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Contactor Arcing Fundamentals

Yoinjun Shi
R&D Twinsolution

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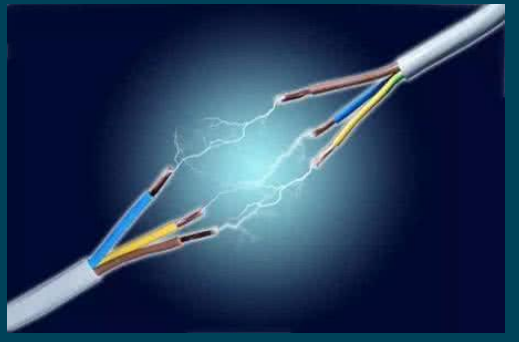
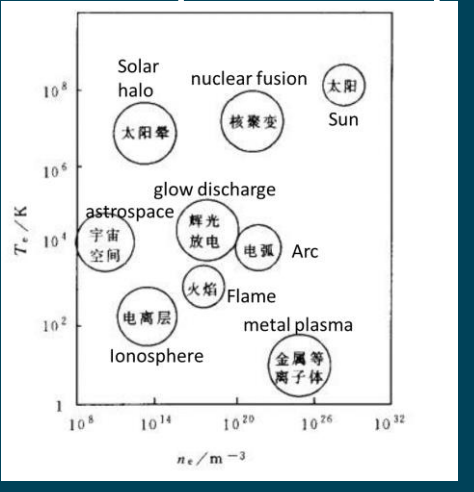
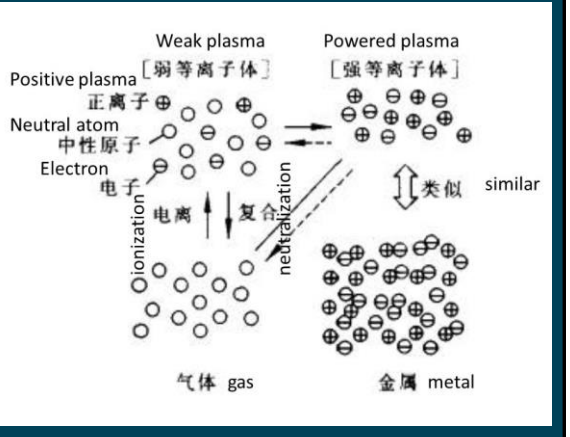
Introduction

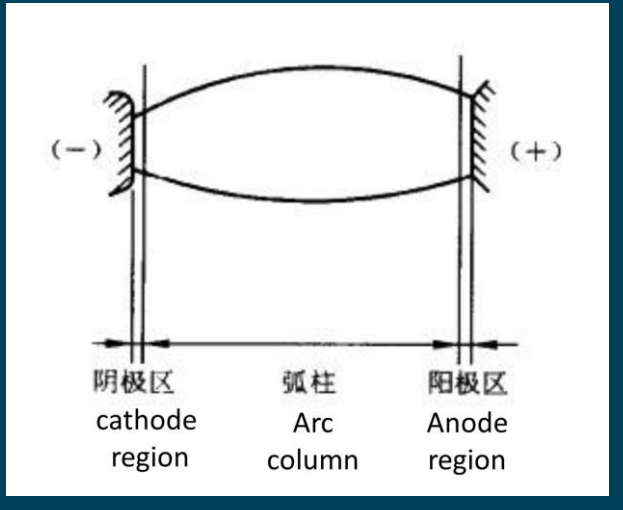


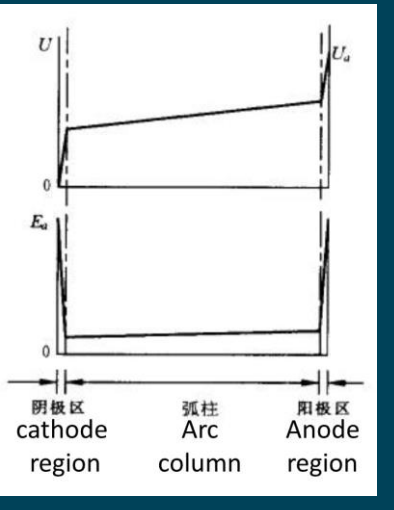
- Arc is a phenomenon of gas discharge and a kind of plasma. Plasma is the fourth state in coordination with solid, liquid and gas. Arc belongs to low temperature plasma





Arcing Basic





- The arc can be divided into three regions: cathode region, arc column and anode region[1]
- Two cases of electron emission by cathode:
  - Emission current density of thermal electron
  - Emission current density of High Electrical Field

Arcing Basic - Continue

Emission current density of thermal electron

$$j = A_1 T^2 \exp(-\frac{e\emptyset}{kT})$$

Emission current density of High Electrical Field

$$j = A_1 (T + A_2 E)^2 \exp(-\frac{11600\emptyset}{T + A_2 E})$$

T - Cathode temperature (K)
Φ - Power function of materials (V)
e - electron charge
k - Boltzmann constant
A_1 - Constant
A_2 - Constant
E - Electrical field strength

Scale down & Speed increase

- **Signal speed**
  - As digital signal speed has increased significantly in the past a few decades, the switching time of electronic circuits has been greatly reduced
  - When the switch closing time becomes too short, it prevents the electrical energy stored in the circuit from being discharged before an electrical contactor or probe is removed. Thereby this potential voltage difference between the contactors pair has the risk of causing the arcing
- **Device pitch**
  - Scale down from 1.27 mm now to 0.2 mm or even 0.15 mm. Contactors mechanism changed and this also increase the electrical field significantly

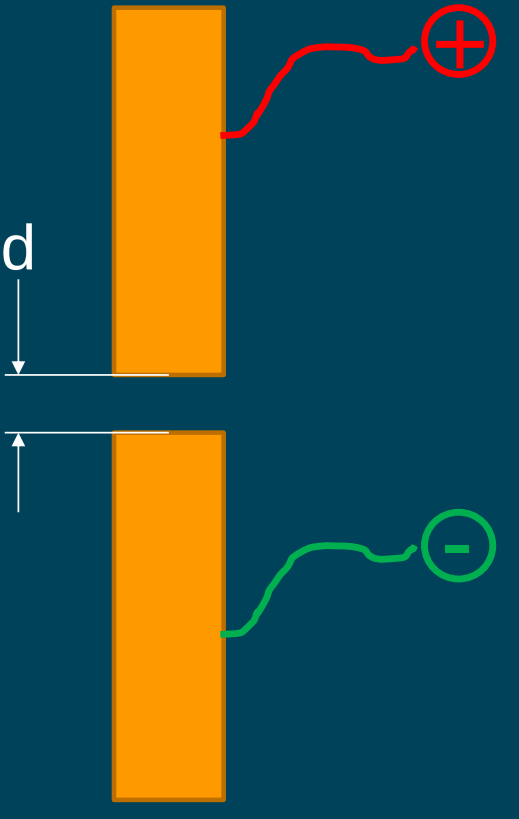
Arcing Impact

- The effect of current on wear was considered without visual observation of arcing and sparking
- R. Holm[2] arrived at the conclusion that the wear of carbon brushes increases in sparking due to two factors:
  - erosion caused by the arc thermal effect
  - mechanical wear rise due to higher metal surface roughness

$$W = N[W_0 + W_1 I + gQ^{1/2}] + \omega Q \quad [\mathrm{cm}^3/\mathrm{km}]$$

Experiment Design

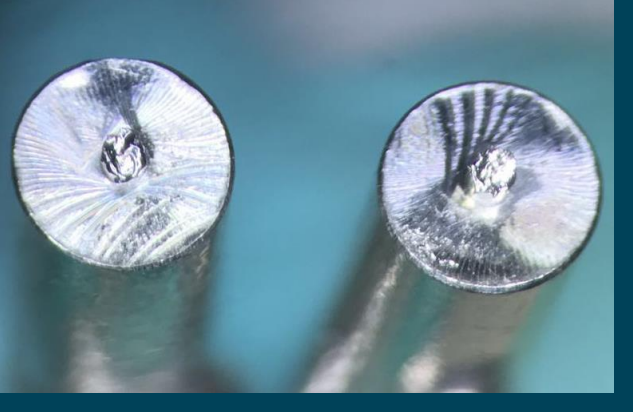
- Material
  - Stainless Steel (SUS304)
  - Beryllium Copper (BeCu)
  - Brass+Gold Plating
  - Pure Tin
- Voltage
- Displacement
- Pin Diameter



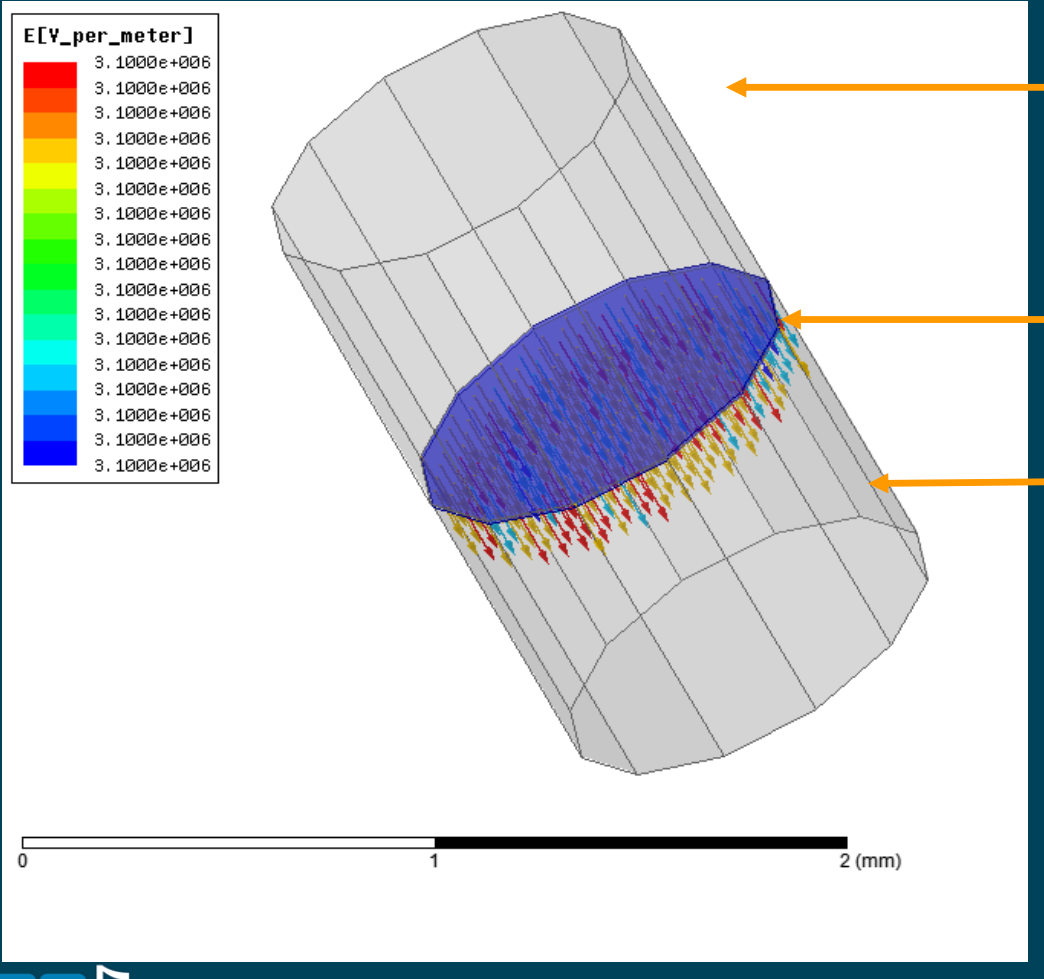
Result & Discussion

- Pin Diameter 1.5mm no arcing observed until 30 V
- Pin Diameter of below table is 0.5 mm.

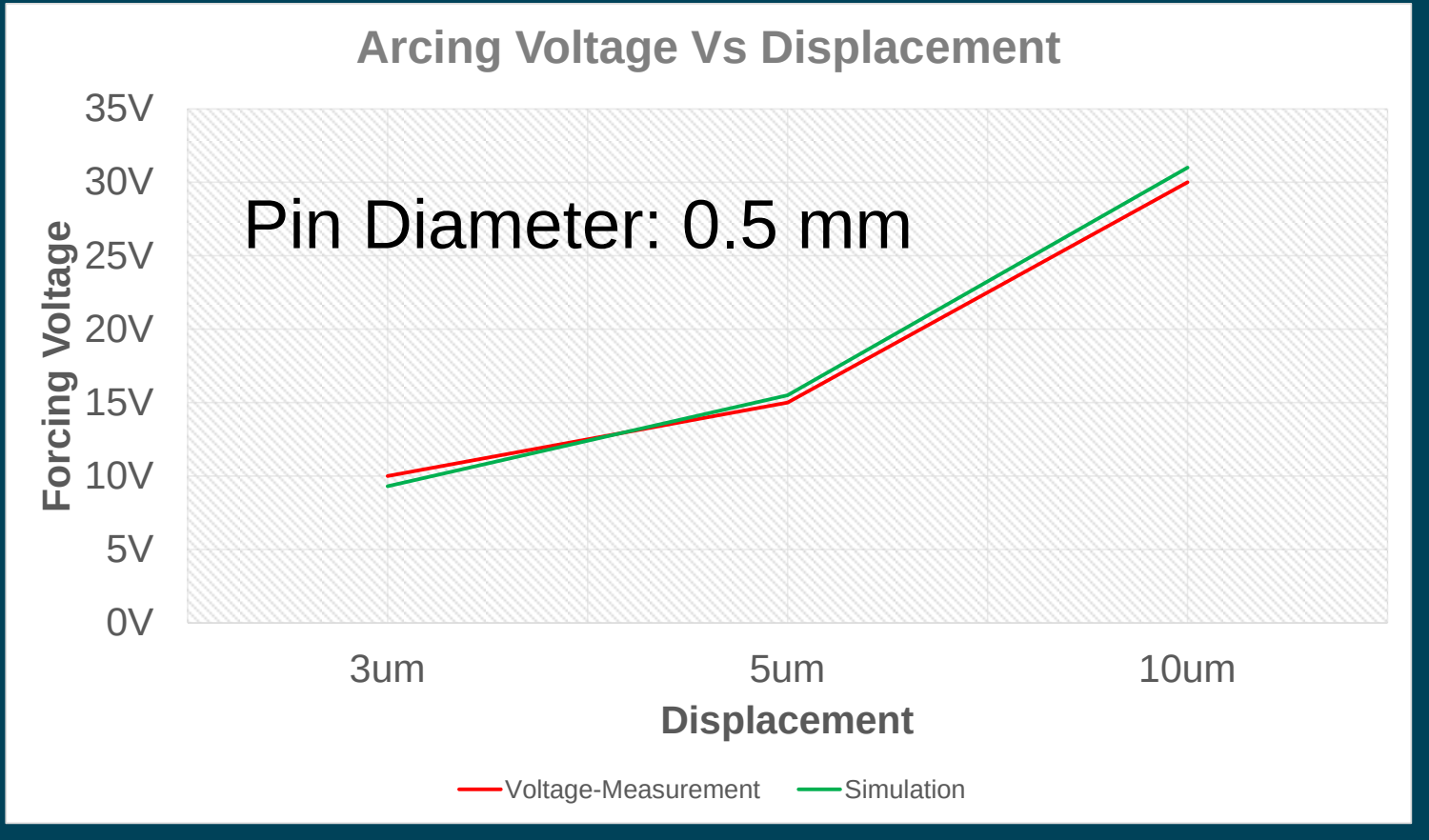
Material	Min_Voltage	Displacement
BeCu	No Arc	
Stainless Steel	10 V	3 um
	15 V	5 um
	20 V	10 um
Brass + Au Plating	No Arc	
Pure Tin	25 V	10 um



Simulation Model Setup

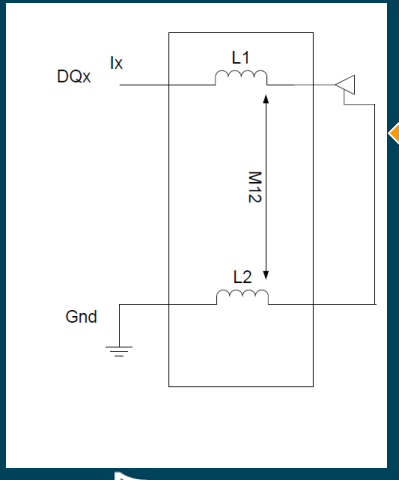


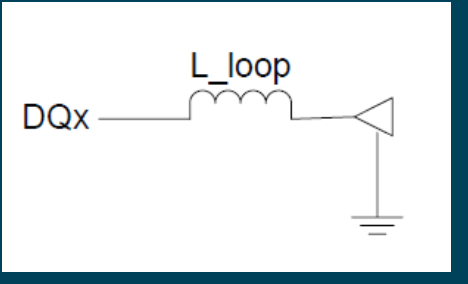
Measurement Vs Simulation Correlation



Pin Inductance

Pin Length(L)	Self Inductance	Loop Inductance
5.7 mm	3.5 nH	2.13 nH
4.75 mm	2.65 nH	1.75 nH
3.3 mm	1.58 nH	1.14 nH



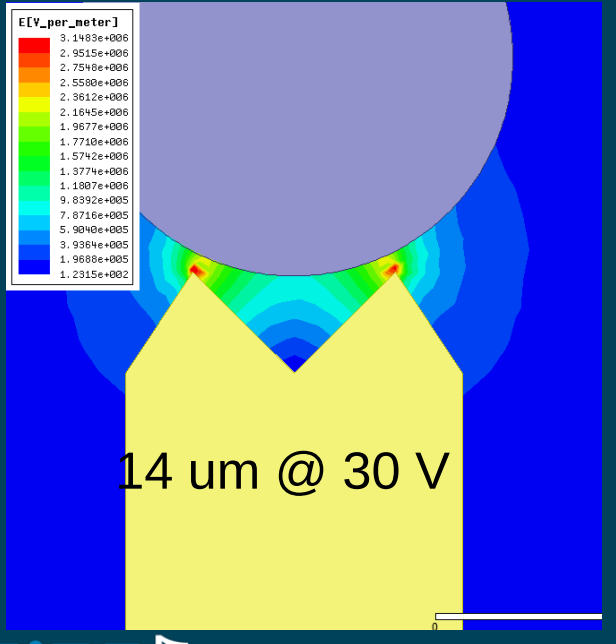


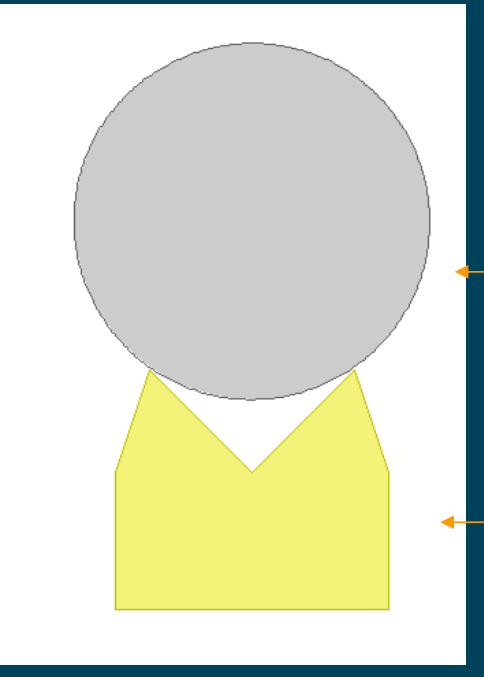
Self inductance is misleading sometime.

Loop Inductance of DQx to Gnd
L_loop = L1 + L2 – 2 * M12

Pin Crown Tip Discussion

Switching time:0.2 ns / 500 MHz
Inductance: 2.13 nH
Current: 500 mA
V : L*di/dt≈5.3 V





Crown Diameter	Arcing Displacement
0.1 mm	2.0 um
0.12 mm	1.8 um
0.15 mm	1.5 um

Discussion Continue

L: Inductance
d: Displacement
E: Electrical Strength

L*di/dt(V)	d(um)	E(10^5 V/m)
5	15	5.35
7.5	15	6.64
10	15	11.67
5	10	7.31
7.5	10	12.5
10	10	13.2
5	5	14.5
7.5	5	19.1
10	5	30.6

自变量	系数	系数标准误	T	P
常量	12.788	5.281	2.42	0.052
L	1.8873	0.5714	3.30	0.016
D	-1.3513	0.2857	-4.73	0.003

S = 3.49933 R-Sq = 84.7% R-Sq（调整） = 79.6%

方差分析

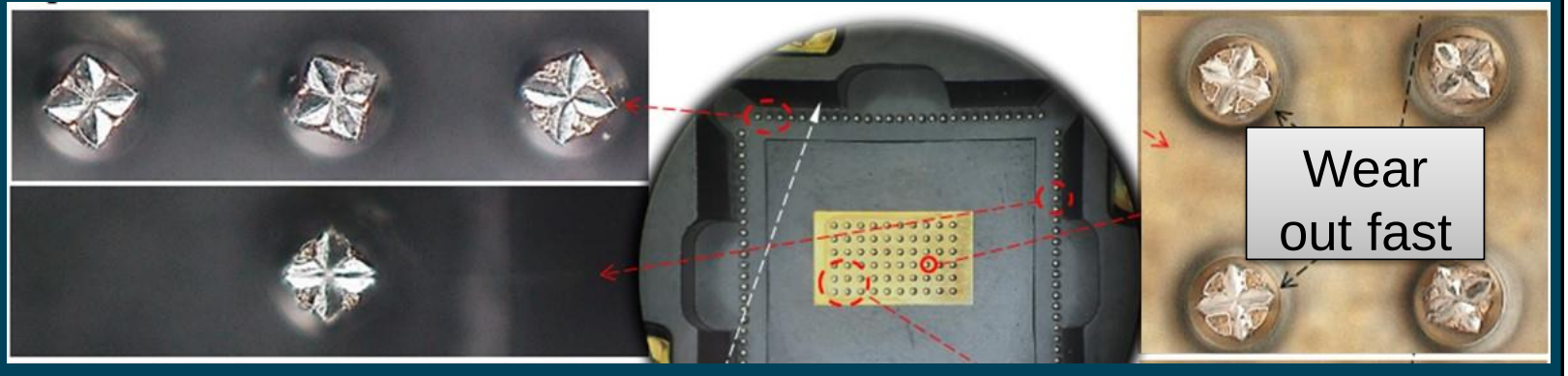
来源	自由度	SS	MS	F	P
回归	2	407.49	203.75	16.64	0.004
残差误差	6	73.47	12.25		
合计	8	480.96			

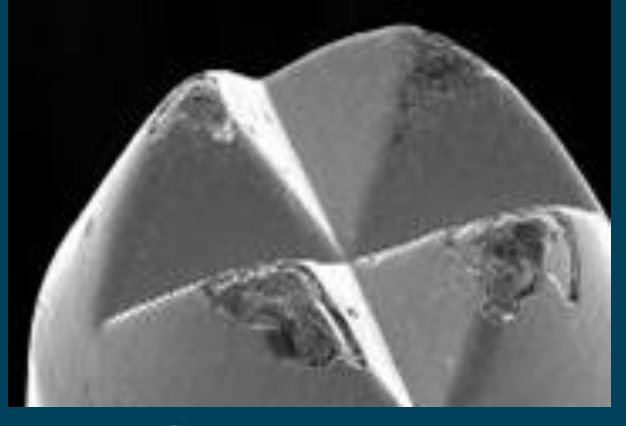
$$E = 12.8 + 1.89\ L*di/dt - 1.35\ d$$

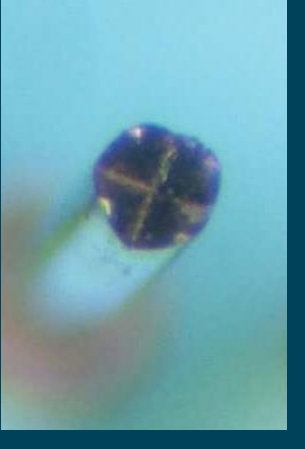
Discussion Continue

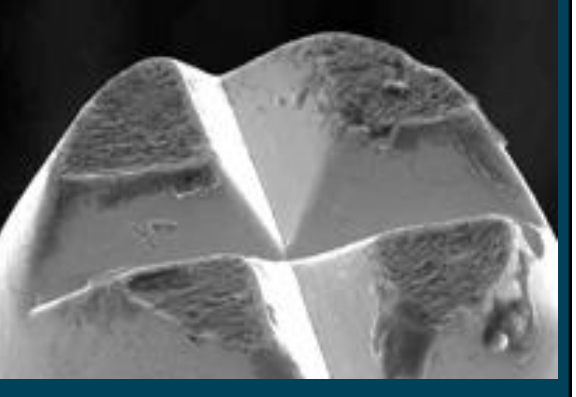
Signal Probe

Ground Probe









Summary

- Simulate the electrical filed strength to predict the arcing power
- Different crown diameter impact the electrical field strength
- Various ways to diminish the arc
  - One important way is increase the separation speed of two contactors. The speed required and voltage levels for hot switching is a very interesting topic for further study.

References

1. Guozhen, X. Principle and application of high voltage circuit . China. Tsinghua University Press
2. Braunovic, M. Electrical Contacts Fundamentals, Applications and Technology. US. China Machine Press