SAND2010-7757P

Electrical Contact Performance of Gold-Plated Pins

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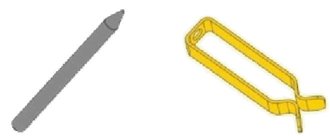
3 November 2010

Overview

- Background
- Problem
- Statement of work
- Test setup
- Test plan
- Analytical model
- Results & Analysis
  - Contact resistance calculations
- Conclusions
- Additional outcomes
- Lessons learned

Background

- **Precision electro-mechanical switch**
- **Several electrical contact pairs, consisting of**
  - **Pin**
  - **Receptacle**



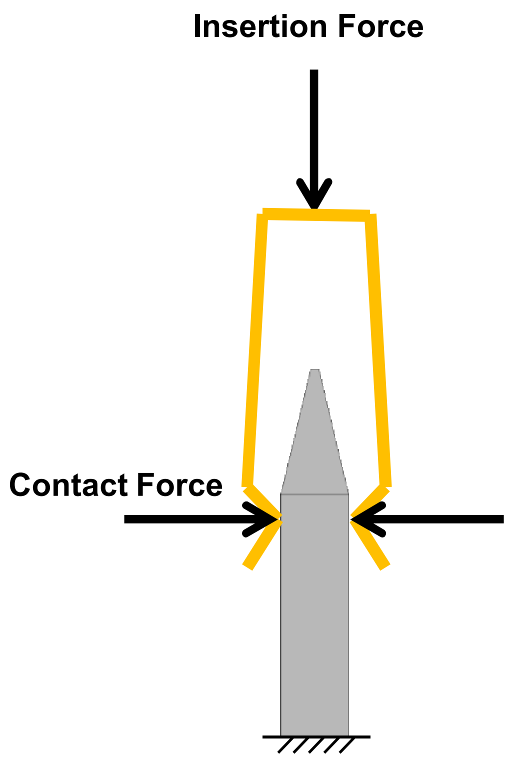
- **Current materials: alloys with high gold content**
- **Similar, older devices used gold-plated pins**

Problem

- **PROBLEM: Need to find a way to reduce CR without raising insertion force**
- **HYPOTHESIS: Gold-plating the pin contacts will solve this problem**

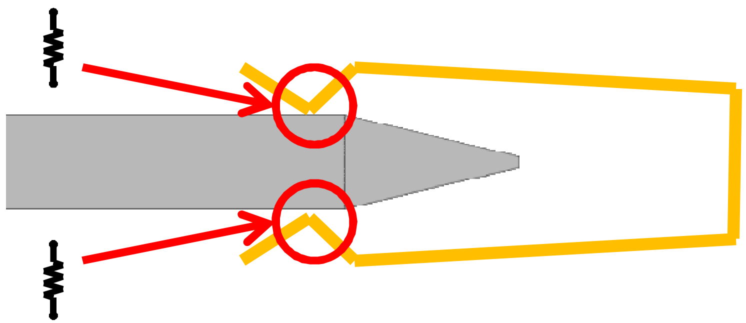
Definitions

- **Contact force:** force due to the spring-like nature of the receptacle, normal to the contact surfaces (usually when fully displaced, i.e. on cylinder)
- **Insertion (or friction) force:** force due to friction between the (pin and receptacle) surfaces, required to insert the pin into the receptacle; function of contact force and friction coefficient



Definitions

- **Contact resistance: the resistance at the interface between the contact surface(s) of the pin and the receptacle**



Statement of Work

- Determine how gold-plating the pin contacts will affect their performance
- Evaluate contact performance according to two (2) criteria:
  - The electrical contact resistance at the pin-receptacle interface
  - The insertion force resulting from pin-receptacle interaction

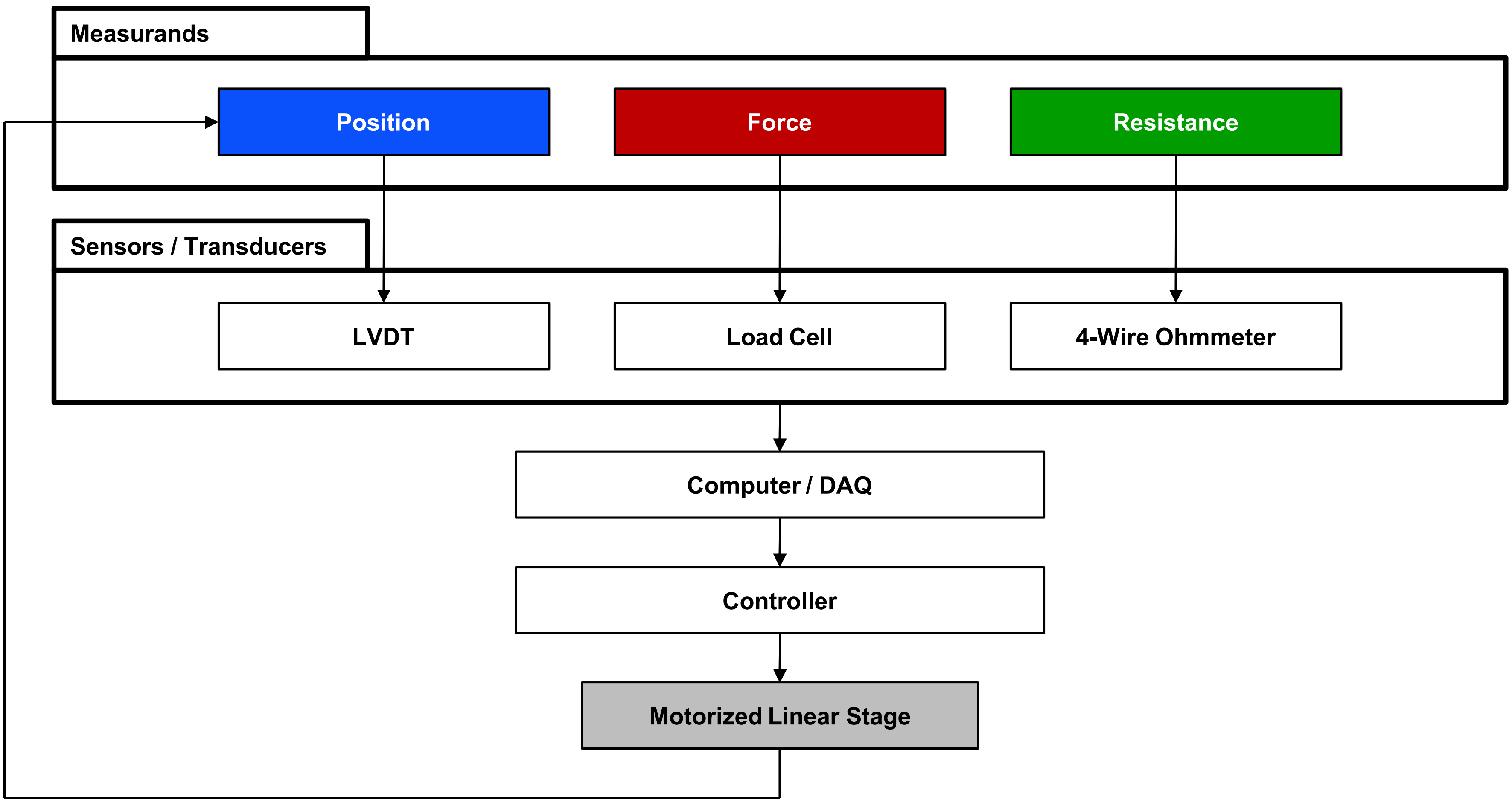
Test Setup – Requirements

- **Perform tests using realistic design configuration**
- **Use existing, available hardware**
- **Parts must be submersed in silicone oil during test**
- **3 measurands**
  - **Position (travel/stroke): < 0.400”**
  - **Force (insertion & removal forces): < 20 grams-force**
  - **Electrical resistance (contact resistance): < 40 mΩ**

Test Setup – Challenges

- Examine a single pin-receptacle contact pair
- Ensure proper alignment of parts
- Submerse parts in silicone oil during test
- Minimize measurement intrusiveness
- Resistance measurements
  - Reliable, consistent electrical connection points
  - Eliminate lead resistance
- Force measurements
  - Minimize additional weight due to electrical connections, fixtures

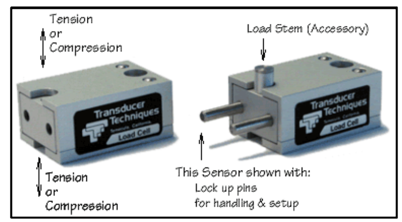
Test Setup – Block Diagram



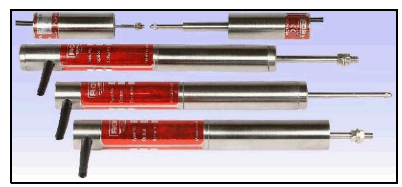
Test Setup – Instruments & Transducers

- **Electrical resistance**
  - **4-wire milliohmmeter, 100 mΩ**
- **Force**
  - **Precision load cell, 25 g**
- **Position**
  - **Linear variable differential transformer (LVDT), 0.3938” stroke**
- **Data acquisition (DAQ) unit**
  - **Digital oscilloscope, 20 S/s (up to 2 GS/s)**

HP 4328 milliohmmeter
Range: 1 mΩ – 100 Ω
Accuracy: ± 2% of full scale
Measuring frequency:
1000 Hz ± 100 Hz



Transducer Techniques, GSO Series
Tension or compression
Linearity: 0.05% of read out (R.O.)
Hysteresis: 0.05% of R.O.
Repeatability: 0.05% of R.O.
Zero balance: 1.0% of R.O.
Temp. effect on output: 0.005% of load/°F
Temp. effect on zero: 0.005% of R.O./°F

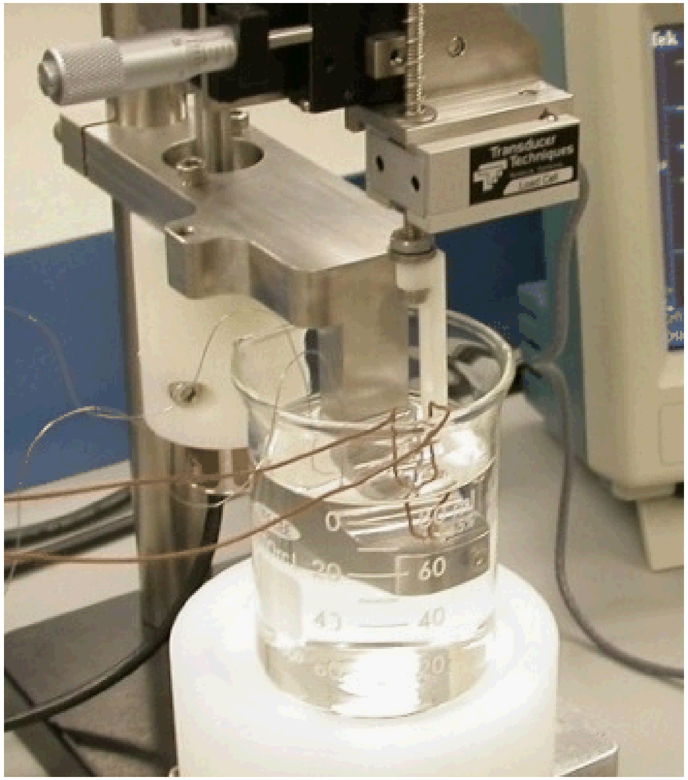


RDP Electrosense, DCTH200AG
Travel range: ± 5 mm (± 0.1969 in)
Linearity: 0.24% (% F.S.)

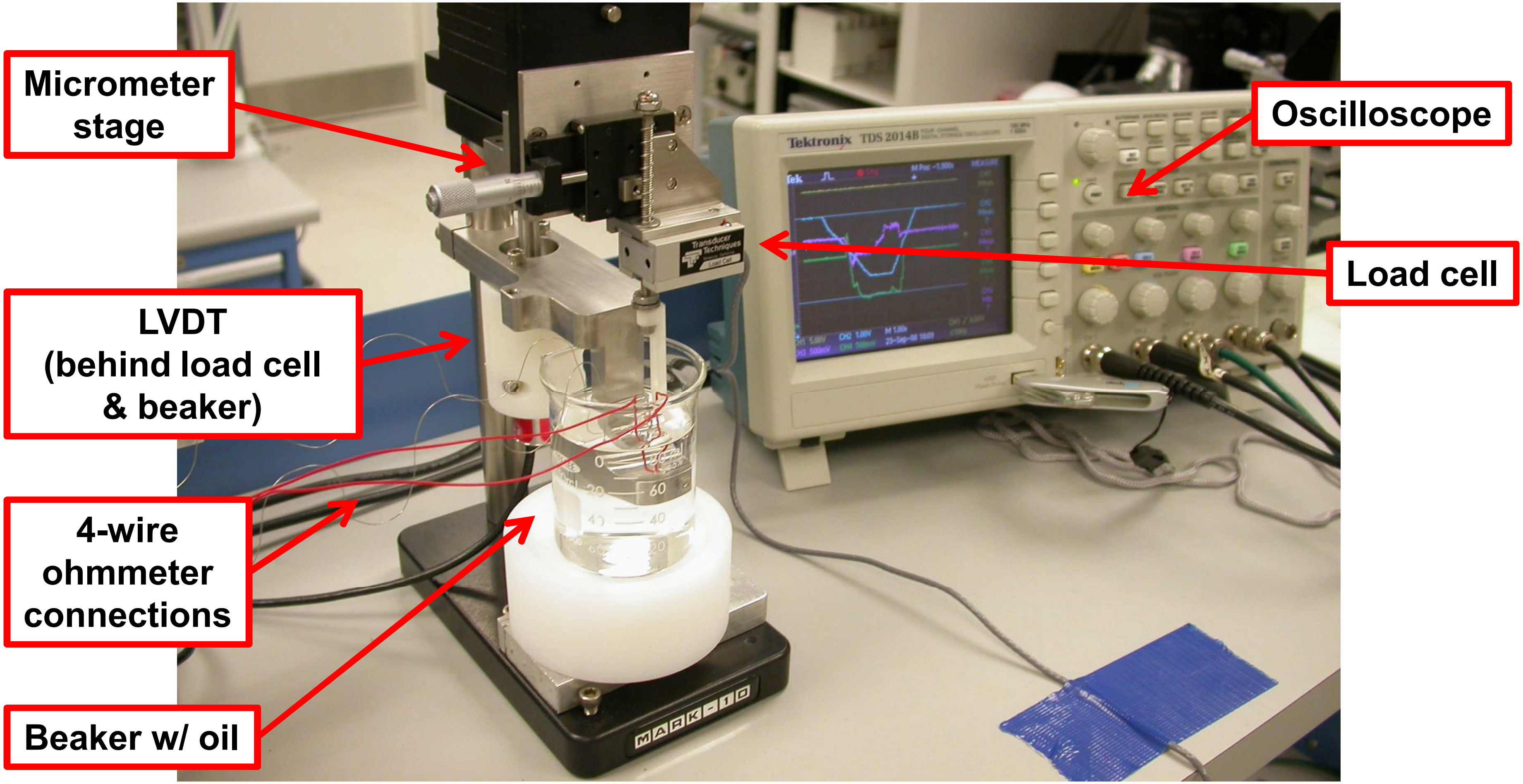
Tektronix TDS644A
500 MHz max analog bandwidth
Up to 2 Gs/s
4 channels
Up to 2000-sample record length per channel
8-bit digitizer

Test Setup – Sample Environment

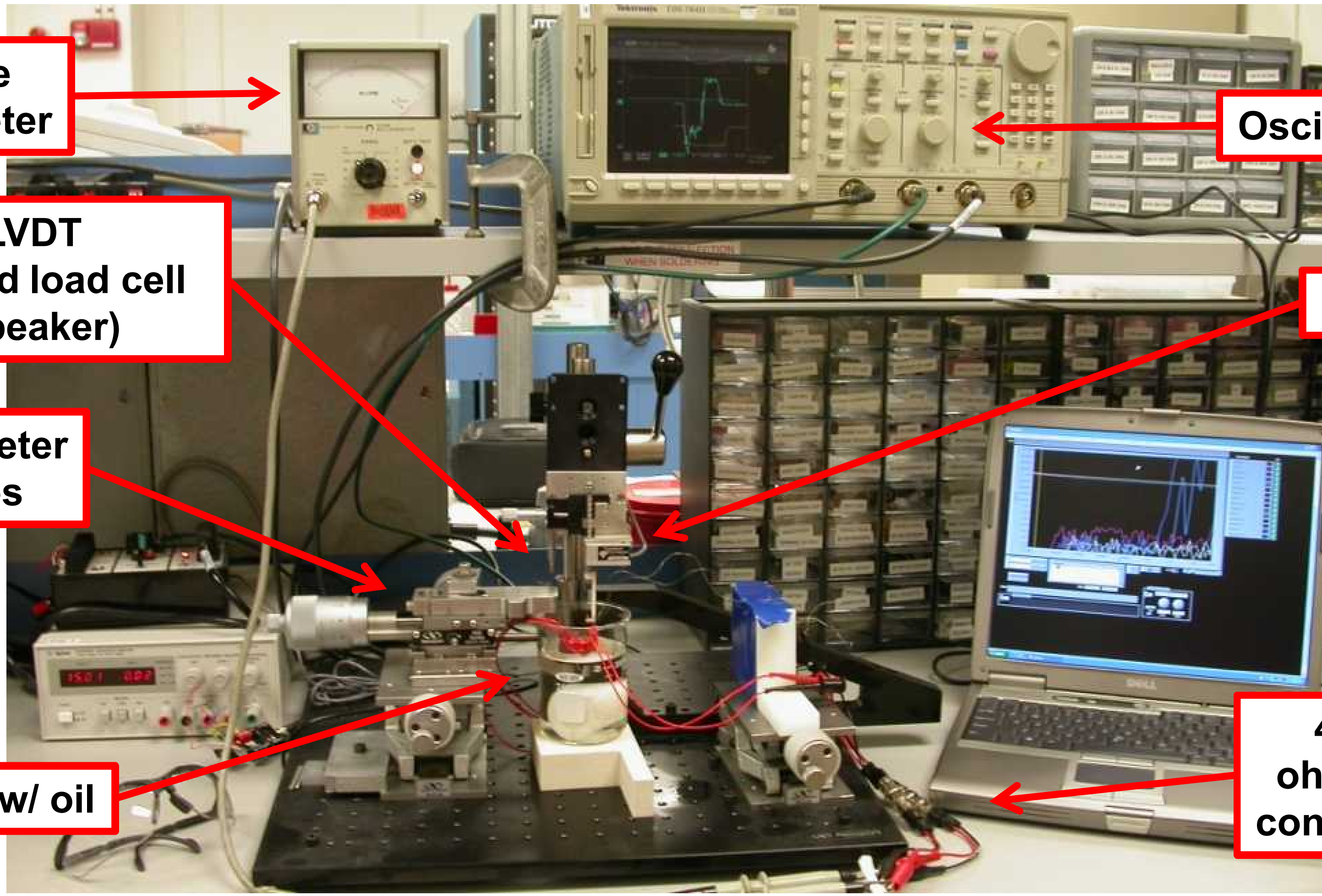
- Controlled environment
  - Test samples were submersed in an oil bath
    - Silicone oil, low viscosity
    - Beaker, 250 mL
- Ambient conditions
  - Temperature
  - Pressure



Test Setup – Actual Setup (OLD)



Test Setup – Actual Setup (Modified)



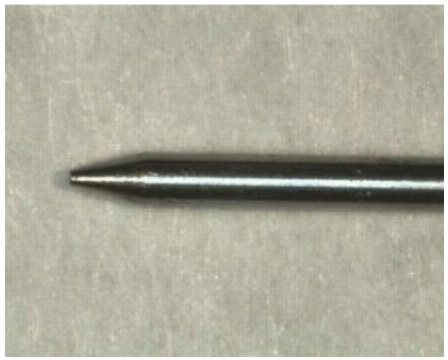
Test Setup – Summary of Capabilities

Measurand	Unit	Span	Accuracy	Resolution *
Position	inches	0.3938	< 0.0010	± 0.0016
Force	grams (force)	25	0.1	± 0.05
Resistance	milliOhms	100	.020	± 0.4

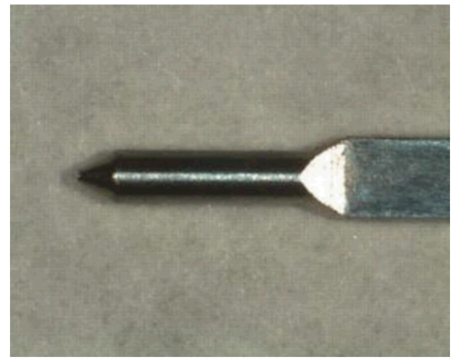
* Resolution depended on A-to-D (i.e., specs & settings)

Test Plan – Samples

PIN TYPE (3 levels)



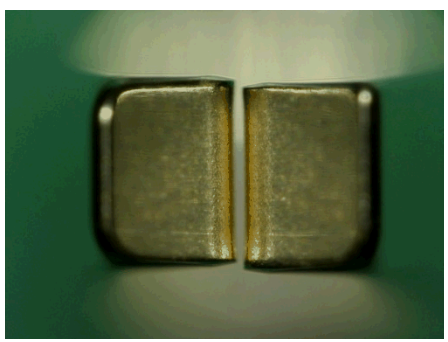
Type A



Type B

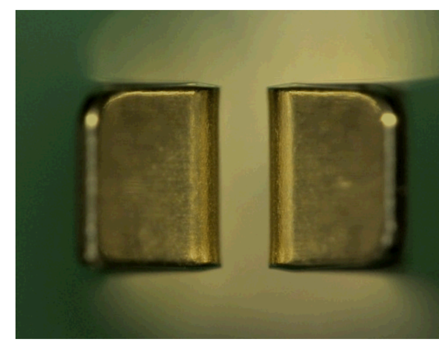
Type C (gold-plated)

RECEPTACLE GAP SIZE (3 levels)



0.004” gap

0.010” gap



0.016” gap

Test Plan – Samples

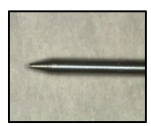
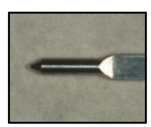
- **2 factors**
  - **Pin type (3 levels)**
  - **Gap size (3 levels)**
- **1 replicate of each combination**
- **Full factorial**

Std Order	Run Order	Pin ID	Recep ID	Gap
1	3	PA-1	R04-1	0.004
2	6	PA-2	R10-1	0.010
3	8	PA-3	R16-1	0.016
4	9	PB-1	R04-2	0.004
5	4	PB-2	R10-2	0.010
6	7	PB-3	R16-2	0.016
7	2	PC-1	R04-3	0.004
8	5	PC-2	R10-3	0.010
9	1	PC-3	R16-3	0.016

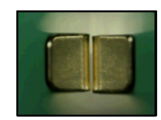
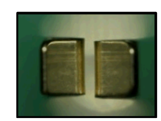
x 2

3 x 3 x 2 = 18 pairs/combinations

Pin Type
PA = Type A
PB = Type B
PC = Type C

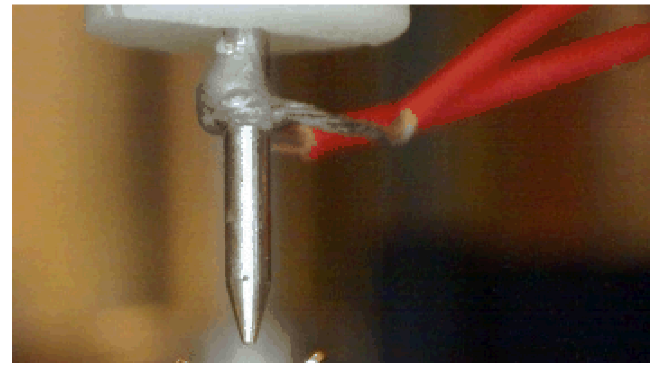



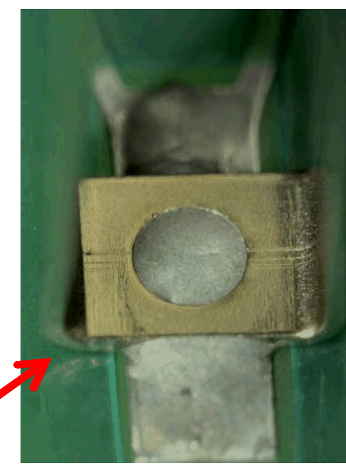

Receptacle Gap
0.004”
0.010”
0.016”


Test Plan – Sample Preparation

- All samples
  - Performed visual inspection
  - Cleaned samples with detergent in ultrasonic cleaner
- 18 Pins
  - Soldered wires to pins
- 18 Receptacles
  - Adjusted & measured receptacle gap sizes w/ optical comparator
  - Heat-treated receptacles
  - Mounted/soldered receptacles to printed circuit board (PCB) fixtures
  - Checked receptacle gap size using digital microscope; re-adjusted, if needed
  - Soldered wires to PCB

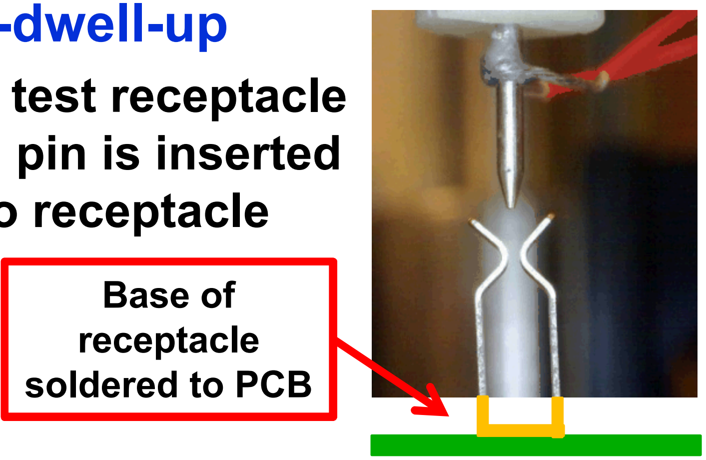


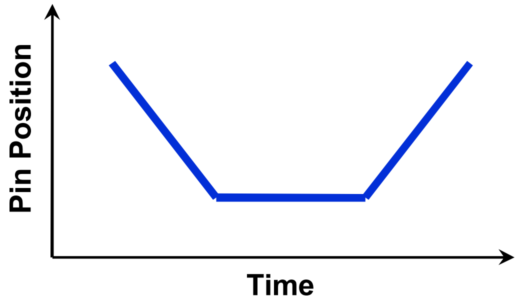


Base of receptacle & solder joint

Test Plan – Procedure

- Insert pin into collet, attach collet to load cell
- Attach PCB w/ receptacle to tester
- Visually align pin and receptacle
- Connect wires from pin and receptacle to 4-wire ohmmeter
- Pour silicone oil into breaker and submerse parts in oil
- Run test: down-dwell-up
  - NOTE: During test receptacle remains fixed, pin is inserted downward into receptacle
- Record data





Test Plan – Procedure

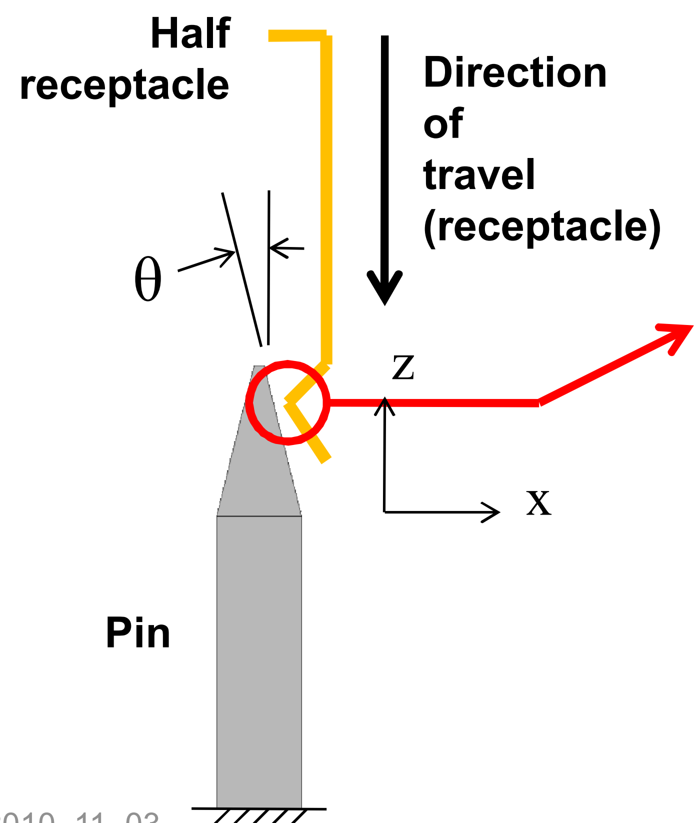
- **Certain data were selected for storage & analysis**
- **Each pair tested multiple times**
  - **5 repetitions in order to observe possible variation between runs**
  - **Repetitions 1, 3, and 5 were recorded**
- **Total: 18 x 3 = 54 data sets**
  - **Each set has 25 seconds of data @ 20 samples/sec**
  - **Each set includes position, force, resistance vs. time**

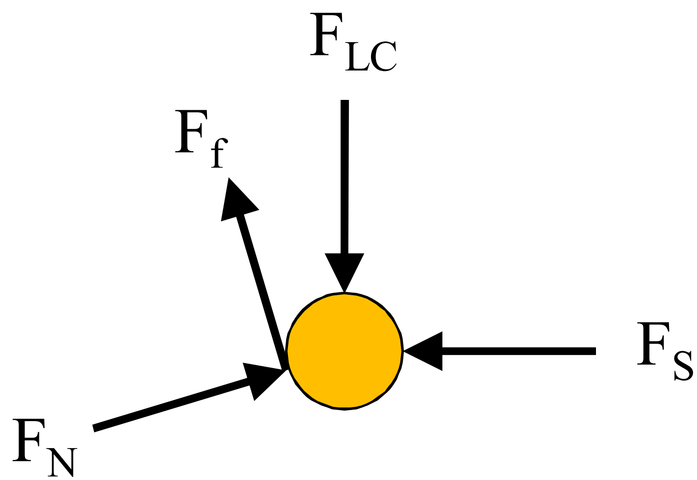
Analytical Model – Expected Force

- **A simple analytical model was created for comparison with test data, to predict expected curve**
  - **Assumptions:**
    - **Half receptacle modeled as cantilever with end being displaced by pin**
    - **Receptacle traveling downward at constant velocity along the pin**
    - **Contact point on receptacle modeled as particle**
    - **Weight of receptacle neglected**
    - **Acceleration = 0 since velocity assumed to be constant (approx. constant during test)**

Analytical Model – Expected Force

- **FDB:**

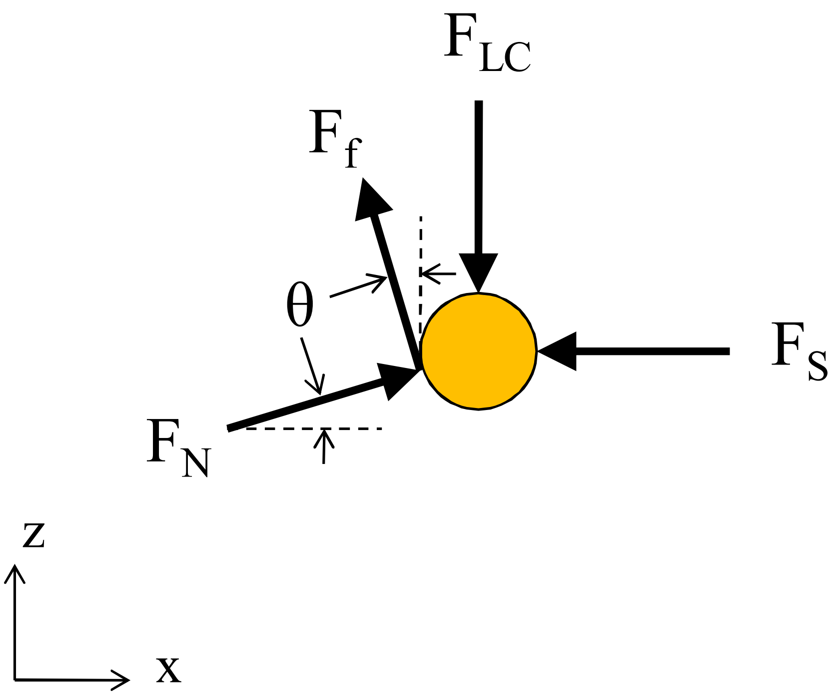




F_{LC}	=	force, downward (seen by load cell)
F_S	=	force, spring (receptacle)
F_f	=	force, friction
F_N	=	force, normal
θ	=	cone angle = 15 deg (from vertical)

Analytical Model – Expected Force

- **Model equations:**



$$\Sigma F_x = ma_x = 0:$$

$$-F_s + F_n \cos\theta - F_f \sin\theta = 0$$

$$\Sigma F_z = ma_z = 0:$$

$$-F_{LC} + F_f \cos\theta + F_N \sin\theta = 0$$

F_s = (k) (interference)

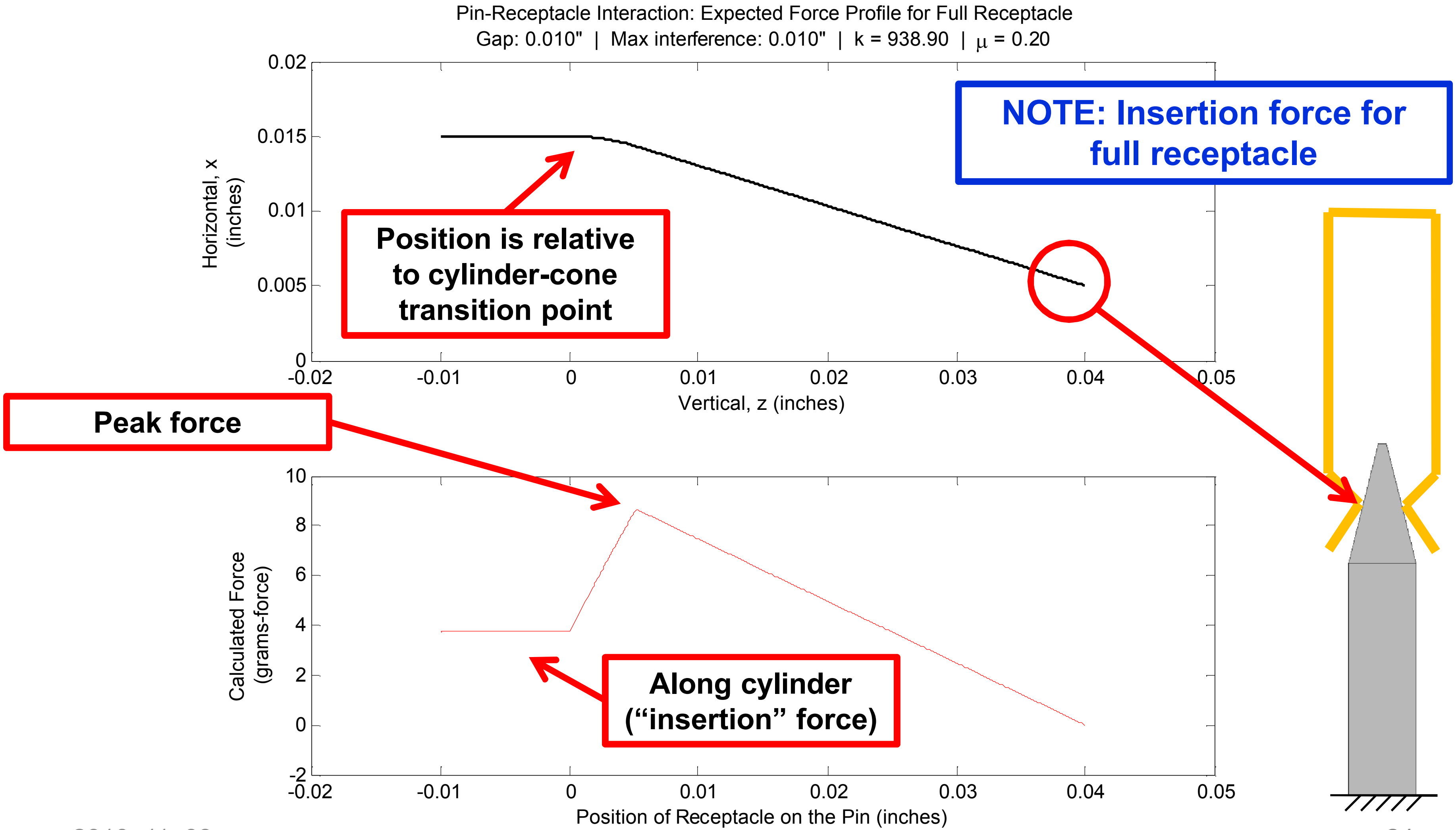
F_N = $(F_s) / (\cos\theta - \mu \sin\theta)$

F_f = $(\mu)(F_N)$

F_{LC} = $F_f \cos\theta + F_N \sin\theta$

= ½ INSERTION FORCE

Analytical Model – Force vs. Position



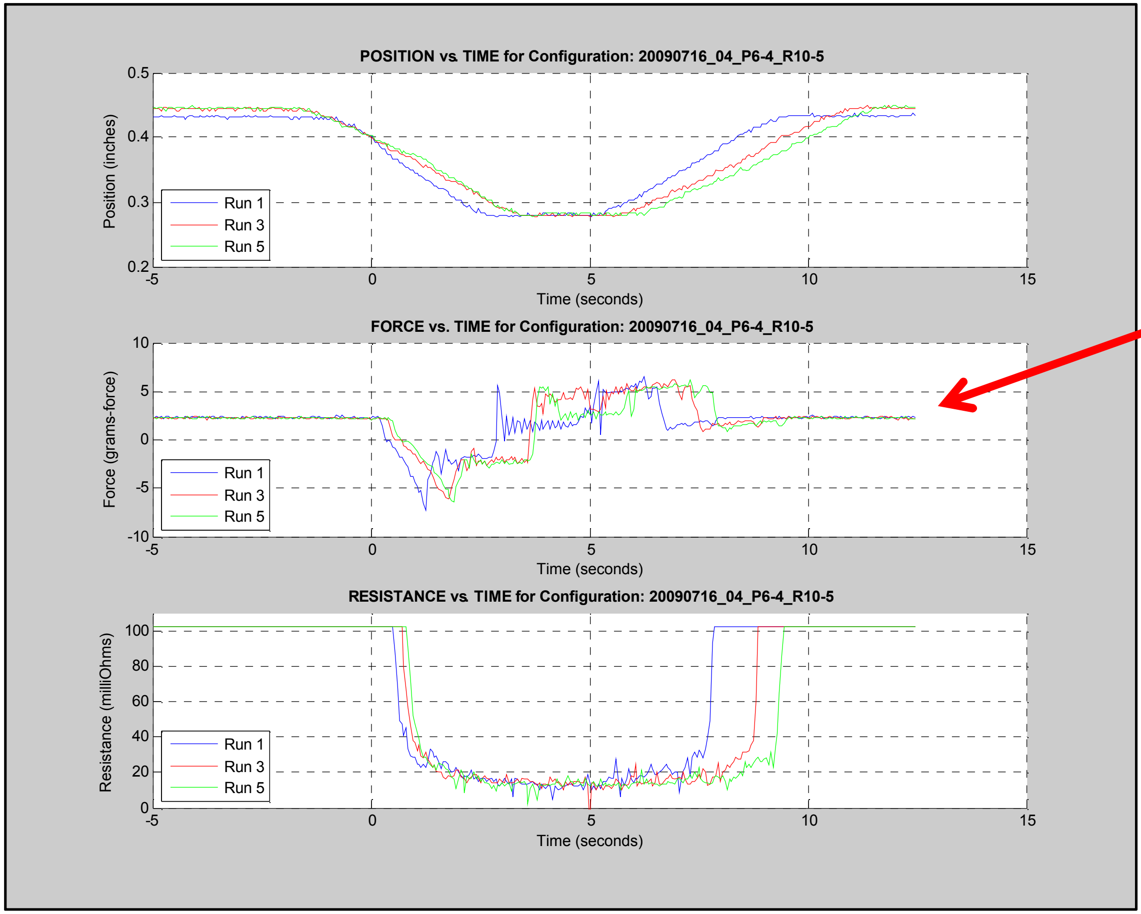
Results – Representative Data

Type A pin with 0.010” receptacle gap

Position

Force

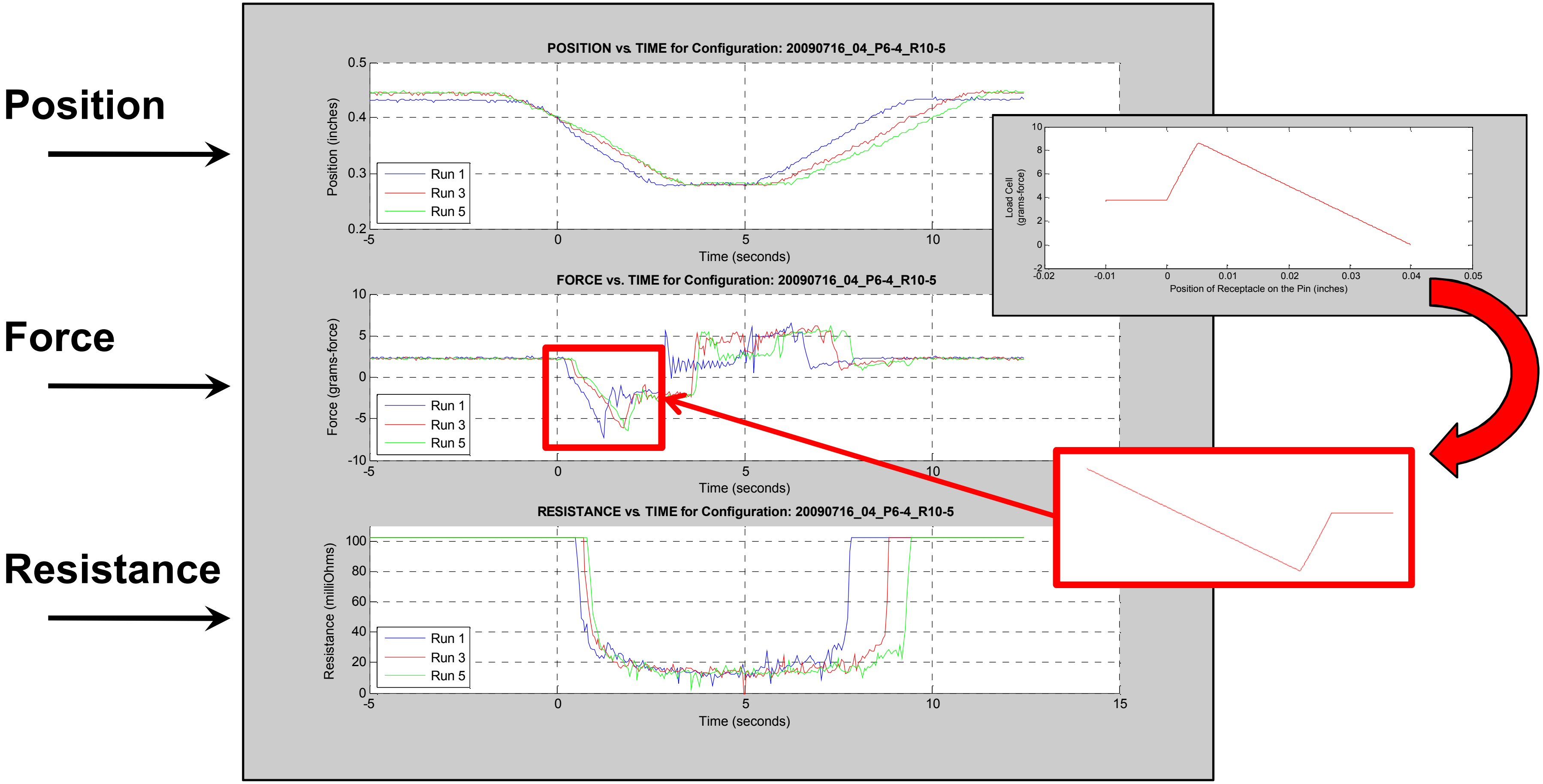
Resistance



NOTE: Zero offset (force only)

Results – Representative Data

Type A pin with 0.010" receptacle gap

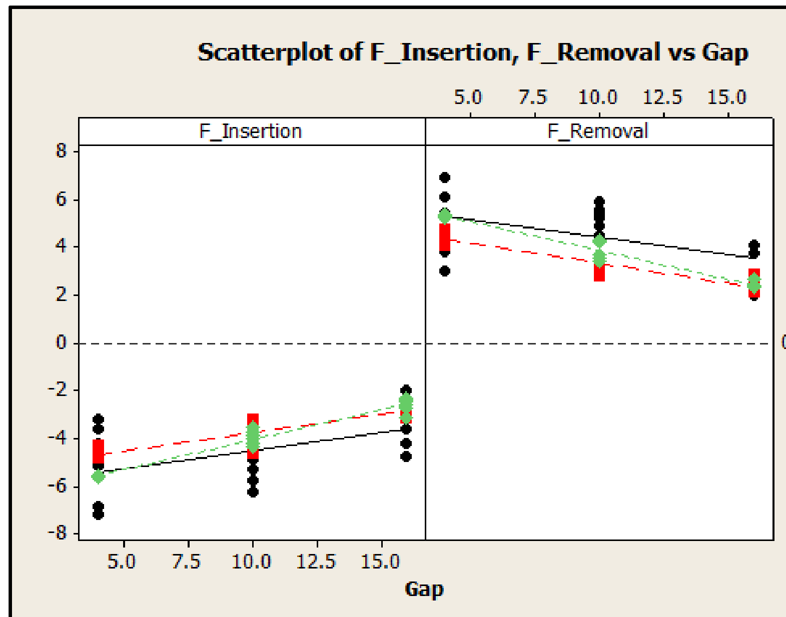


Results – Force

- **Linear relationship between force and gap size**
- **Gold-plated pins have highest peak, insertion, and removal forces**

$N_i = 6$

Material	Gap (mil)	Statistical Measure	Peak Force (g)	Cylinder Insertion Force (g)	Cylinder Removal Force (g)
PA	10	**MEAN**	**-9.4**	**-3.9**	**3.1**
		STDEV	2.0	0.6	0.2
PB	10	**MEAN**	**-10.1**	**-4.0**	**3.9**
		STDEV	0.7	0.3	0.4
PC	10	**MEAN**	**-11.5**	**-5.2**	**5.2**
		STDEV	2.3	0.7	0.5

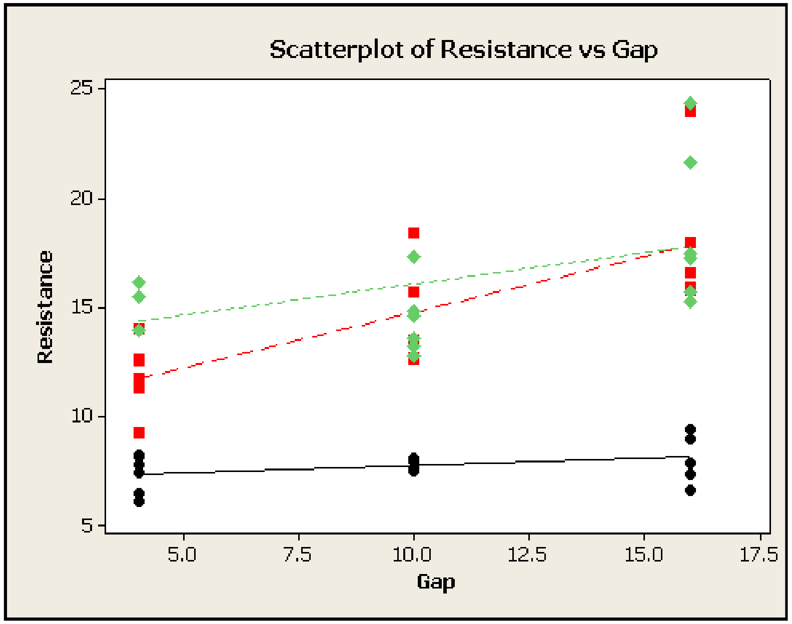


Results – Total Resistance

- Resistance increases slightly as gap increases
- Gold-plated pins exhibit a nearly constant resistance regardless of gap size
  - At nominal gap width, this value is half that of PA & PB

$N_i = 6$

Material	Gap (mil)	Statistical Measure	Total Resistance (mΩ)
PA	10	MEAN	14.41
		STDEV	2.27
PB	10	MEAN	14.40
		STDEV	1.63
PC	10	MEAN	7.71
		STDEV	0.22



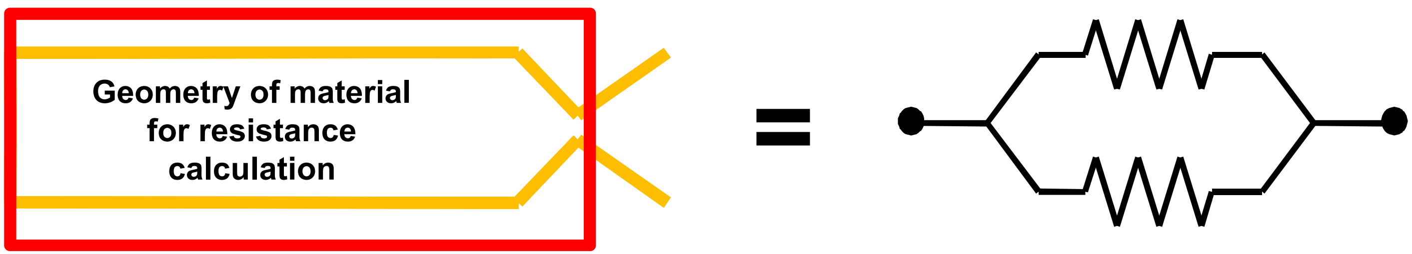
Calculating Contact Resistance

- Circuit resistance ($R_{circuit}$): combined resistance due to multiple contact pairs (i.e., one circuit) in the switch
- Total resistance (R_{total}): electrical resistance measured
- Bulk resistance (R_{bulk}): resistance due to material & geometry
  - Receptacle as 2 resistors in parallel
  - Pin as cylinder
- Contact resistance, (CR or R_{CR}): resistance at interface between pin & receptacle contacts

$$R_{CR} = R_{total} - R_{bulk}$$

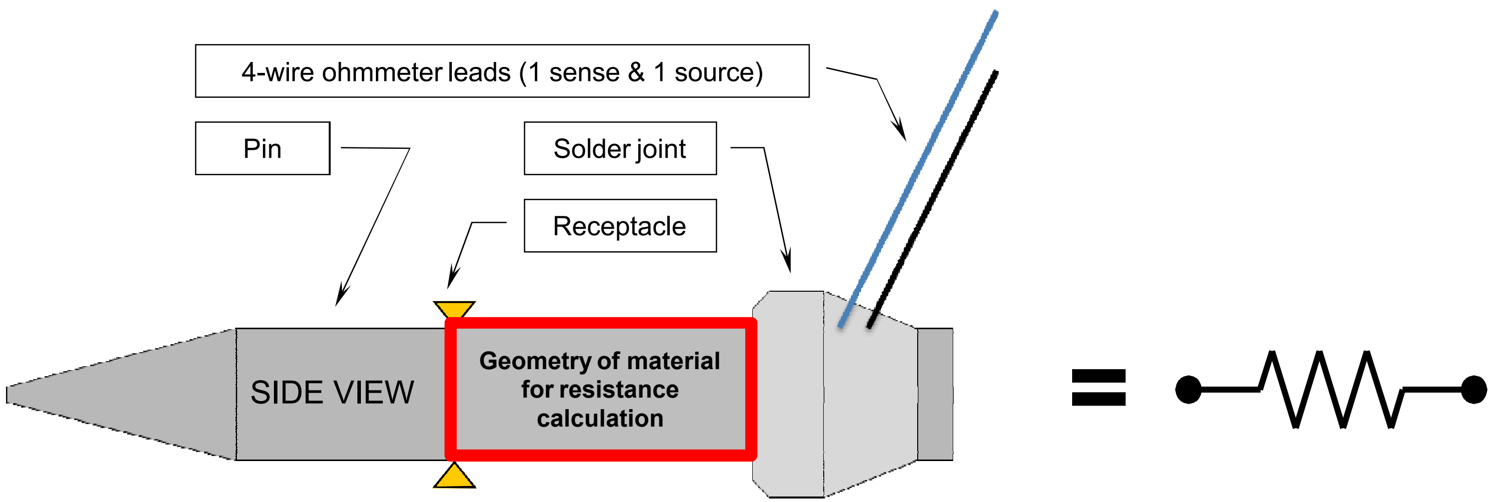
Calculating Contact Resistance

- Bulk resistance includes resistance from receptacle
- Calculated as 2 resistors in parallel
- Nominal geometry assumed



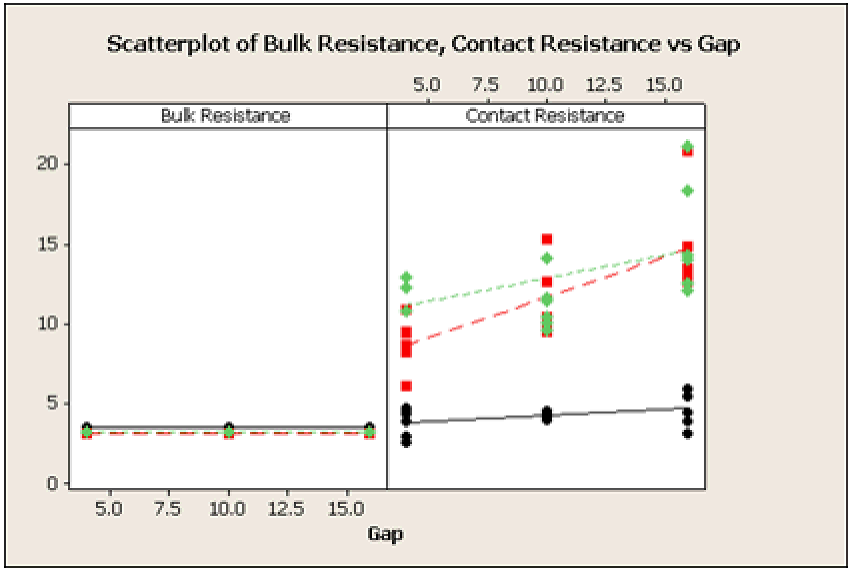
Calculating Contact Resistance

- Bulk resistance includes resistance from pin
- Calculated as a single resistor
- Nominal geometry assumed
- Gold-plating neglected for Type C pin



Results – Resistance (Bulk vs. CR)

- Contact resistance is more significant than the bulk resistance (contributed by the material)
- The contact resistance of the gold-plated pin is nearly equal to the bulk resistance of the contacts
  - Significantly lower than the Type A, Type B pins



Results – Gold-Plated Comparison (Nominal)

$N_i = 6$

Material	Gap (mil)	Statistical Measure	FORCE: Peak Force (g)	FORCE: Cylinder Insertion Force (g)	FORCE: Cylinder Removal Force (g)	ELECTRICAL RESISTANCE: Total Resistance (mΩ)	ELECTRICAL RESISTANCE: Receptacle Resistance (mΩ)	ELECTRICAL RESISTANCE: Pin Resistance (mΩ)	ELECTRICAL RESISTANCE: Bulk Resistance (mΩ)	ELECTRICAL RESISTANCE: Contact Resistance (mΩ)
PA	10	**MEAN**	**-9.4**	**-3.9**	**3.1**	**14.41**	**2.65**	**0.58**	**3.23**	**11.18**
		STDEV	2.1	0.6	0.2	2.27	0.00	0.00	0.00	2.27
PB	10	**MEAN**	**-10.1**	**-4.0**	**3.9**	**14.40**	**2.65**	**0.71**	**3.36**	**11.04**
		STDEV	0.7	0.3	0.4	1.63	0.00	0.00	0.00	1.63
PC	10	**MEAN**	**-11.5**	**-5.3**	**5.3**	**7.71**	**2.65**	**0.97**	**3.62**	**4.09**
		STDEV	2.3	0.7	0.5	0.22	0.00	0.00	0.00	0.22

PC vs PA	**10**	**MEAN**	**+23%**	**+35%**	**+72%**	**-46%**	**-**	**+67%**	**+12%**	**-63%**
PC vs PB	**10**	**MEAN**	**+14%**	**+32%**	**+35%**	**-46%**	**-**	**+37%**	**+8%**	**-63%**

Conclusions

- RE-STATEMENT OF PROBLEM: Need to find a way to reduce CR without raising insertion force
- Comparatively, the Type C gold-plated pin produces lower contact resistance; however, it also exhibits higher insertion force
  - Gold-plating therefore seems to introduce a trade-off between lower contact resistance and higher friction
- Contact force (and thus insertion force) is a linear function of contact interference, as expected
- Type A and Type B pins are almost identical in performance

Additional Outcomes

- Characterization of pins and receptacles
- Useful setup for testing future contacts
- Test setup for other types of switches

Lessons Learned

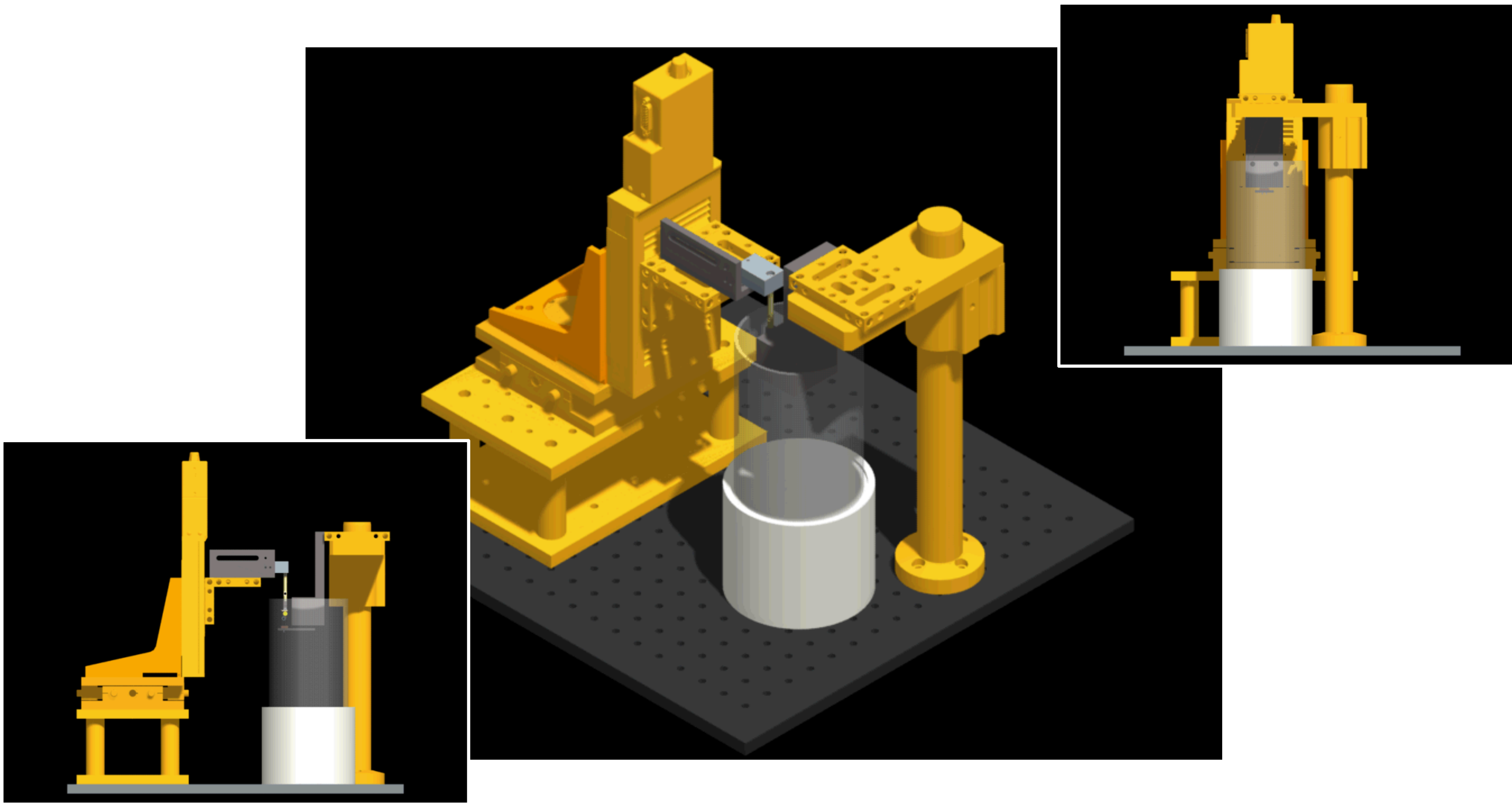
- Due to size of samples (miniature scale), better environmental controls can and should be implemented in order to minimize variance in measurements caused by changes in temperature, pressure, humidity, etc.
- Ensure that pedigree of all parts/samples is known and traceable
- Find a better way to align parts
  - Image sensing control system?
- Use a motorized precision linear stage to achieve desired motion
  - NOTE: This has been implemented in the test setup
- Consistency!

References

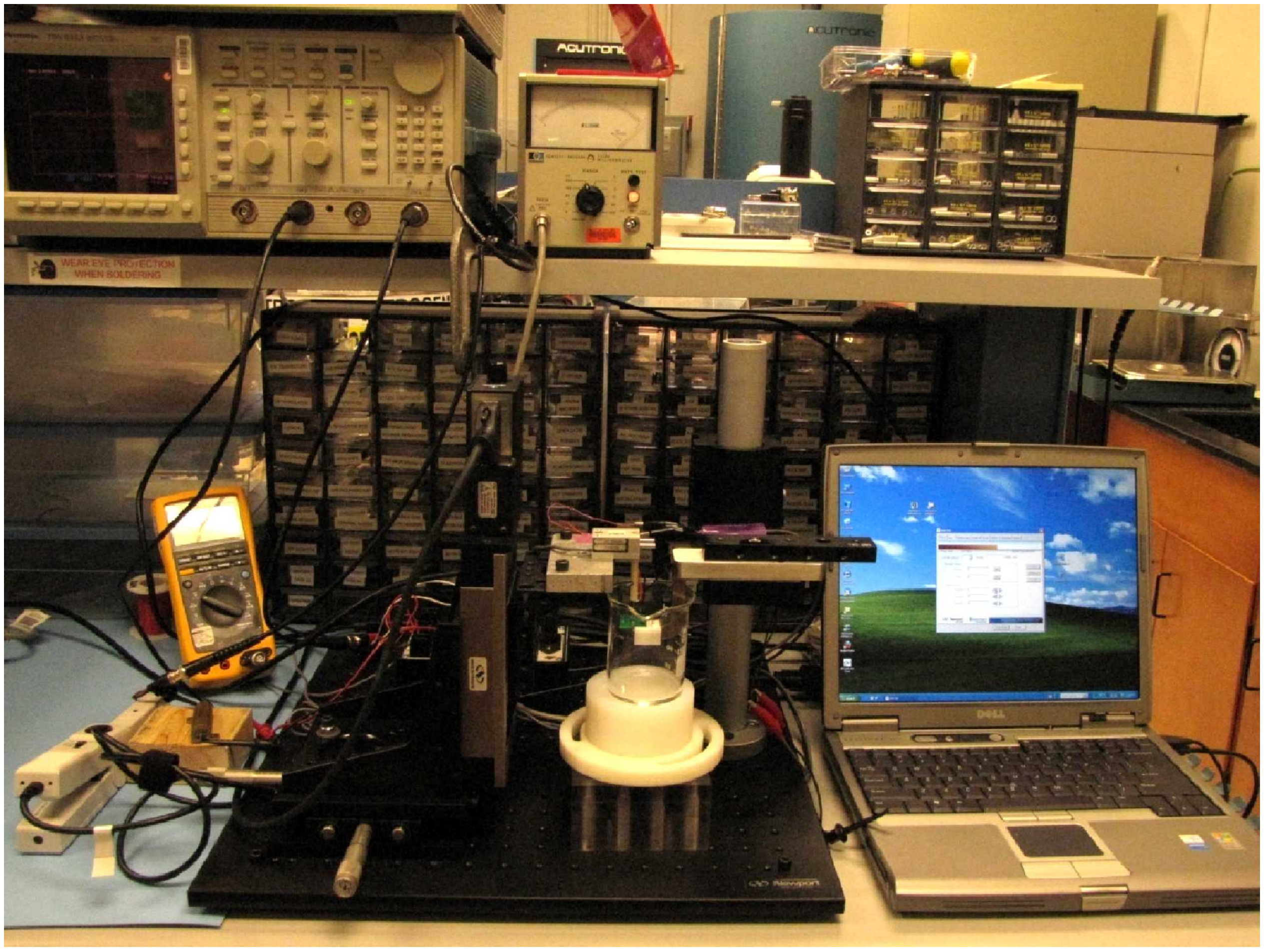
- **SNL presentation by G. Benavides**
- **Part drawings & documents**
- **K. Pitney, *Ney Contact Manual* (1973)**
- **Material properties from alloy manufacturer**

EXTRA SLIDES FOLLOW

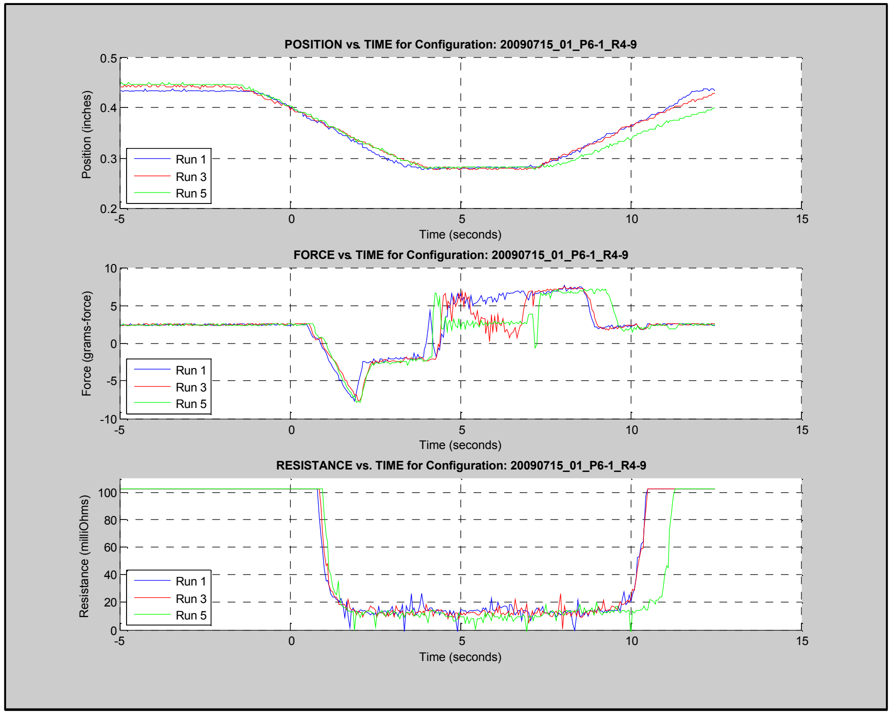
Test Setup – Planned Modification



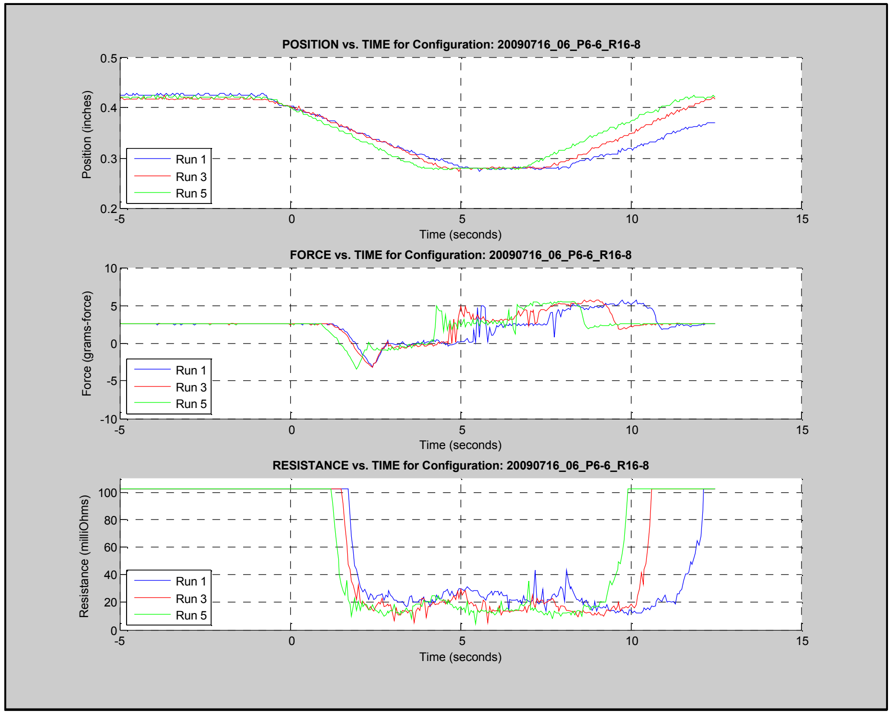
Test Setup – Current Configuration



Results – Representative Data



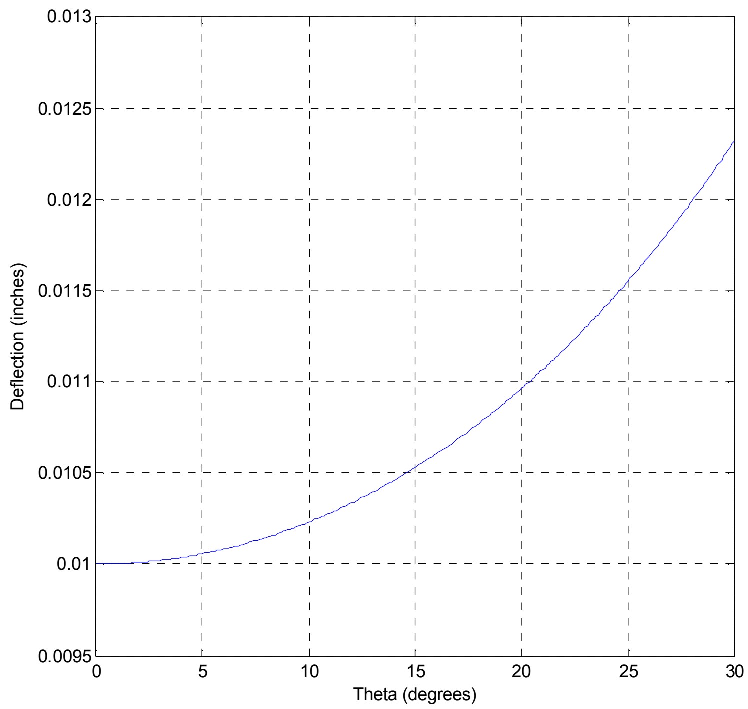
0.004" gap



0.016" gap

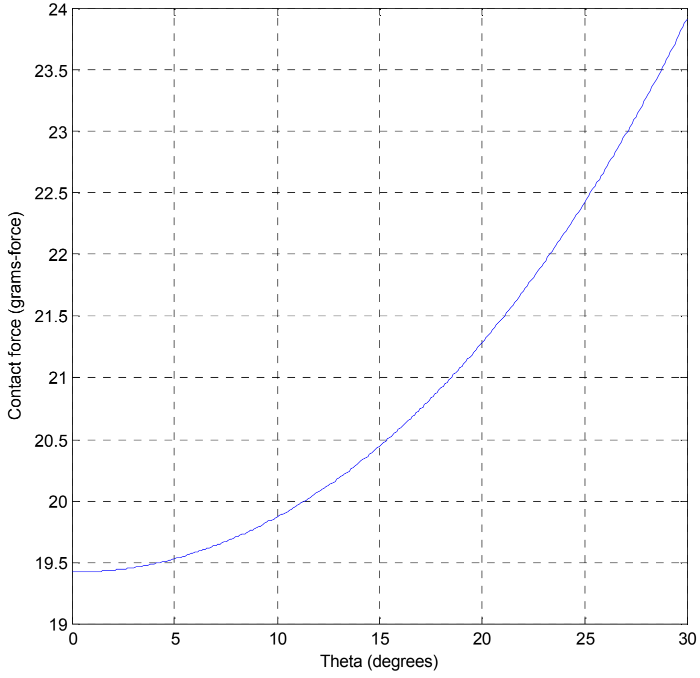
Sensitivity Study – Receptacle Misalignment

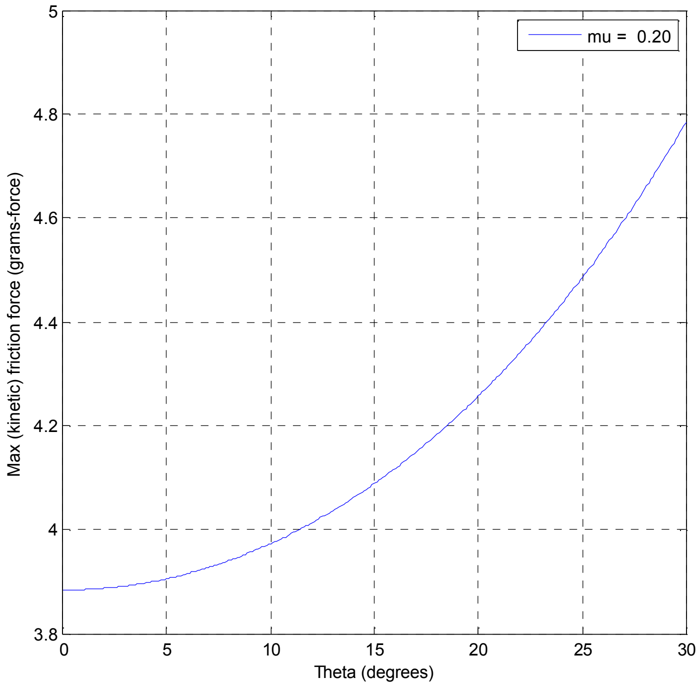
- **What if the receptacle is angled and therefore misaligned relative to the pin?**



Sensitivity Study – Receptacle Misalignment

- **What if the receptacle is angled and therefore misaligned relative to the pin?**





Receptacle Fixture (OLD)

Soldering – Problems