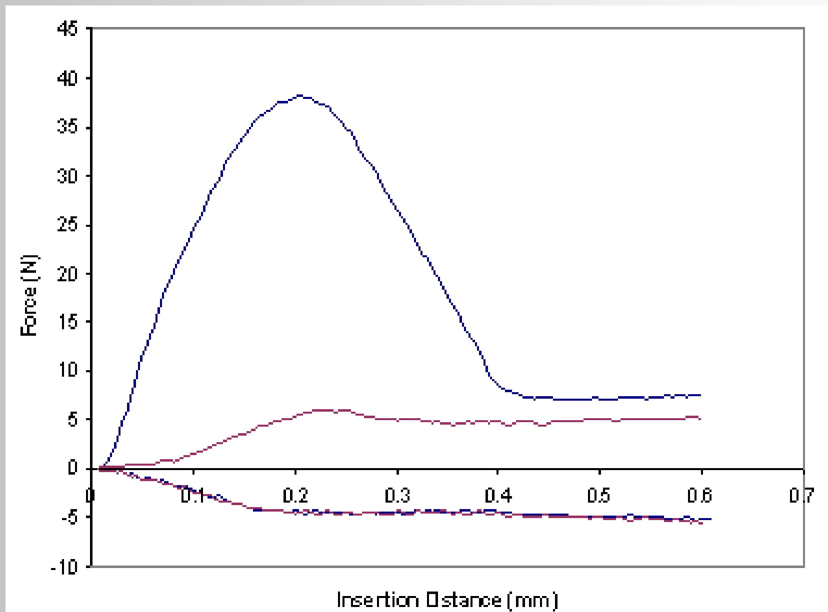


Repeated insertion/extraction of a 500µm diameter hard steel shaft into a 500µm thick LIGA hub. Insertion is indicated as a positive force while extraction is negative. The first insertion/extraction is plotted in blue and the second in red.



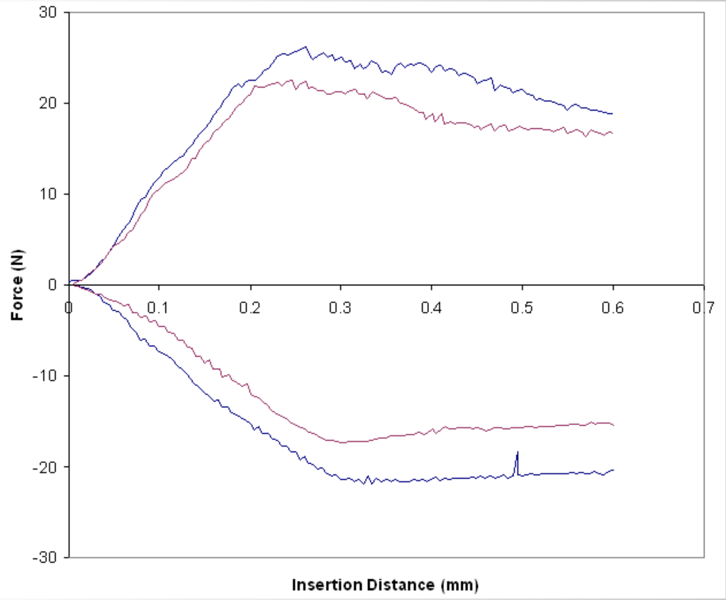
SEM image of LIGA hub after repeated insertions. Note sidewalls remain smooth.

Brass

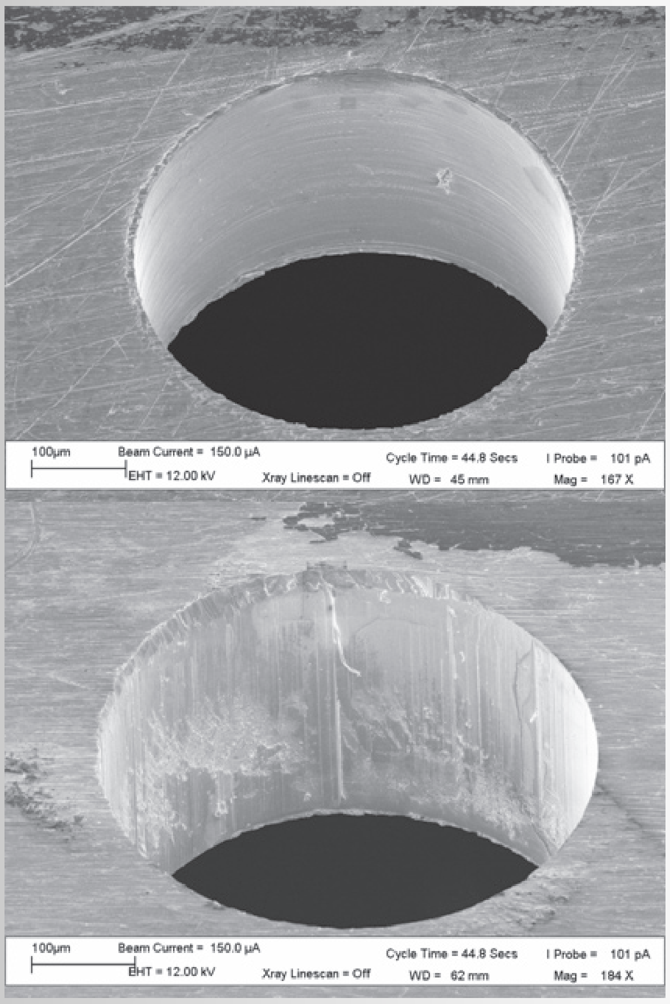


Repeated insertion/extraction of a 500µm diameter hard steel shaft into a 300µm thick Brass hub. Insertion is indicated as a positive force while extraction is negative. The first insertion/extraction is plotted in blue and the second in red.

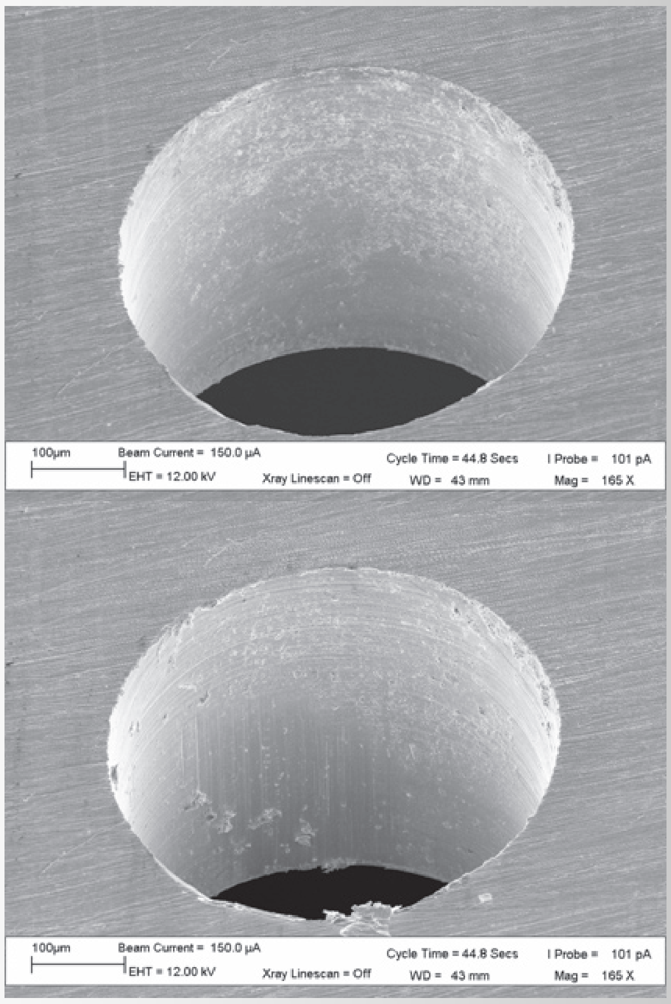
Stainless Steel



Repeated insertion/extraction of a 500µm diameter hard steel shaft into a 300µm thick Stainless Steel hub. Insertion is indicated as a positive force while extraction is negative. The first insertion/extraction is plotted in blue and the second in red.



SEM image of brass hub before and after insertion.
Note significant change is sidewall morphology.



SEM image of stainless steel hub before and after insertion.
Note less significant change in sidewall morphology.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Analytical Models

Geometric Effects

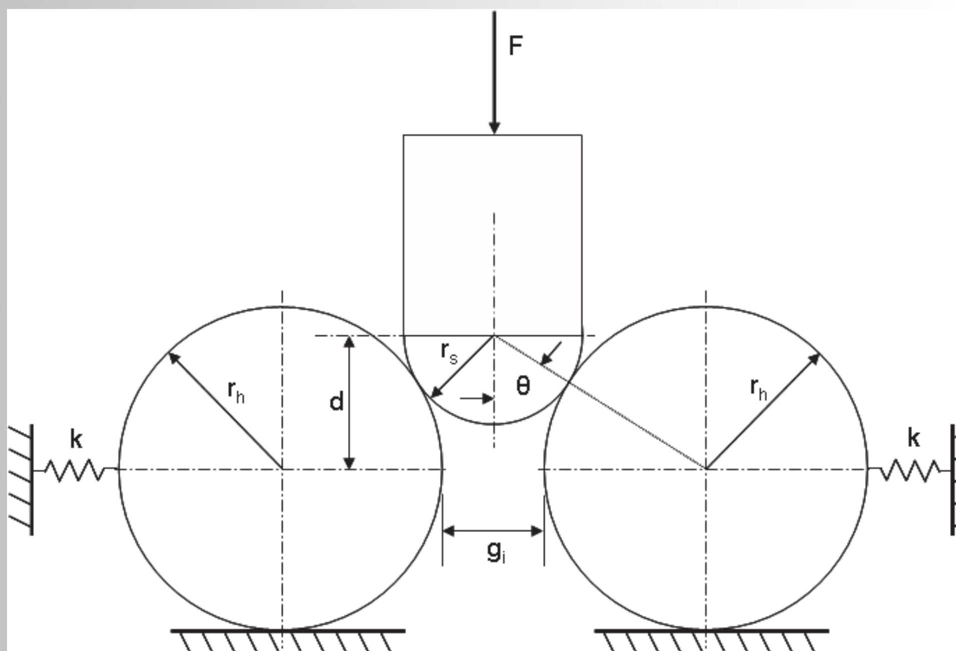
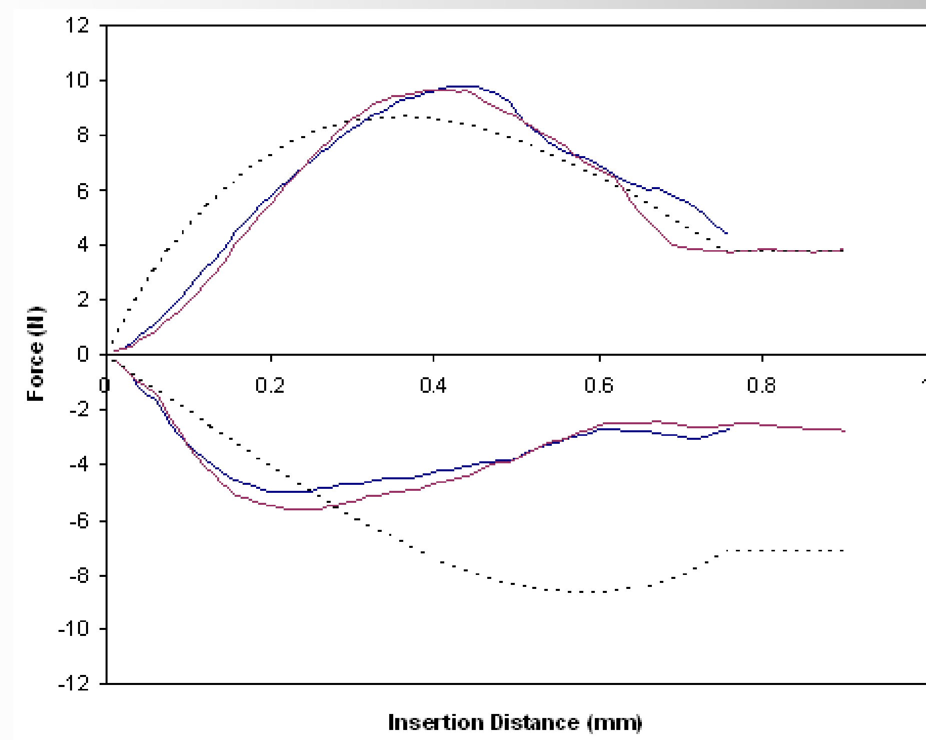


Diagram of interference fit insertion/extraction which accounts for curved hub sidewalls and bulged shaft



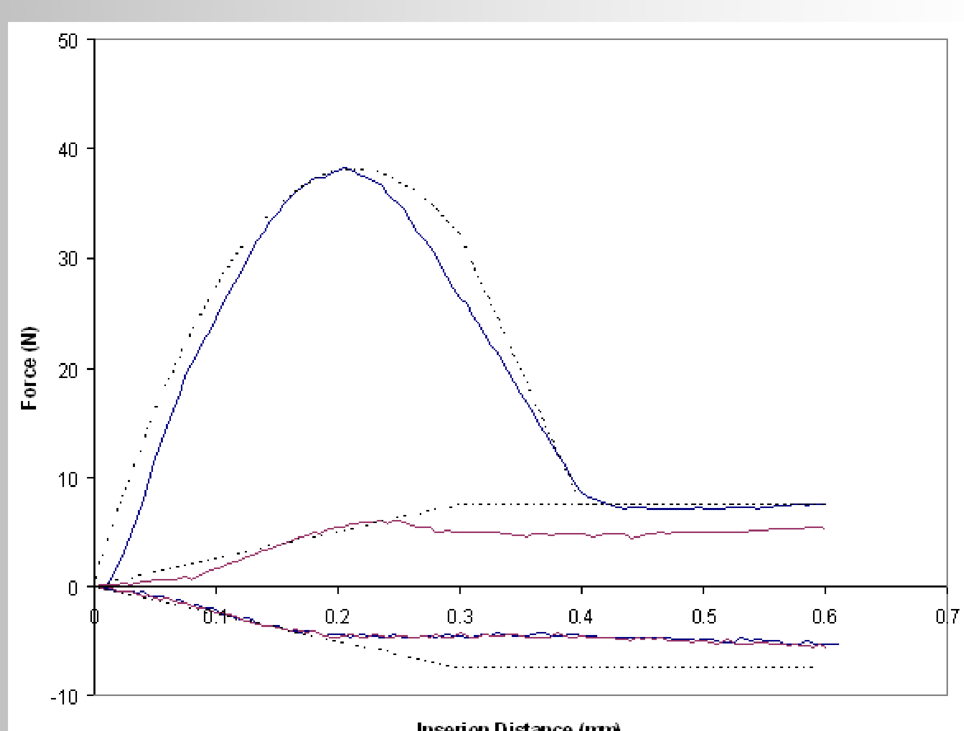
Insertion/extraction force curves calculated (dashed line) compared with LIGA hub experimental data. Calculation assumes curved hub sidewall and burr on shaft chamfer.

$$F_I = \frac{2k[(r_s+r_h)\sin\theta-(r_h+{}^1/_2\, g_i)](\cos\theta+\mu\sin\theta)}{(\sin\theta - \mu\cos\theta)}$$

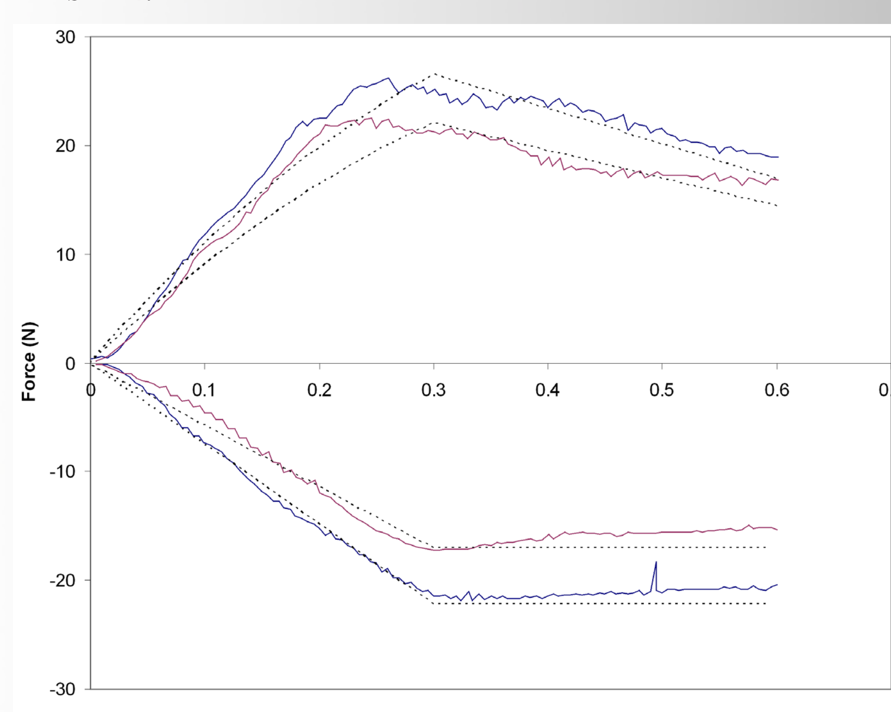
$$F_E = -\frac{2k[(r_s+r_h)\sin\theta-(r_h+{}^1/_2\, g_i)](\mu\sin\theta-\cos\theta)}{(\mu\cos\theta + \sin\theta)}$$

Varying Friction

$$F = \tfrac{1}{2}\, \mu(x)\pi\, E(d_s-d_h)L$$



Insertion/extraction force curves calculated with varying friction (dashed line) compared with Brass hub experimental data. Calculation assumes decreasing friction on first insertion.



Insertion/extraction force curves calculated (dashed line) compared with Stainless Steel hub experimental data. Calculation assumes decreasing friction on both insertions.

Conclusions

- Of significance is that the force required to create an interference fit assembly is not necessarily a good indicator of the assembly's resistance to disassembly.
- From the experimental data it appears that the performance of an interference fit assembly is a complex function of material characteristics (modulus and ductility) and fabrication processes used to form the parts (surface roughness which affects the coefficient of friction, small residual burrs, etc.).

Sandia National Laboratories