NSTX

13-040528-CLN-01

TO: DISTRIBUTION
FROM: C NEUMEYER
SUBJECT: 2D IN-PLANE ANALYSIS OF TF JOINT

Summary of Results

A 2D transient thermal analysis of the TF joint has been performed using the finite element program FEMLAB.

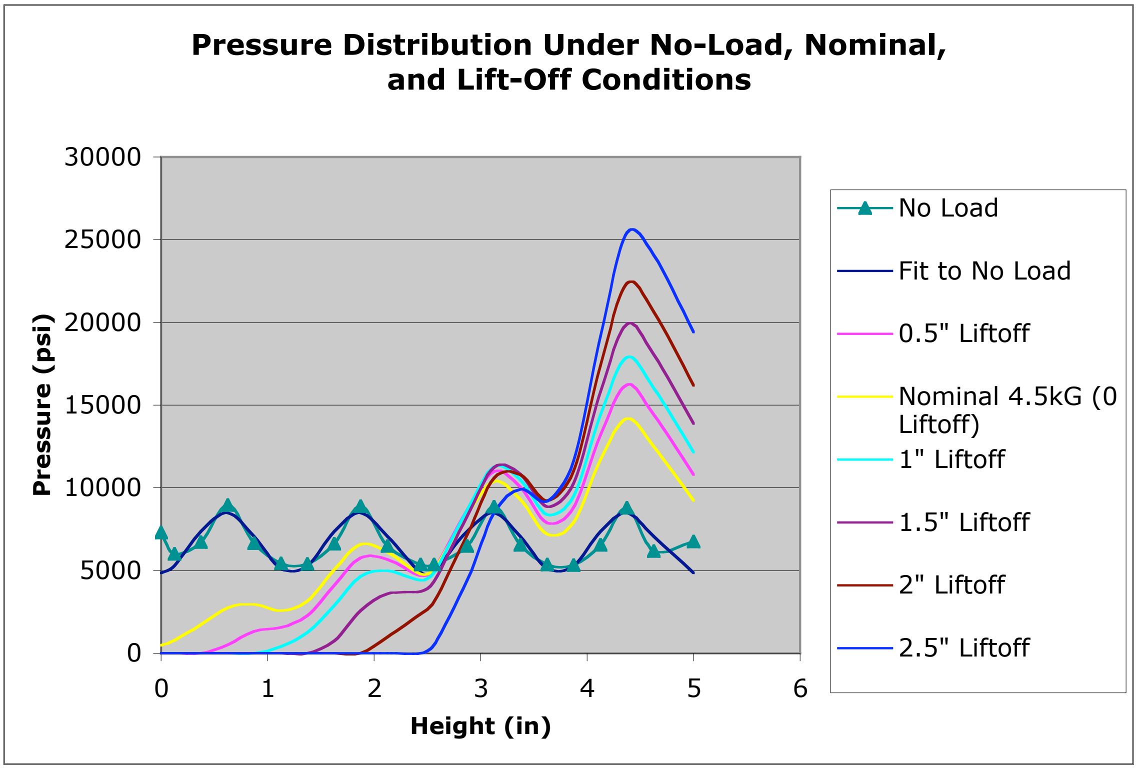
The joint contact is simulated using a 1mm layer with copper properties except conductivity (electrical and thermal) is varied according to pressure. Conductivity vs. Pressure data is based on measurements made on a prototype joint in March 2004.

The model is 2D, but the copper conductivity is varied according to the conductor and flag depth in the third dimesion, and is varied to simulate the volume lost to the inserts and bolt holes.

Pressure distribution is modeled as a linear function with superimposed sinusoid to simulate the effect of the inserts. Pressure distribution is skewed based on an input parameter. Liftoff is allowed. Total force is maintained constant no matter the pressure distribution. For transient analysis the amount of skew is assumed to be based on the ratio (Itf/Itf_flat)^2.

The voltage probe signal is simulated by integrating the electric field gradient from the contact surface along the flag to the point where the probe barrel makes its last point of electrical contact with the flag.

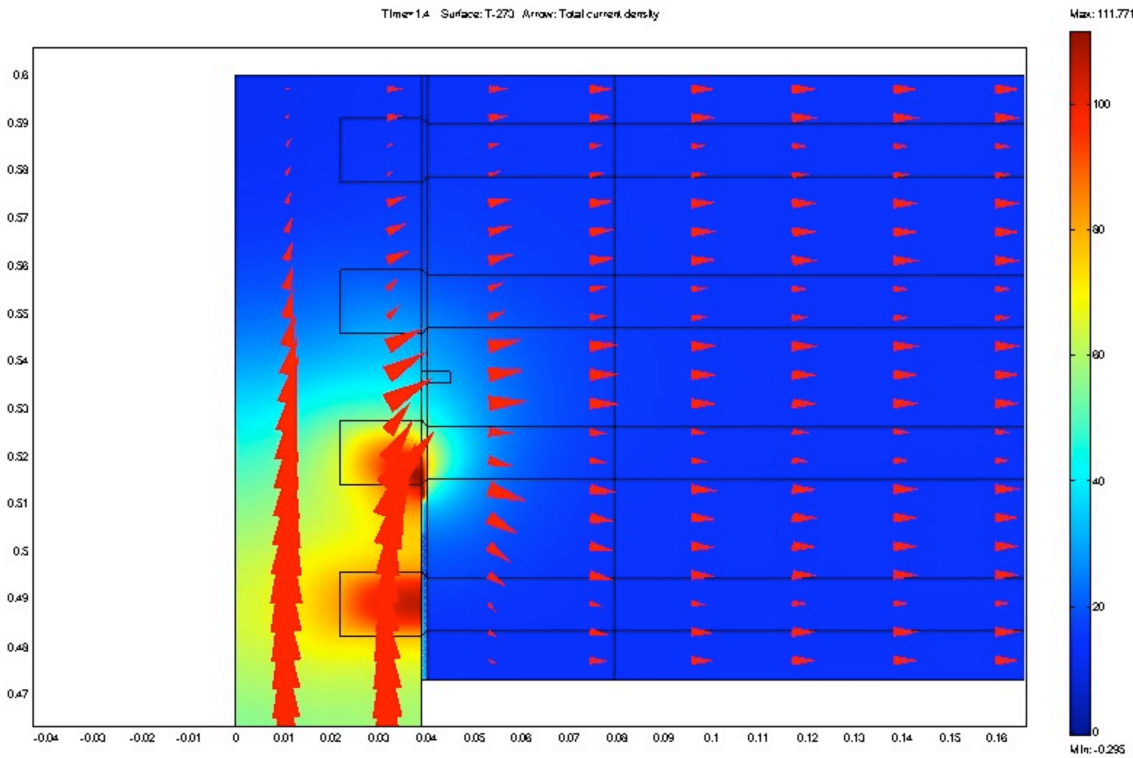
Multiple runs were made for 4.5kG, 1.0 second flat top with differing amounts of liftoff, from 0 to 2.5”. Pressure profiles are shown in the following figure.



Data was obtained for peak temperature, peak voltage probe reading. In addition waveforms for temperature vs. time were saved for the location corresponding to that of the fiber optic temperature probe which is installed on some of the NSTX joints.

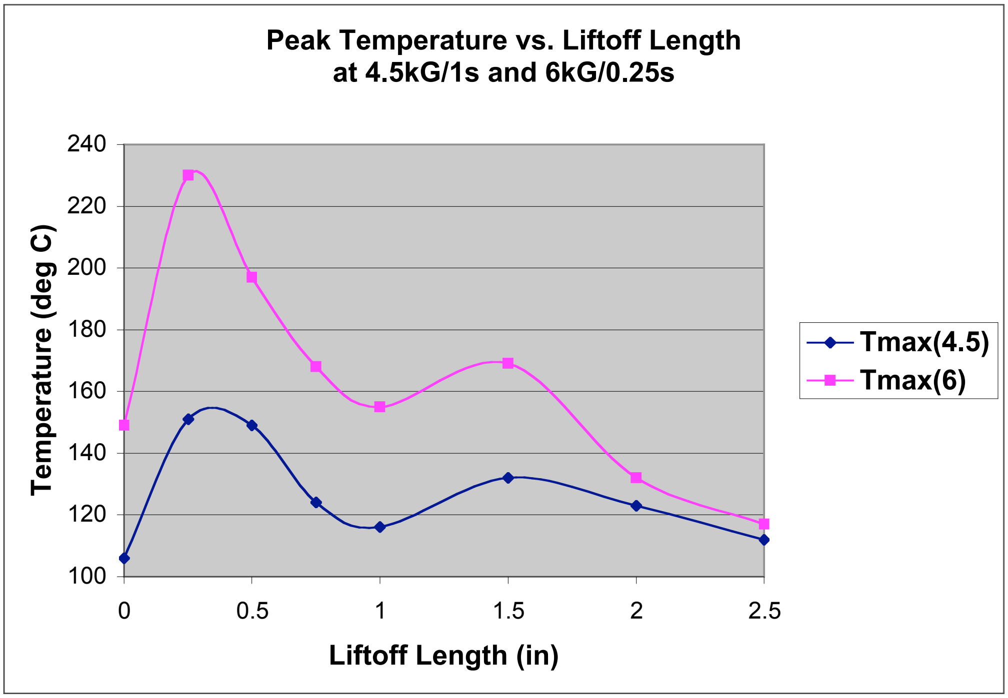
An interesting phenomenon was noted, namely that the peak temperature due to liftoff does not increase directly with the extent of liftoff. Instead, the peaks are maximized when the liftoff length correlates with the location of the threaded inserts. This is to be expected because the peak current density occurs at the point where the liftoff ends, and if that point coincides with the inserts, the cross section available to carry the current is minimized.

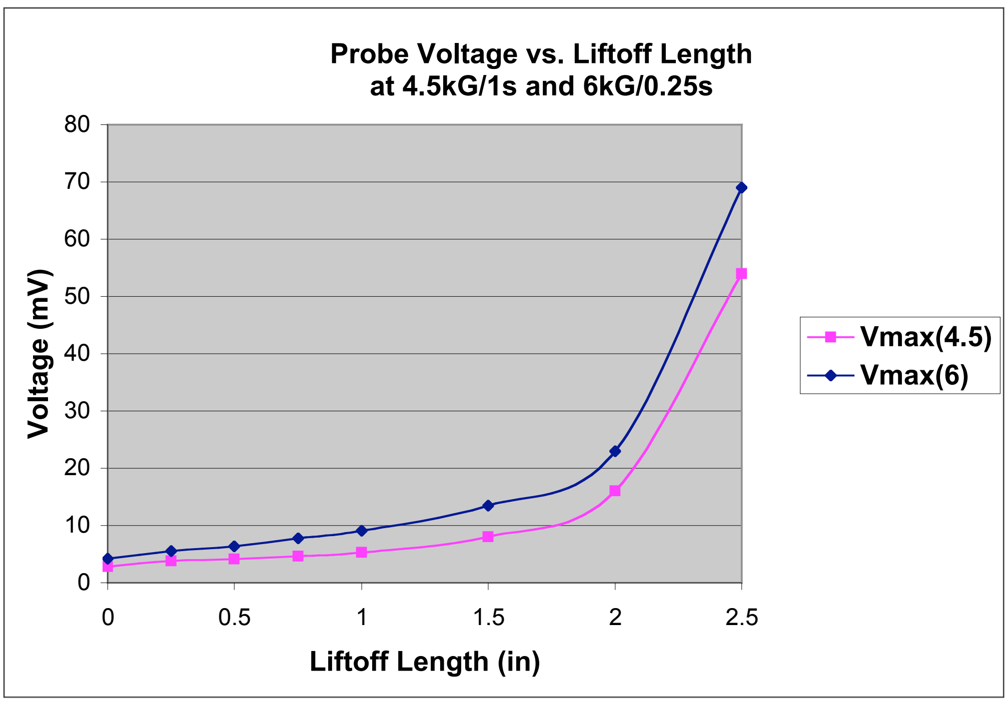
A typical case showing the peak heating at the insert is shown in the following figure (4.5kG/1s, 1.5” liftoff length).



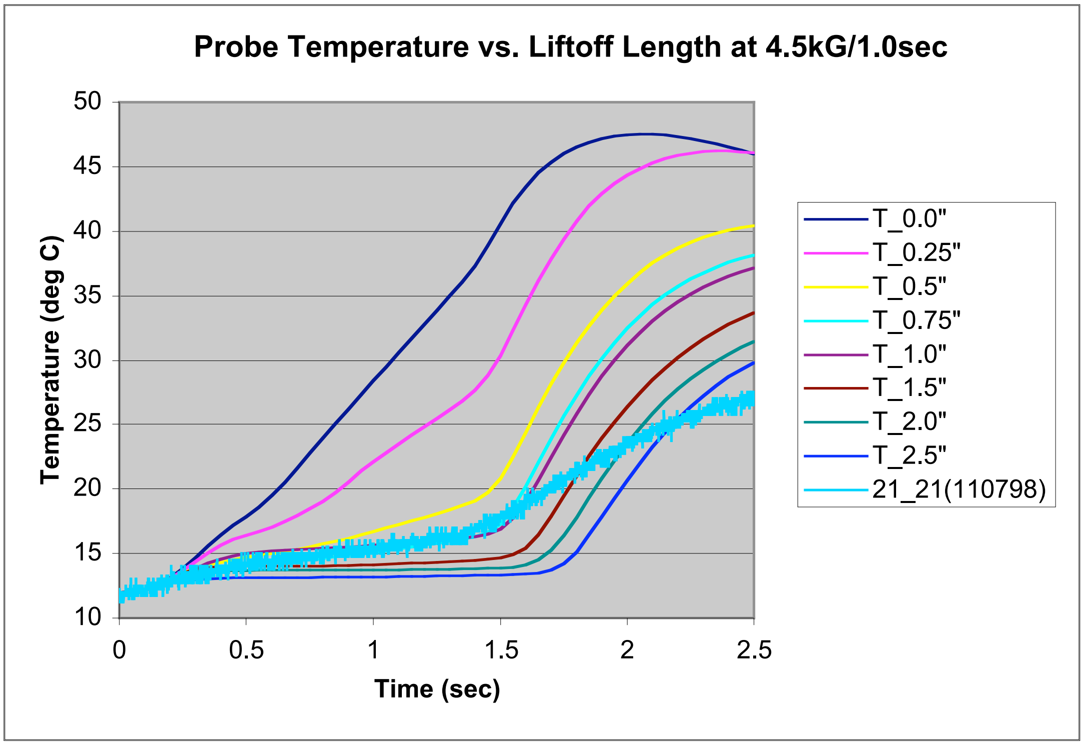
Additional runs were made at 6.0kG. Flat top time was limited to 0.25 seconds due to excessive temperature rise. At longer flat tops, and higher temperatures, thermal runaway was observed to occur, where the increasing temperature caused increasing resistance which caused increasing temperature, etc.

Curves of peak temperature and peak probe voltage are given in the following figures. Note the correlation of peak temperature with the insert locations. Slightly higher temperatures would likely have been obtained if the simulated liftoff lengths near the inserts (0.25” and 1.5”) had been precisely aligned with the lower elevation of the inserts (0.22” and 1.47”).





Comparing these results to measurements made on NSTX, it would appear that joint 22_22 (the worst one) experiences a liftoff of order 1" to 1.5" during 4.5kG TF-only operations and that 16_16 experiences little or no lift-off. This is further corroborated by the signals from 21_21 taken during the ISTP. This joint includes the fiber optic temperature measurement. The voltage probe signal along with the temperature measurement (shown in the following figure superimposed with the FEA results) indicates a liftoff or order 0.5" to 0.75".



Note that the actual measured data tracks the FEA result for 0.75" liftoff quite well during the initial period but not very well afterwards. This may be explained by the effect of the water cooling, which is not modeled in the FEA.

These results predict that peak temperatures are at present (with 4.5kG operations) reaching ~ 150C for TF-only in-plane (IP) operations. Higher temperatures would be expected with the addition of out-of-plane (OOP) loads. However, the extent of this is not known at this time.

One can speculate that 6kG operation might increase the skewedness of the pressure disribution in proportion to the square of the current, e.g. (6/4.5)=1.77, in which case a 1" liftoff would increase to 2.3". In any case, liftoff lengths correlating to the locations of the threaded inserts are to be expected.

It should be pointed out that this analysis does not include several physical effects which may be important in determining the outcome. These include the following...

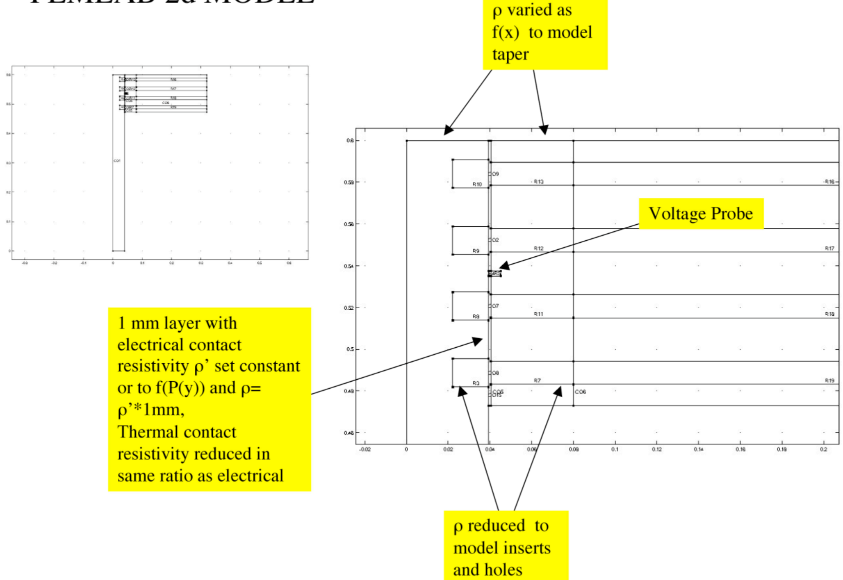
- $\int I^2T$ will change the pressure distribution, probably in a favorable way not accounted for herein. Pressure distribution at the end of flat top will be more favorable than that at the start of flat top. Pressure distribution is assumed only a function of I^2 herein.
- Local temperature increase will result in a local (favorable) pressure increase not accounted for herein.
- The detailed pressure distribution around the inserts is not modeled herein.

The 3D ANSYS analysis presently underway is expecteed to provide more information related to these points, along with the inclusion of OOP loads.

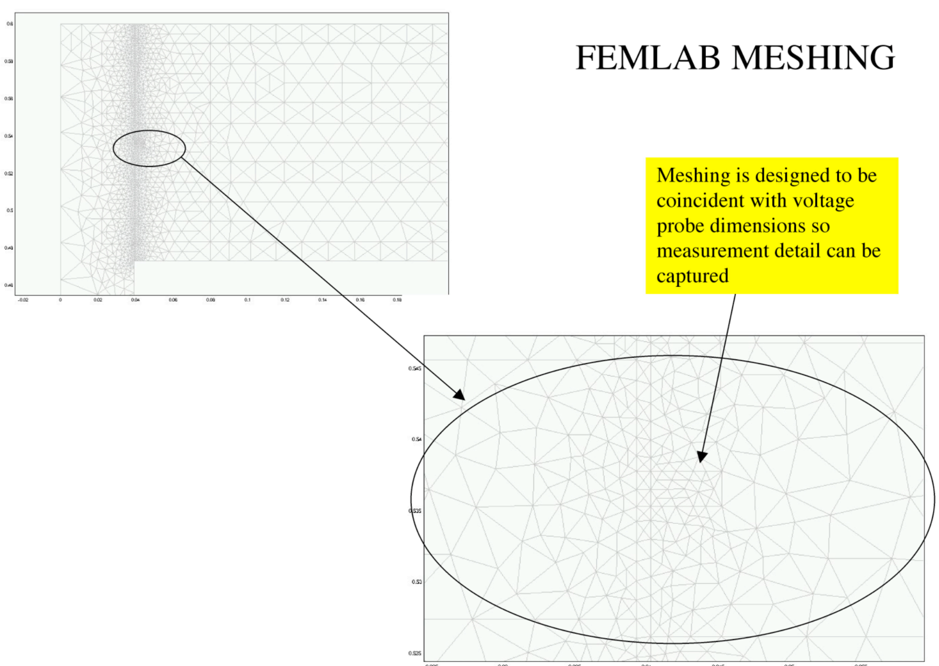
Modeling Information

FEMLAB model and mesh density are shown in the following figures.

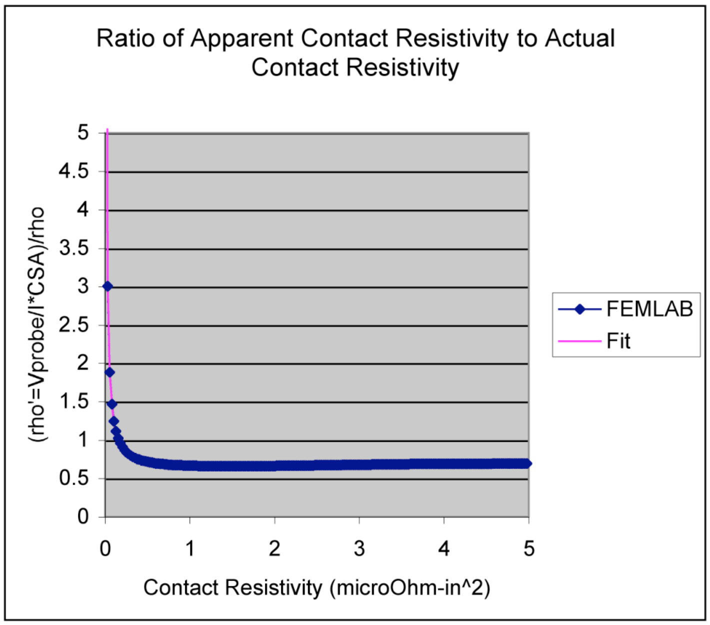
FEMLAB 2d MODEL



FEMLAB MESHING



In order to develop a means for translating the resistance measurements made by H. Schneider in March into a resistivity vs. pressure curve, FEMLAB runs were first made using constant contact resistivity across the joint. Using these results a function was derived using a least squares fit to the FEMLAB data which relates apparent resistivity to measured resistivity for the 90 degree configuration. Fit results are shown in the figure below.

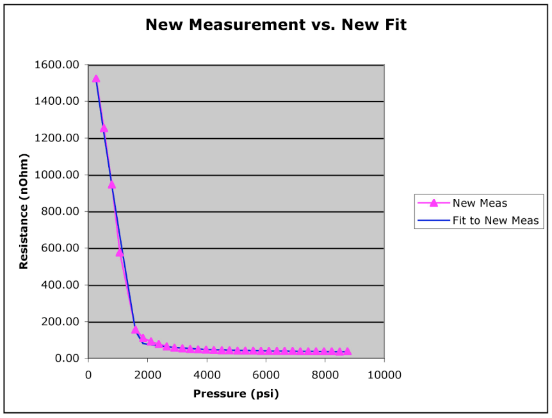


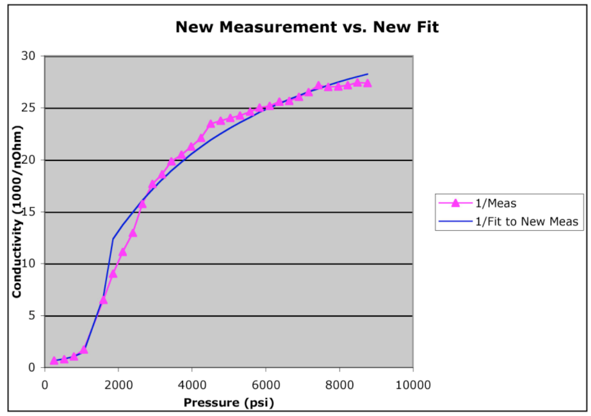
Obtained by varying ρ with uniform distribution across joint

Fit: Ratio = A*ρ^B+C* ρ ^D

A	0.080
B	-0.993
C	0.589
D	0.088

Then an equation for resistivity vs. pressure was derived from the above and from the measurement data as shown in the following figure. This equation was used in the subsequent FEMLAB runs.



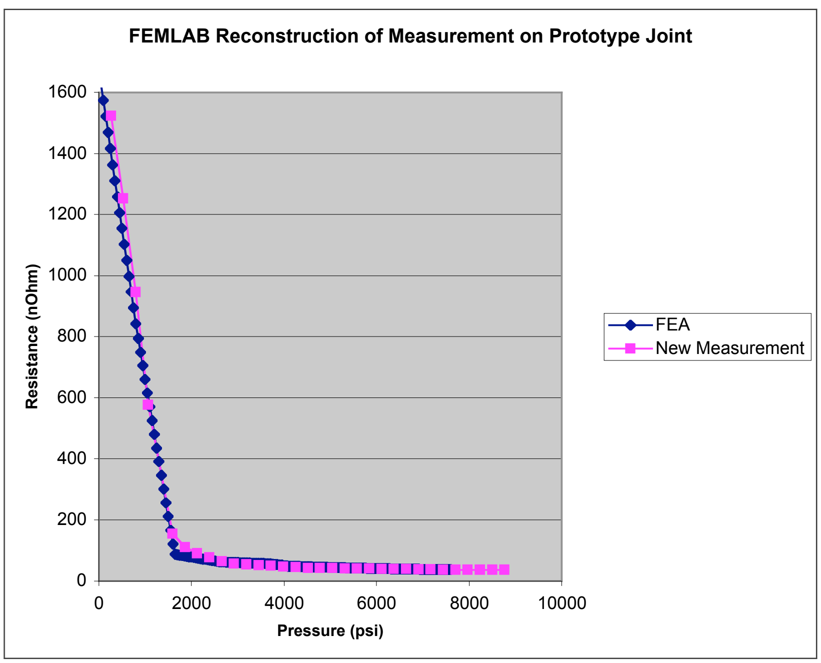


Fit: $\rho = \max(KA+KB*P, KC*P)^{\wedge}KD$

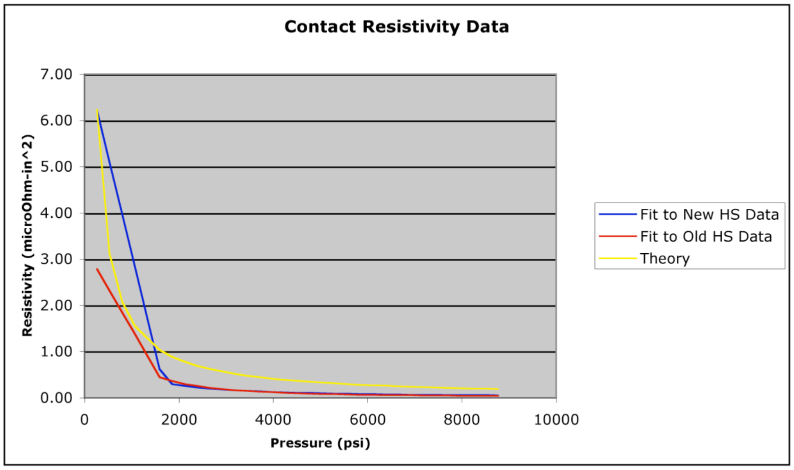
Resistance = $CSA*Ratio(\rho(P))$

KA	7.336E+00
KB	-4.218E-03
KC	1.178E+03
KD	-1.102E+00

As a check, the new function incorporated into FEMLAB was able to reproduce measurements quite well as shown in the figure below.



A comparison of the basic resistivity fit with others is shown in the figure below.



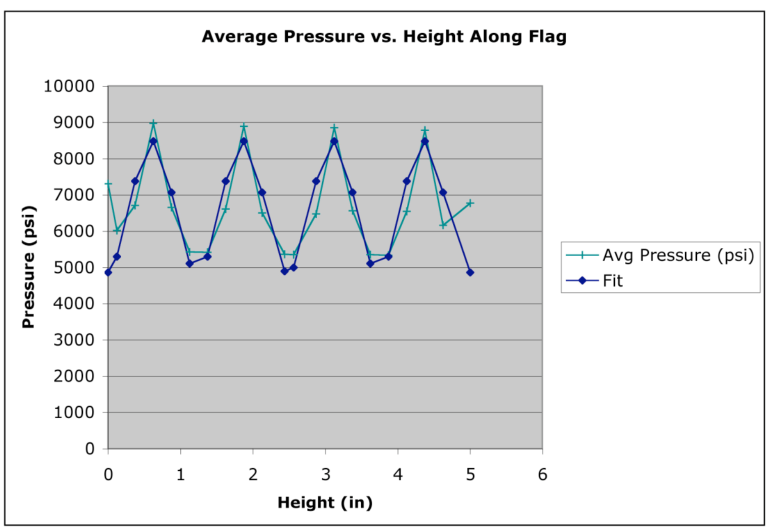
HS = H Schneider data

Theory = "A Survey of Contact Resistance TheoryFor Nominally Clean Surfaces",
W. Ittner, P. Magill, IBM Journal, January 1957

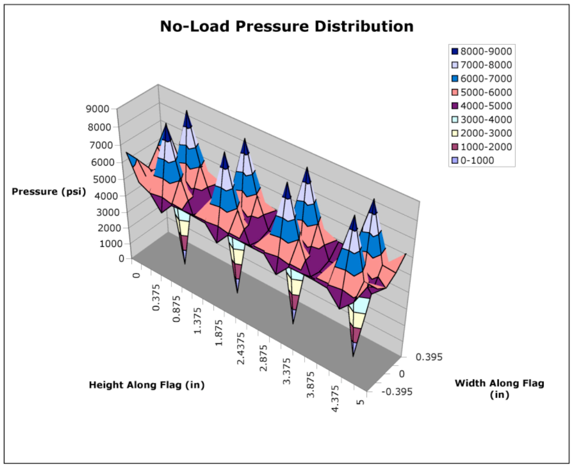
For Silver: ρ=1.9e-6, p=2e6, σ=2.2e9, ϕ=4.73, s=4.0
Rfilm=σ*p/F, Rcontact=(ρ*p^1/2*π^1/2)/(2*F^1/2), Rtotal=Rfilm+Rcontact
where F is force in grams

To account for the pressure disribution variation where the inserts are located, data from an I. Zatz FEA was used as shown below.

Pressure Distribution for 2d Model



Fit: P = Pavg + ΔP/2*sin(ωz+ϕ)
where Pavg=6667,ΔP=3634,ω=5.0265,ϕ=-1.482

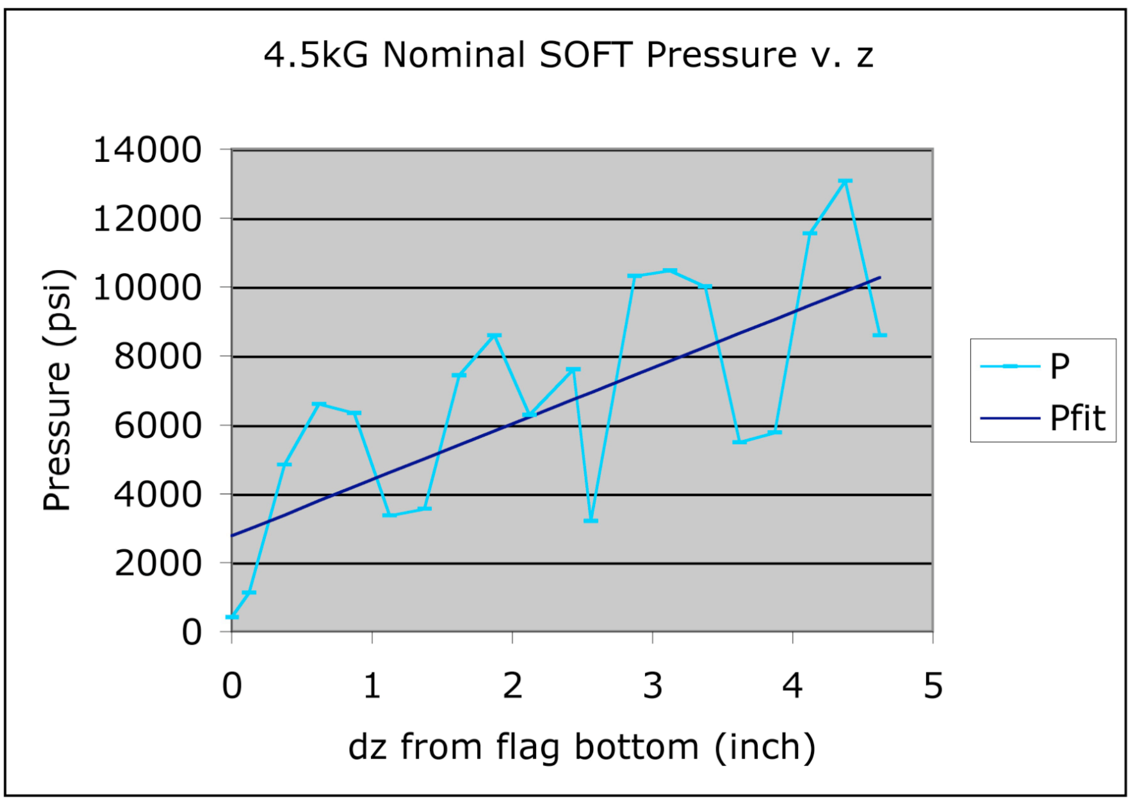


Pressure at Nodes

	-0.395	-0.1975	0	0.1975	0.395
0	6730	5939	5094	5933	6866
0.125	5314	4824	4541	4850	5339
0.375	5013	6161	4468	6158	5010
0.625	4143	8863	Bolt	8862	4142
0.875	4922	6127	4464	6127	4922
1.125	4965	4277	4103	4277	4966
1.375	4956	4272	4098	4272	4956
1.625	4910	6077	4410	6077	4910
1.875	4086	8798	Bolt	8798	4087
2.125	4905	5897	4412	5897	4906
2.4375	4914	4229	4050	4230	4915
2.5625	4908	4224	4045	4224	4909
2.875	4891	5878	4397	5879	4893
3.125	4056	8766	Bolt	8767	4058
3.375	4861	6039	4382	6040	4864
3.625	4894	4220	4047	4221	4898
3.875	4885	4208	4035	4210	4890
4.125	4821	6022	4394	6024	4827
4.375	4001	8702	Bolt	8711	4016
4.625	4781	5481	4294	5476	4787
5	6180	5457	5040	5410	6030

Pressure Distribution from I Zatz gap53na.txt for no-load (bolted only) condition

Also, the base case for 4.5kG operation, which has zero liftoff, was taken from an I Zatz FEA as shown below.



Pressure Distribution From I Zatz gap47.txt cc:

M Bell	M Ono	J Schmidt	A Von Halle	M Williams
R Woolley	I Zatz			