SWTW 2017

SW Test Workshop
Semiconductor Wafer Test Workshop

Vertical Probe Mechanical & Thermal-electrical Characterization using Finite Element Analysis

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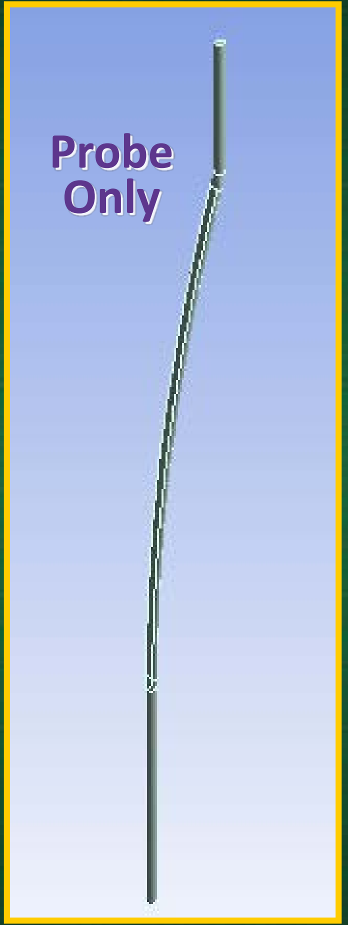
Overview

- **Objective**
- **Modeling Approach: SPM vs. ALM**
- **ALM Convergence**
- **Trio™ Probe Model**
  - BCF
  - Deflection
  - Stress Profile
  - Scrub
  - Thermal-electrical Behavior
- **Other Vertical Probe Models: SmartTouch™**
- **Conclusion**

Objective

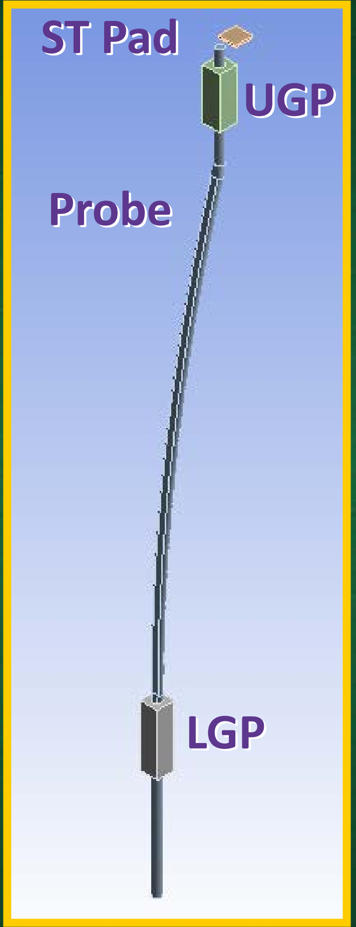
- **Speedy vertical probe characterization with validated FEA probe models**
  - BCF Validation
  - DOE Size Reduction
- **Performance evaluation of vertical probes at extreme testing conditions**
  - CCC under high temperature & high current

Modeling Approach



Single Probe Model (SPM)

VS.



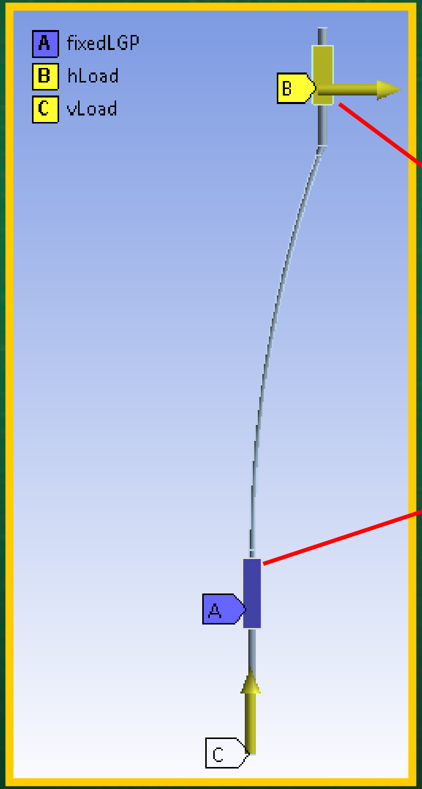
Assembly Level Model (ALM)

- **Single Probe Model (SPM)**
  - Probe only geometry
  - Artificial boundary conditions
  - Linear system with short runtime
  - Higher stiffness than the experimental setup
- **Assembly Level Model (ALM)**
  - Probe & components in contact with the probe
  - Frictional contact conditions
  - Highly non-linear system with long runtime & difficult to converge
  - Matching stiffness to the experimental setup with fine tuned contact conditions

ALM Convergence

Non-linear contact models with gaps often face convergence issues, which require fine tuning of the contact conditions for the most accurate output. At times, some compromises in contact conditions are necessary to achieve convergence.

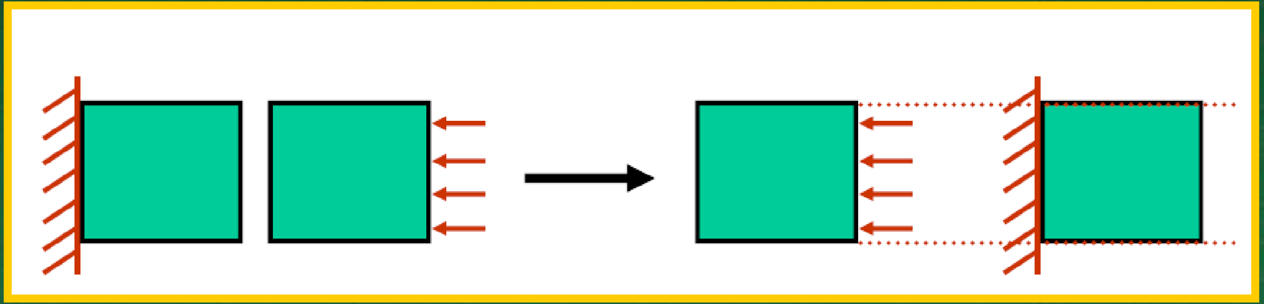
- **Major parameters to be adjusted in contact conditions include:**
  - Mesh Density (especially in contact regions)
  - Coefficient of Friction (u)
  - Contact Interface Treatment
  - Normal Stiffness Factor (n)



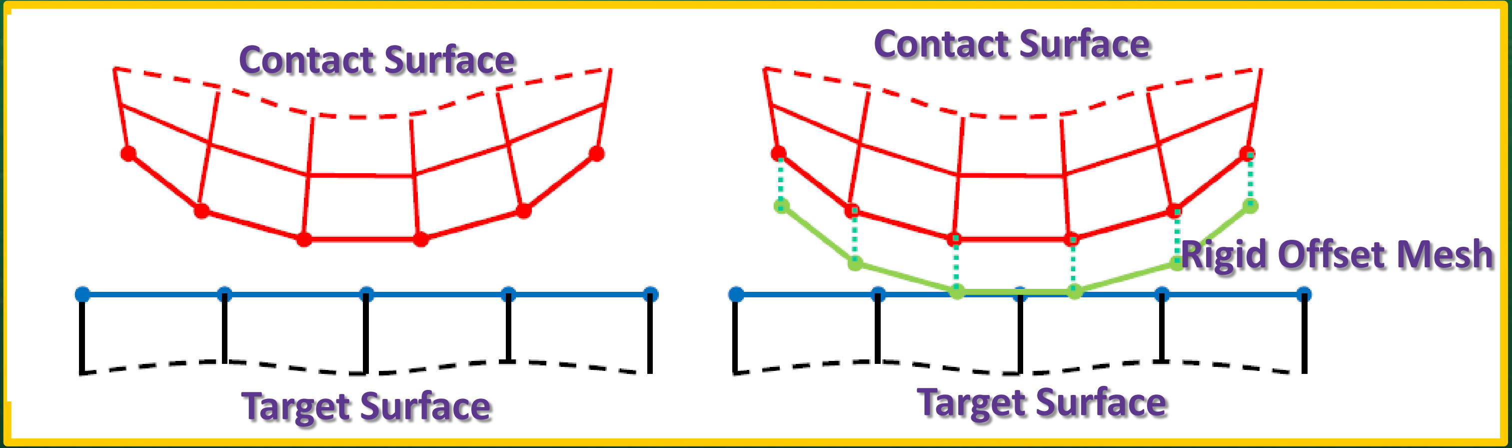
Gaps between probe & guide plates allow rigid body motion in FEA.

ALM Convergence: Contact Interface

Certain contact interface treatment or gap treatment in FEA codes allow establishment of contacts prior to loading, to prevent rigid body motion; or leave gap as is. It is crucial to choose the correct or the most appropriate gap treatment at different contact surfaces.



Rigid Body Motion

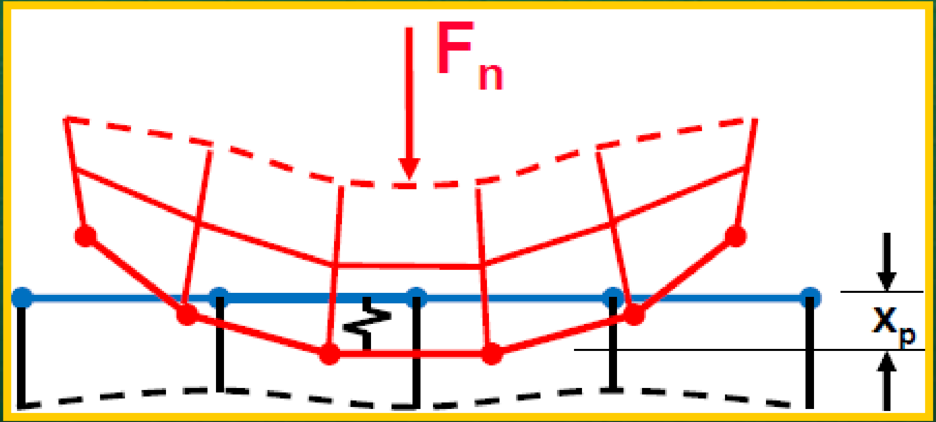


Contact Interface Treatment

Reference: *ANSYS Inc. "Introduction to Contact." Web.*

ALM Convergence: Normal Stiffness

- **Normal stiffness in contact:**
  - When two separate surfaces touch each other & become mutually tangent, they are considered in contact
  - Surfaces in contact should not interpenetrate & be able to transmit compressive normal forces & tangential friction forces
  - FEA solvers often use normal stiffness in penalty based contact formulations to enforce contact compatibility
  - Lower normal stiffness factor relieves convergence issues due to high contact force, but it causes more penetration



Normal Stiffness & Penetration

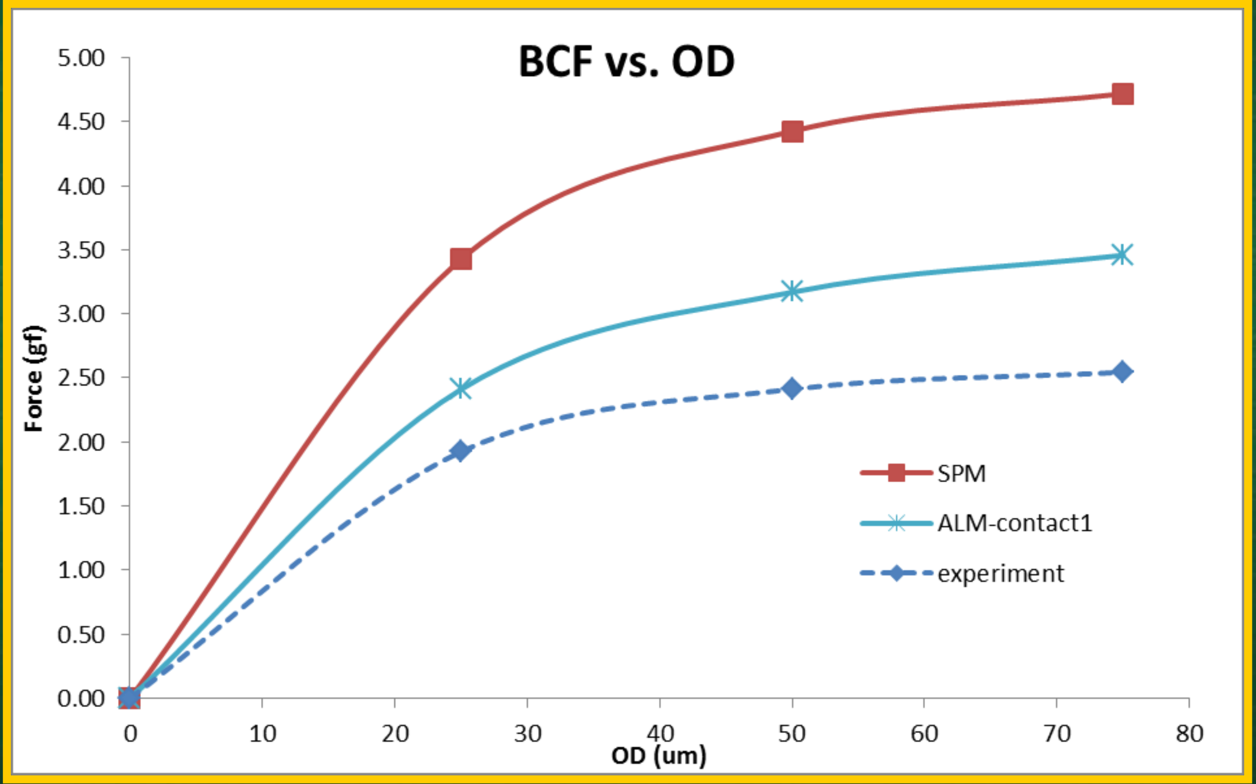
$$F_{normal} = k_{normal} x_{penetration}$$

Ideally, $x_{penetration}$ should be zero and k_{normal} should be infinite, which is numerically impossible.

Reference: *ANSYS Inc. "Introduction to Contact." Web.*

Trio™ Probe Model: BCF

The above-mentioned modeling approach is applied to SV TCL's Trio™ probe (a Cobra-style probe). The experimental BCF results are plotted with the SPM & ALM BCF data for the 1.5 mil probe as below.



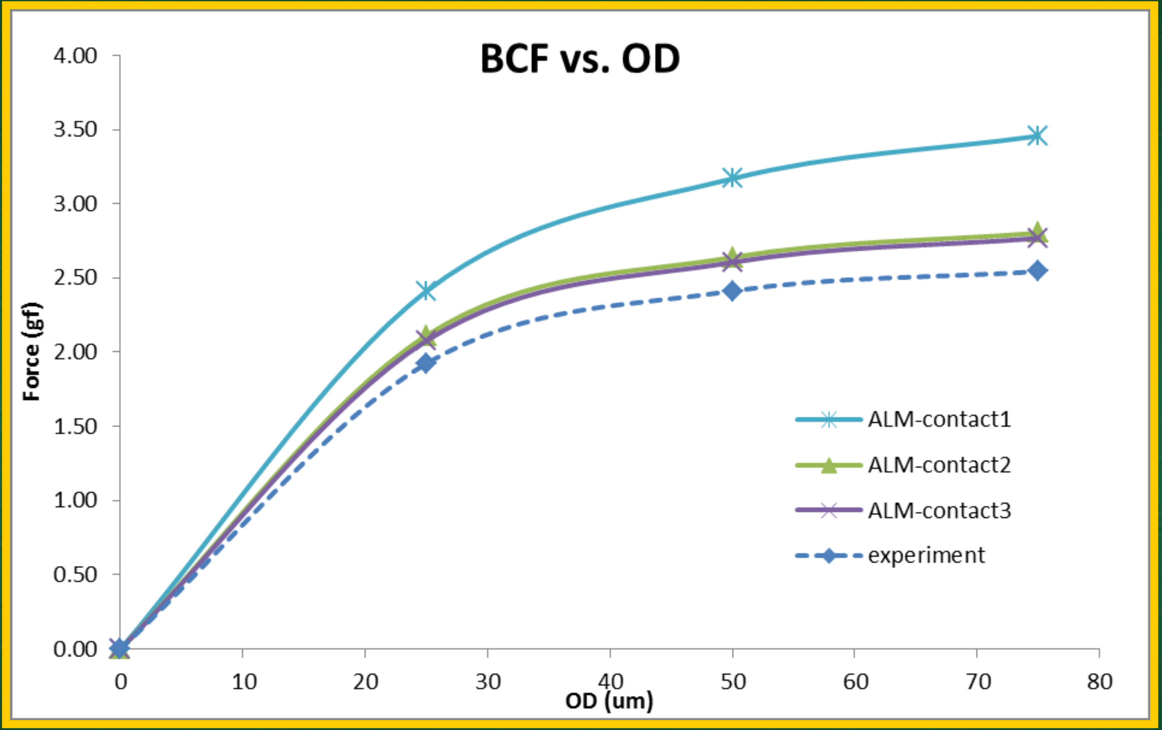
BCF Results on 1.5 mil Trio™

	BCF (gf)	Error (%)
SPM	4.72	+86%
ALM-contact1	3.46	+36%
Experimental	2.54	

Trio™ Probe Model: BCF (cont.)

With proper contact conditions, the Trio™ probe ALM can accurately predict BCF to +9% on the 1.5 mil probe.
As shown, contact 2 & contact 3 models have similar BCF results. Depending on the purpose of a study, either contact 2 or contact 3 model can be selected, i.e. contact 2 is more accurate for LGP stress analysis.

	ALM-contact1	ALM-contact2	ALM-contact3
Coefficient of Friction	a	b	b
Normal Stiffness Factor	x	x	x
UGP Contact	t	t	s
LGP Contact	t	s	t
BCF (gf)	3.46	2.80	2.77
Error (%)	+36%	+10%	+9%
Experimental BCF = 2.54 gf			

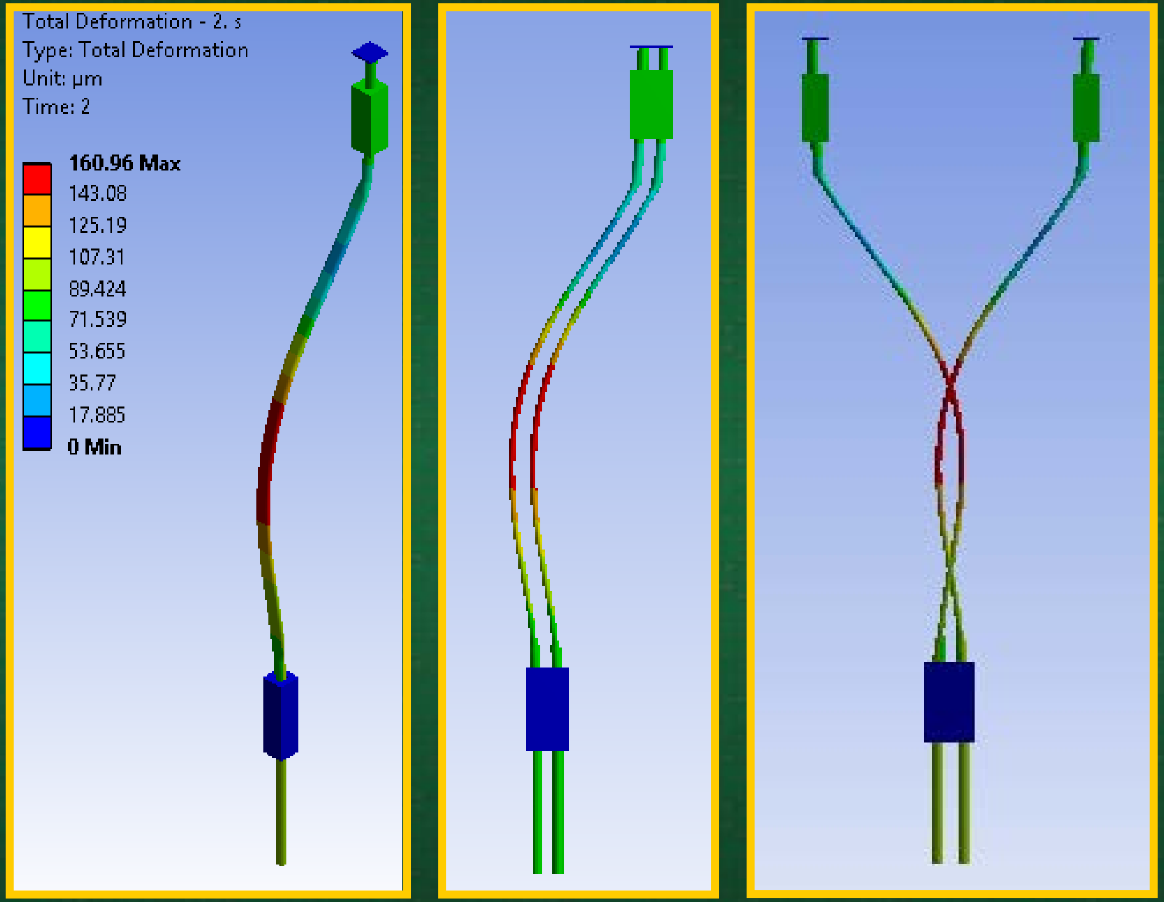


BCF Results on 1.5 mil Trio™

Trio™ Probe Model: Deflection

Probe deflection profiles can help visualize probe interactions under various configurations. For Trio™ probes, the deflection mode is predetermined by the direction of the stamped ribbon regardless of the contact conditions.

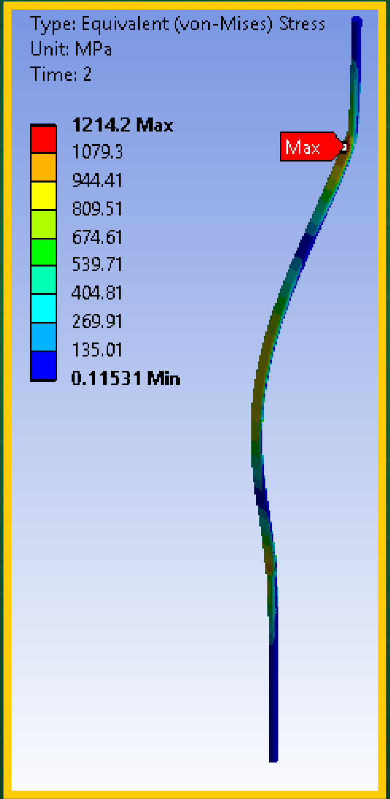
On other vertical probes, the deflection mode is highly dependent on contact conditions between the probe & the guide plates. The deflection profile is necessary for BCF matching & contact tuning.



Example of 1.5 mil Trio™ Probe Deflection Profiles

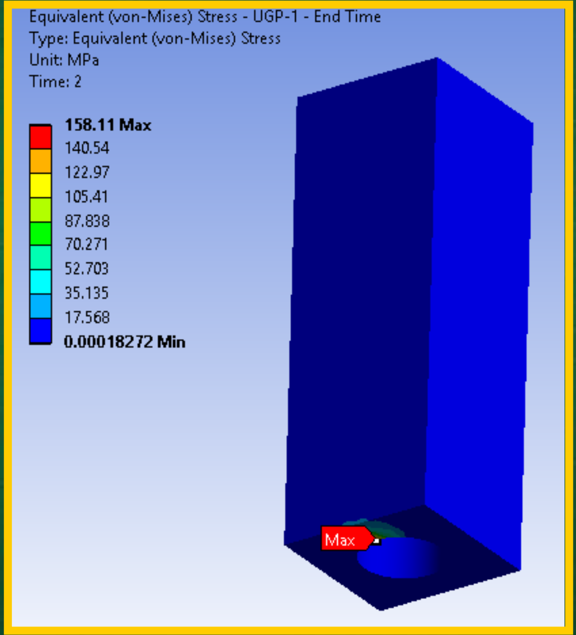
Trio™ Probe Model: Stress Profile

Stress profiles on the probe & the guide plates indicate the probe overdrive tolerance & frictional effects between the probe & guide plates.



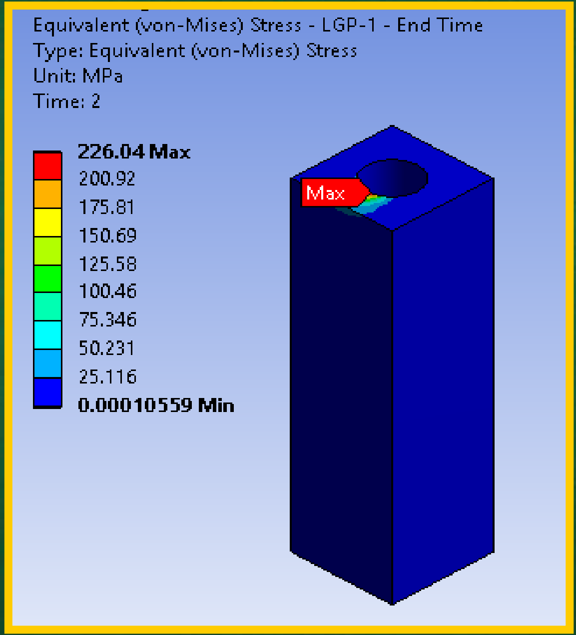
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 2

Stress on 1.5 mil Trio™ Probe



Equivalent (von-Mises) Stress - UGP-1 - End Time
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 2

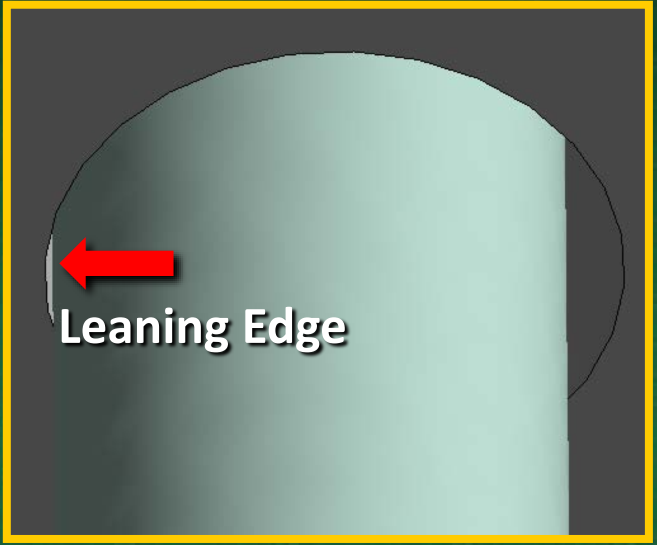
Stress on 1.5 mil Trio™ UGP



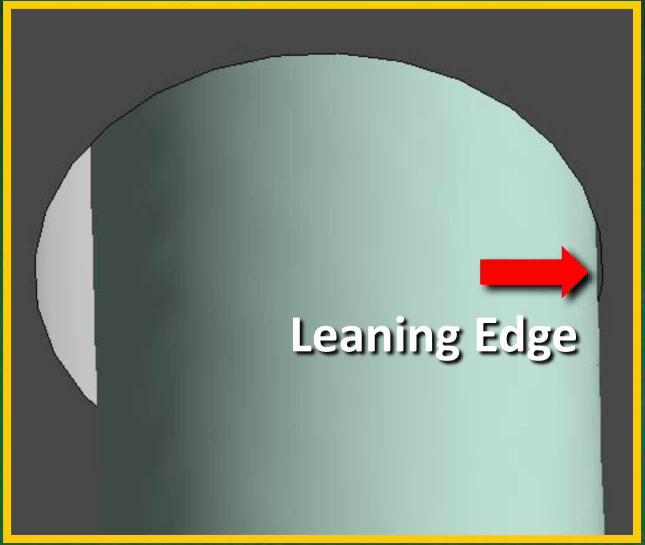
Equivalent (von-Mises) Stress - LGP-1 - End Time
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 2

Stress on 1.5 mil Trio™ LGP

Trio™ Probe Model: Scrub

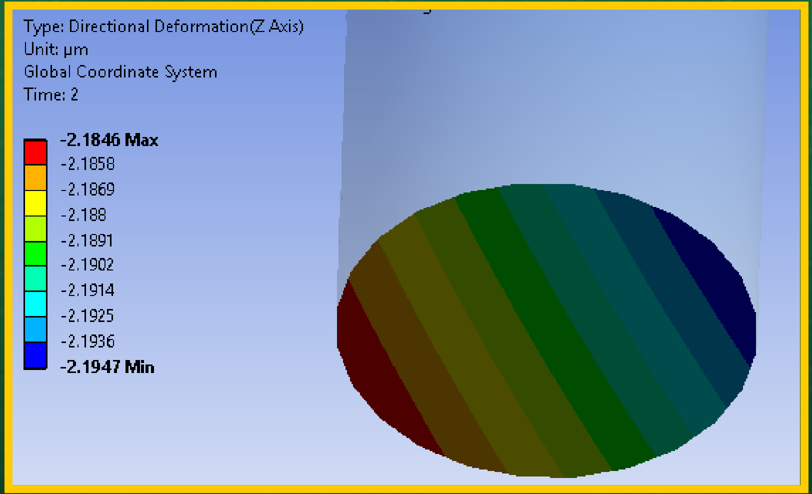


Probe in LGP before Overdrive



Probe in LGP after Overdrive

The 1.5 mil Trio™ model predicts a scrub length of 4.4 µm (2.2 µm *2), close to an experimental measurement of 5 µm scrub on a glass surface.

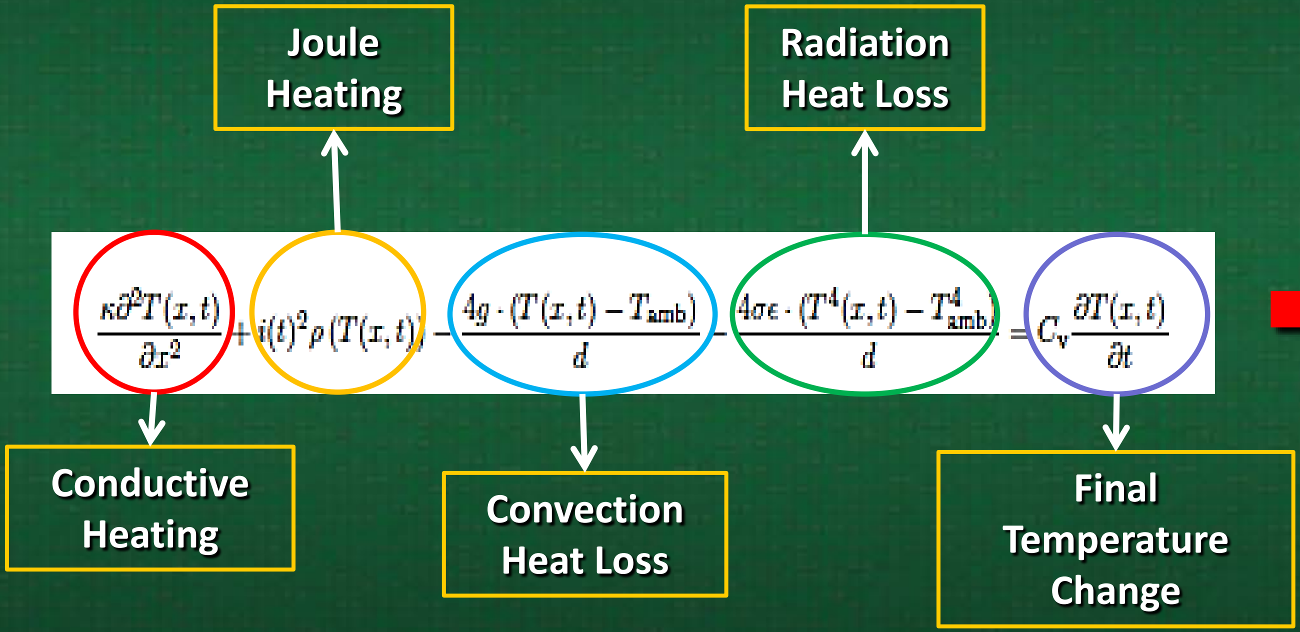


Type: Directional Deformation(Z Axis)
Unit: µm
Global Coordinate System
Time: 2

Scrub Length on 1.5 mil Trio™

Trio™ Probe Model: Thermal-electrical

For high temperature and high current applications, the following heat equation governs the temperature change on the probes. The ALM Trio™ model can be modified for thermal-electrical studies to better capture all the heat terms in the equation. This ALM variation assists to evaluate the current carrying capability (CCC) of Trio™ probes under ISMI-CCC standard.



$$\kappa\frac{\partial^2 T(x,t)}{\partial x^2} + i(t)^2\rho(T(x,t)) - \frac{4g\cdot(T(x,t)-T_{\text{amb}})}{d} - \frac{4\sigma\epsilon\cdot(T^4(x,t)-T^4_{\text{amb}})}{d} = C_v\frac{\partial T(x,t)}{\partial t}$$

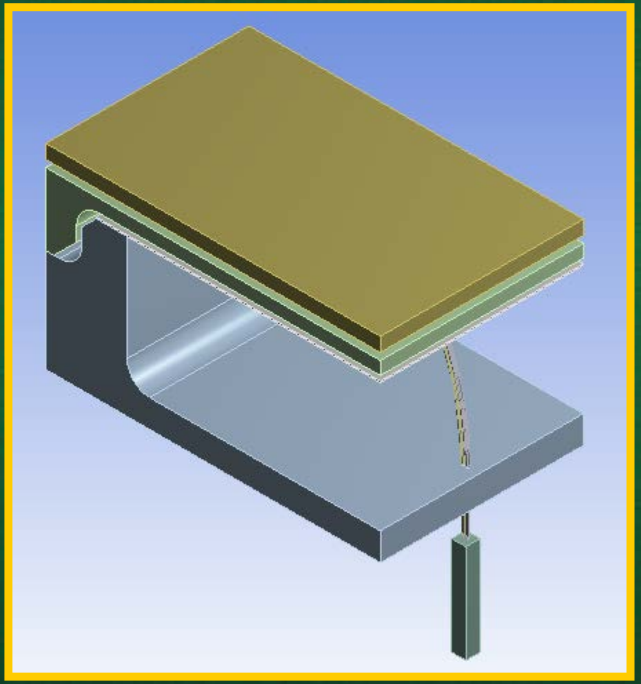
Joule Heating

Radiation Heat Loss

Conductive Heating

Convection Heat Loss

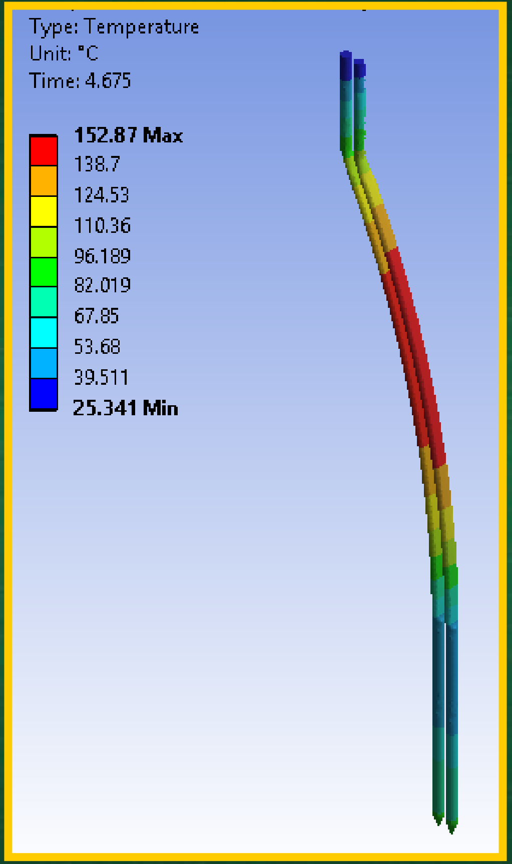
Final Temperature Change



Modified ALM

Reference: *Wang, Xuan, Natnael Behabtu, Colin C. Young, Dmitri E. Tsentalovich, Matteo Pasquali, and Junichiro Kono. "High-Ampacity Power Cables of Tightly-Packed and Aligned Carbon Nanotubes." Advanced Functional Materials 24.21 (2014): 3241-249. Web.*

Trio™ Probe Model: Thermal-electrical (cont.)



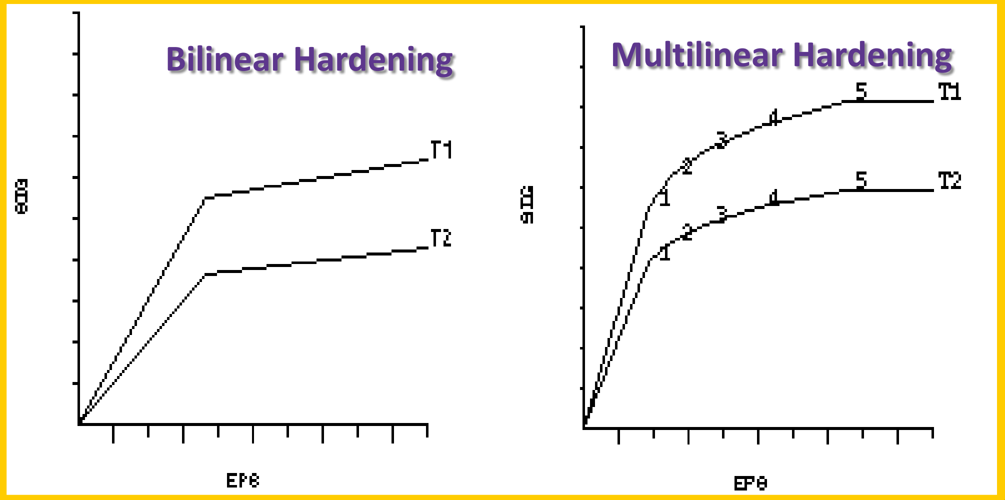
Temperature on 2 mil Trio™ probe
(average current = 500 mA at 25 C)

In the example here, Joule heating & conductive heating effects are observed on the probes as the temperature rises due to the flowing current.

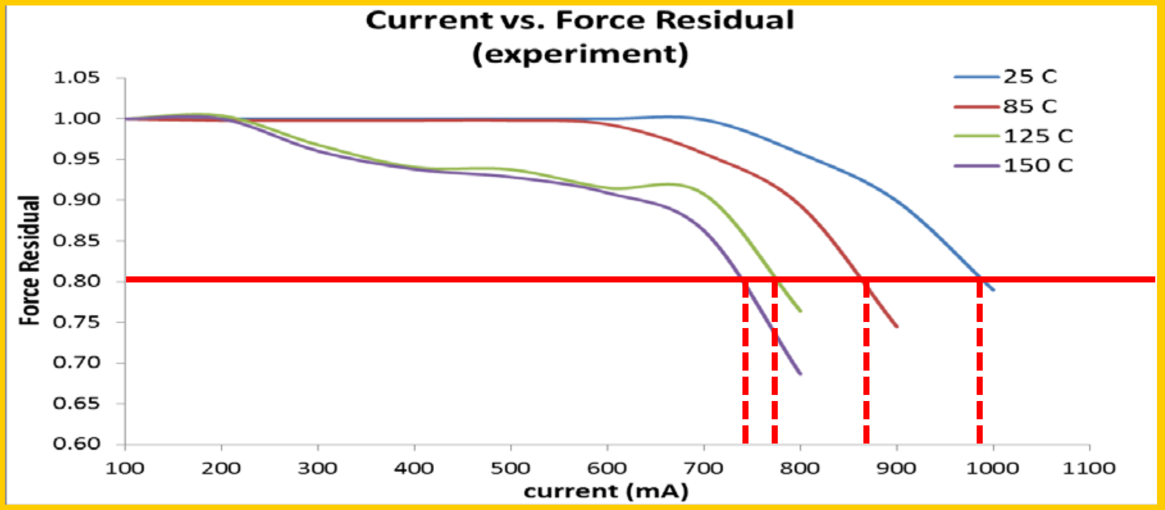
The temperature profiles on the probes can be obtained for all chuck temperature & current combinations, which then become the inputs to the mechanical SPM or ALM model for evaluation of BCF drop/residual curves.

Trio™ Probe Model: Thermal-electrical (cont.)

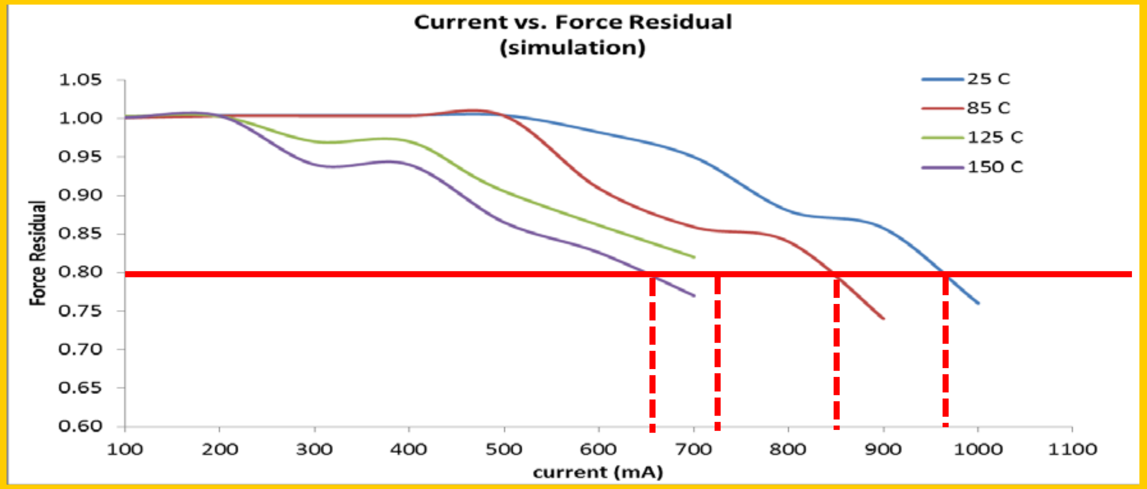
With an assumed plastic model for the probe material (bilinear hardening), the ALM thermal-electrical model yields more conservative CCC values than the experiment. The accuracy can be improved with a material model based on temperature dependent strain-stress curves (multilinear hardening).



Reference: *ANSYS Inc. “Nonlinear Structural Analysis" Web.*



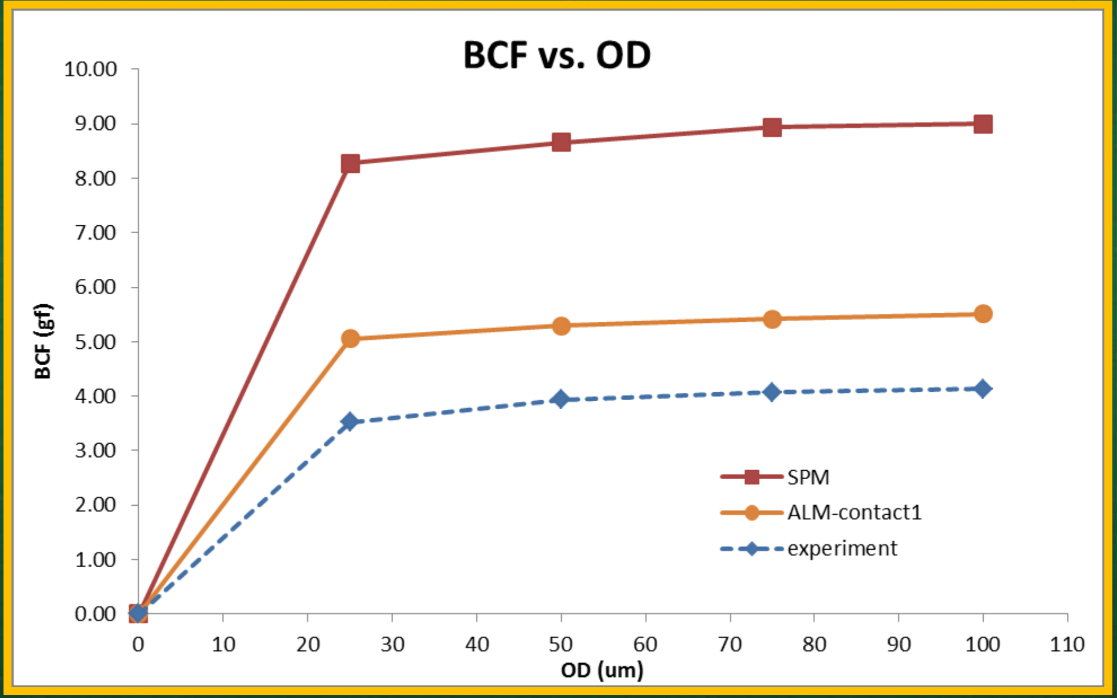
Experimental BCF Residual on 2 mil Trio™



Simulated BCF Residual on 2 mil Trio™

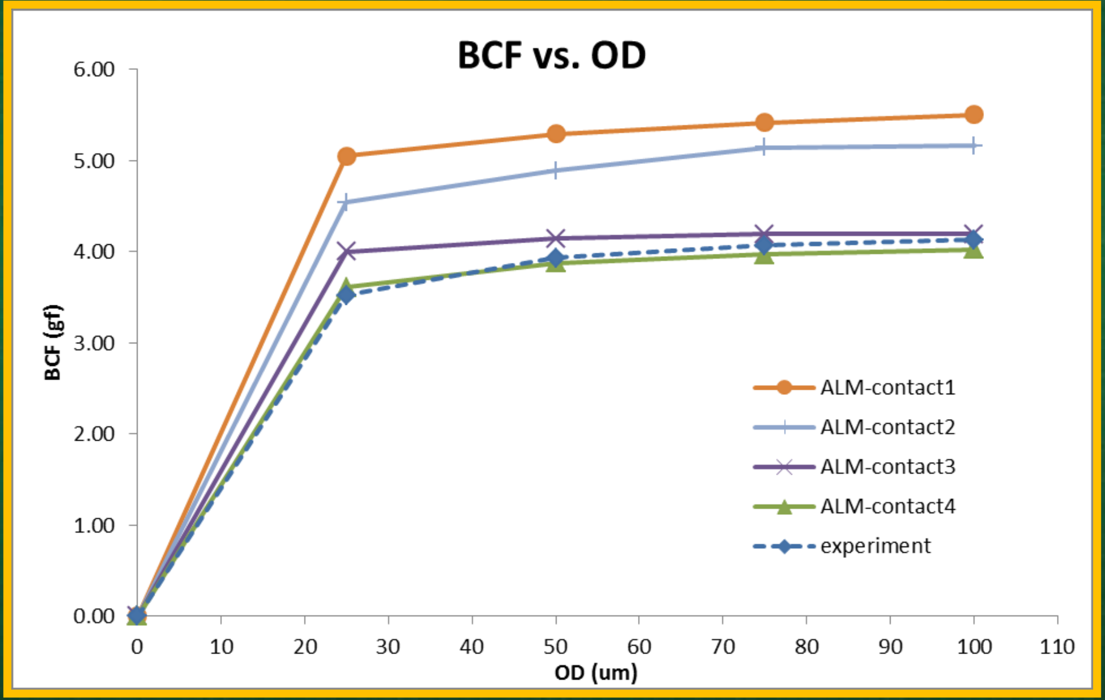
SmartTouch™ Probe Model

The ALM approach is not limited to the Trio™ probe. It is applicable to any vertical probes. Below are the BCF correlation results on SV TCL's SmartTouch™ probe (straight probe). The simulated BCF is accurate to +2.5% of the experimental value.



BCF results on SmartTouch™

Contact Tuning

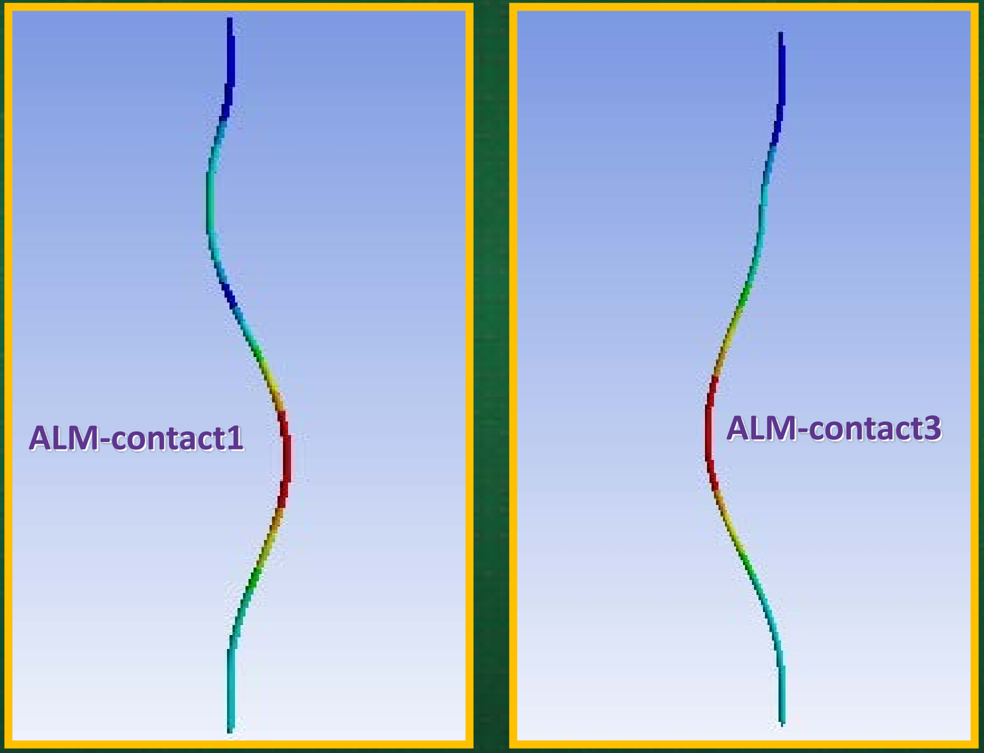


BCF results on SmartTouch™

SmartTouch™ Probe Model (cont.)

For the SmartTouch™ probe model, deflection profiles are necessary to identify correct contact conditions. The effects of contact conditions on SmartTouch™ deflection is demonstrated in the example below.

	ALM-contact1	ALM-contact3
Coefficient of Friction	a	b
Normal Stiffness Factor	x	x
GP1 Contact	t	t
GP2 Contact	t	s
GP3 Contact	t	s
	Same material properties **Same geometry** **Same loadings** **ONLY contact changes**	



Deflection modes under different contact conditions

Parametric Study on SmartTouch™

	VARIABLES		
Run#	**var1**	**var2**	**var3**
~~**1**~~	~~a~~	~~x~~	~~u~~
~~**2**~~	~~a~~	~~x~~	~~v~~
3	a	y	u
4	a	y	v
~~**5**~~	~~b~~	~~x~~	~~u~~
~~**6**~~	~~b~~	~~x~~	~~v~~
7	b	y	u
8	b	y	v
~~**9**~~	~~c~~	~~x~~	~~u~~
~~**10**~~	~~c~~	~~x~~	~~v~~
11	c	y	u
12	c	y	v

Reduced DOE on SmartTouch™

A parametric study on the SmartTouch™ probe model before a design optimization reduced the DOE size by half, as it showed extreme high stress within the system on certain configurations. Those runs were eliminated from the actual DOE.

The study indicated Run#8 to be the optimal configuration. The final DOE results lined up closely with the parametric study.

Conclusion

- ALM models are more accurate than SPM models in terms of characterizing BCF, deflection profile, stress profile & scrub
- Thermal-electrical studies require geometric modifications for better thermal boundary condition match
- ALM models require longer computational time, which can be challenging for large size parametric studies
- Whenever possible, preliminary studies can be performed on SPM to reduce the size of the study before a full-fledged ALM parametric study

Future Work

- In-depth scrub studies of scrub length & depth on different pad materials
- Develop an ALM probe model for MEMS probe characterization
- Incorporate more accurate plastic probe material models for the thermal-electric study
- Incorporate fatigue probe material models to study effects of pulsed current loadings in the thermal-electric study

References

- ANSYS Inc. "Introduction to Contact." Web.
- ANSYS Inc. “Nonlinear Structural Analysis." Web.
- Wang, Xuan, Natnael Behabtu, Colin C. Young, Dmitri E. Tsentalovich, Matteo Pasquali, and Junichiro Kono. "High-Ampacity Power Cables of Tightly-Packed and Aligned Carbon Nanotubes." Advanced Functional Materials 24.21 (2014): 3241-249. Web.

Acknowledgements

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Questions?