



Technische
Universität
Braunschweig

TMF-Contacts in Vacuum Interrupters with gaps above 20 mm

Benjamin Weber | ITG Vacuum Workshop | 02.09.2022

Agenda

- 1 Motivation**
- 2 Test Setup**
- 3 Evaluation Method**
- 4 Results**
- 5 Conclusion**

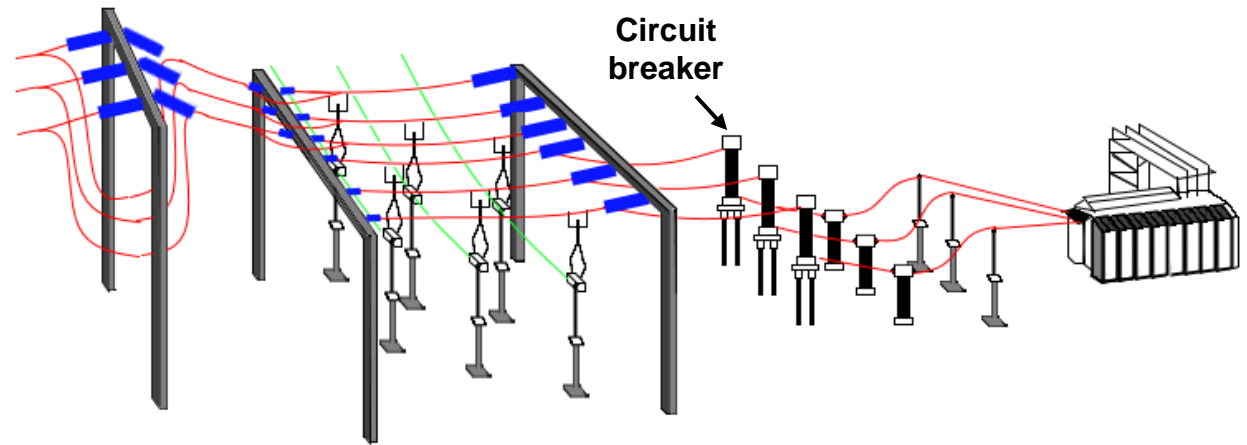
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Motivation

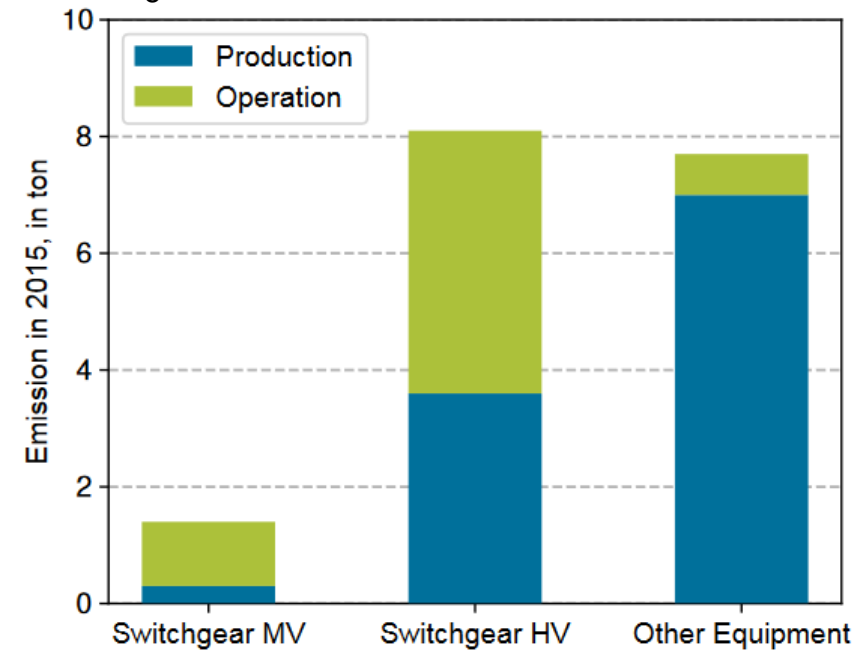
Circuit Breaker in Power Grids

- Circuit breaker (CBs) perform making and breaking operations for rated currents
 - CBs can interrupt a rated short-circuit current up to several kA
 - They withstand applied grid voltage in open position
 - High voltage switchgear due to SF_6 -switches (gas pressure) contributes to climate change
 - Over the next decade new installed switchgear will have to be more climate friendly
- ➔ Vacuum circuit breaker are established in medium voltage switchgear



[1]

SF_6 Emission in power transmission

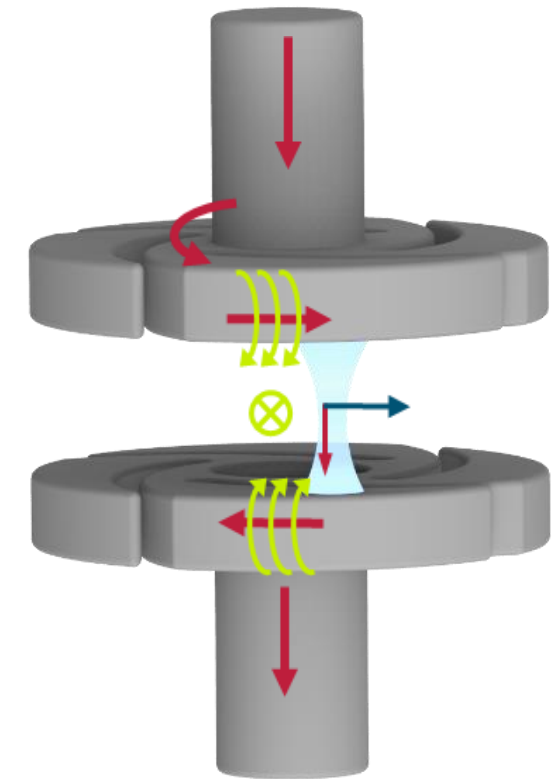


[2]

Motivation

Vacuum circuit breaker (VCB) as SF₆ alternative

- Vacuum has a degressive withstand voltage
→ Increase gap further or use a series of switches
 - Contact separation of electrodes in vacuum
(here: transversal magnetic field (TMF-) contacts)
 - Current flow through evaporating contact material
→ Vacuum arc
 - Dielectric and thermal recovery at current zero
 - Contact geometry generates a magnetic field
 - Distribution of contact stress due to driving magnetic force
- TMF-contacts with enlarged gaps in VCBs offer an inexpensive solution up to a certain voltage level



- Current
- Magnetic field
- Lorentz force

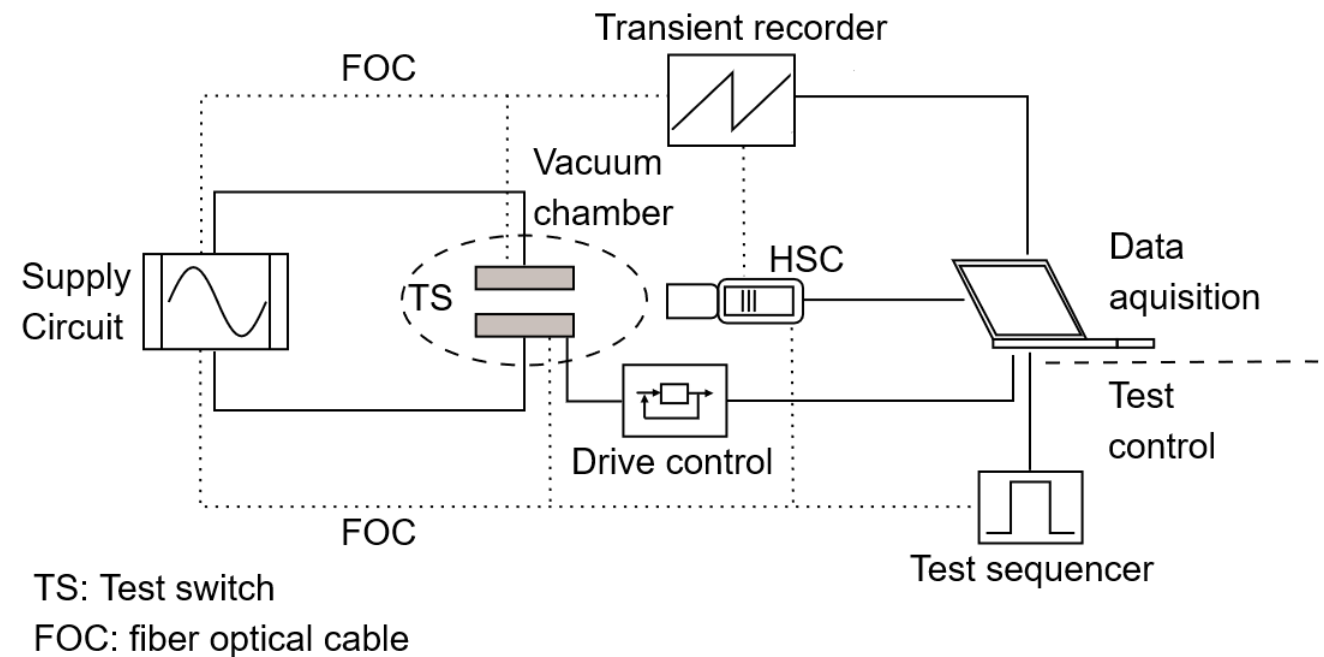
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Test setup

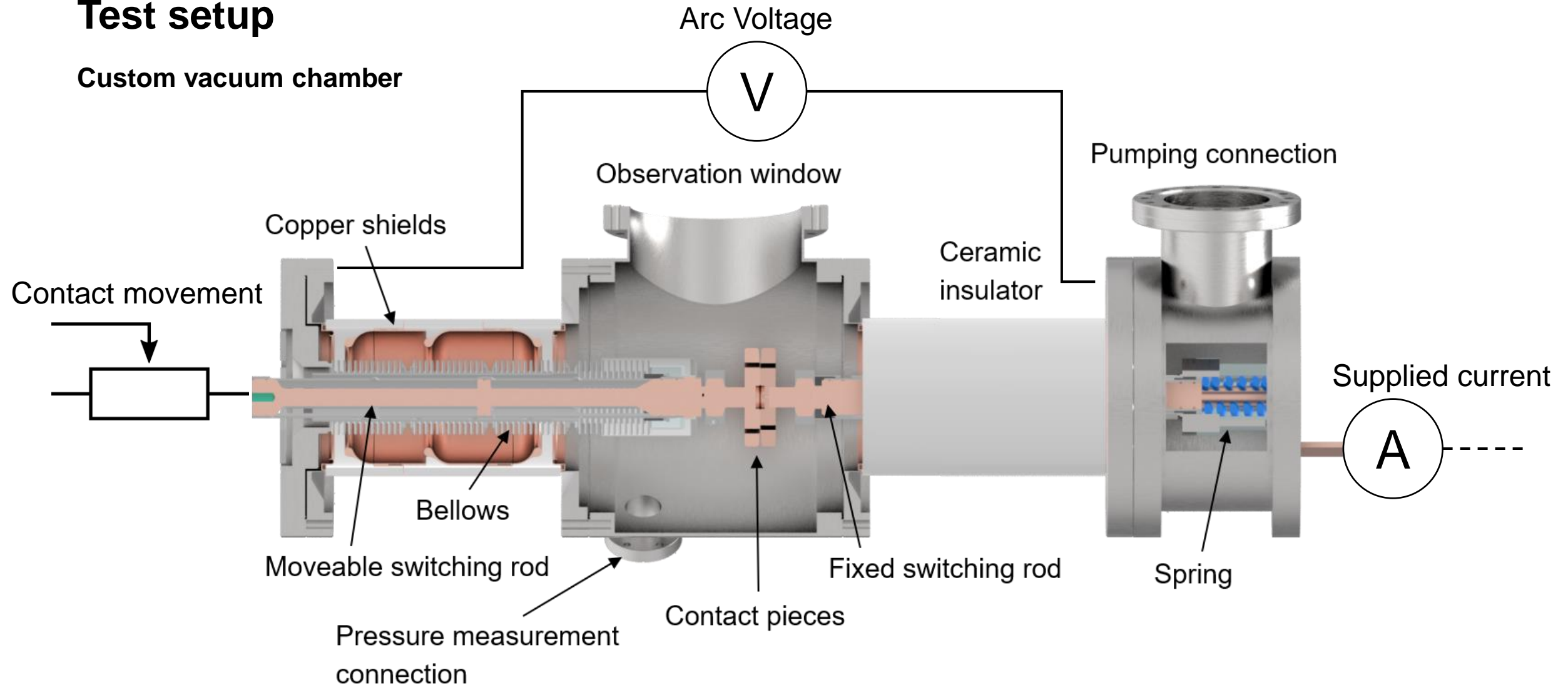
Components for generating and measuring a vacuum arc

- Supply Circuit (synthetic) generates short-circuit current (here up to 31.5 kA RMS)
- Switching contacts are moved with a programmable AC-motor
- Test procedure is controlled with a sequencer (HBM BE3200)
- Optical data is recorded with a Photron Nova S6 with 12-bit resolution
- Electrical data recording via transient recorder (HBM Gen7t)



Test setup

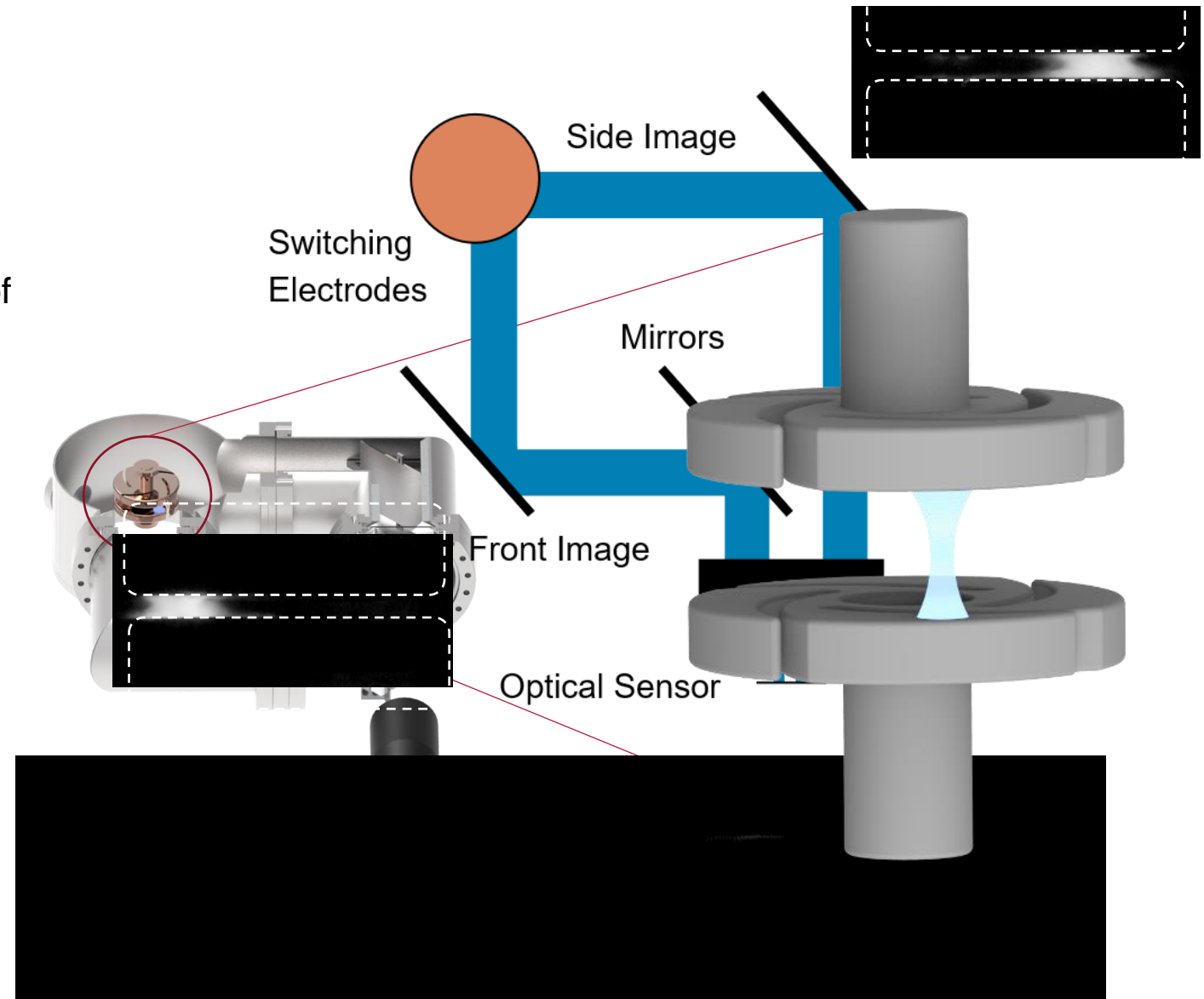
Custom vacuum chamber



Test setup

Optical recording the vacuum arc

- Mirror arrangement for perpendicular recording of the moving arc
- Integration time 200 ns
- Aperture f/32
- Addition of neutral density filters
- ➔ Prevent motion blur, depth blur and over exposure
- Images are separate in front and side image based on camera position



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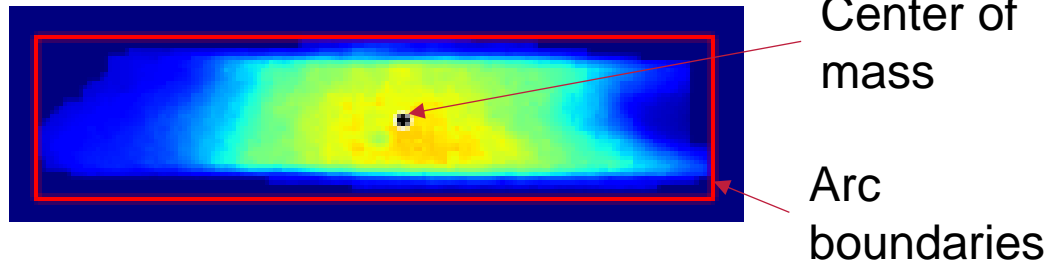
4 Results

5 Conclusion

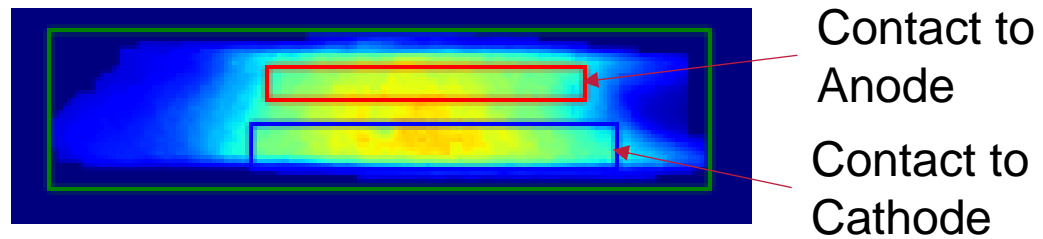
Evaluation Method

Image processing and object detection

- Tracking of optimized object with consideration of intensity distribution



- Tracking of footpoints on electrode surface



Original Recording



Arc Tracking



Footpoint Tracking

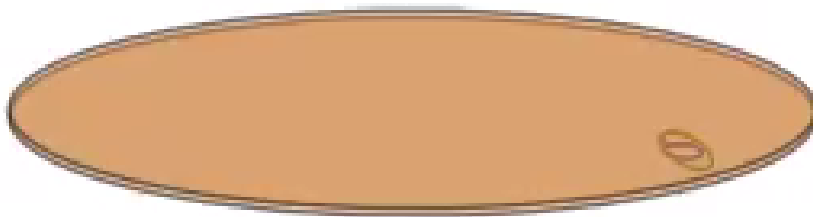


Evaluation Method

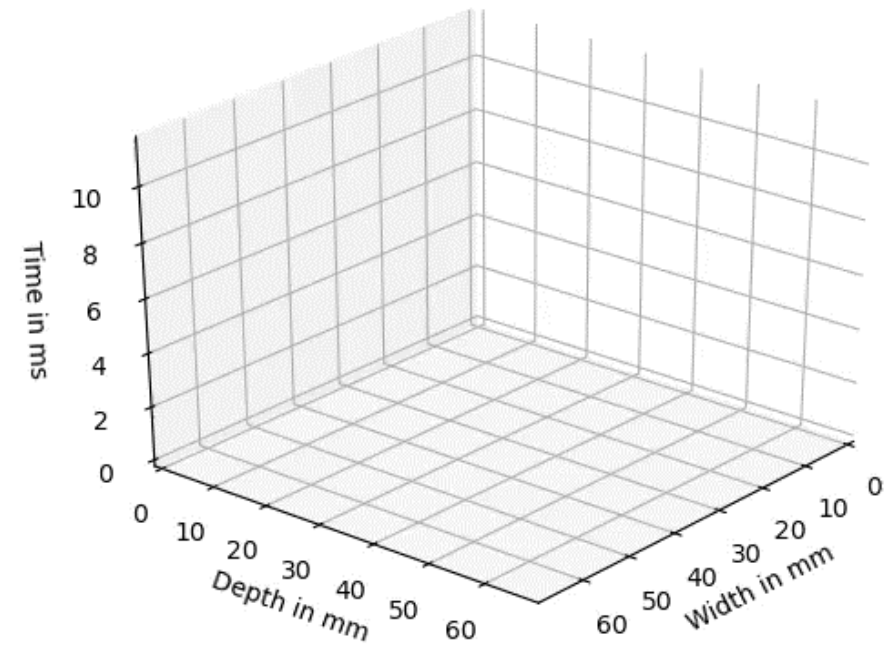
Arc Movement

- Detection of arc location and its derived movement over time

Tracking of footpoints (**anode** / **cathode**) and **arc width**



Center movement over time



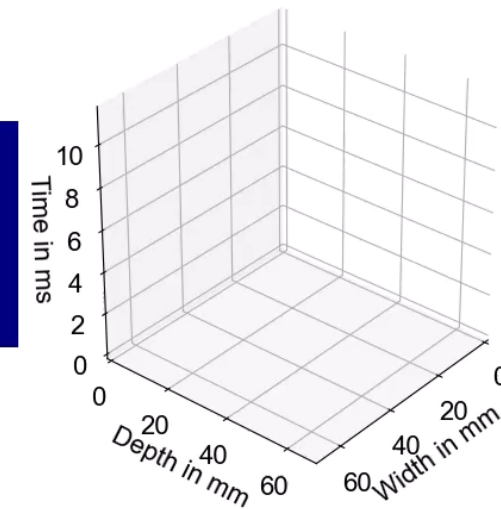
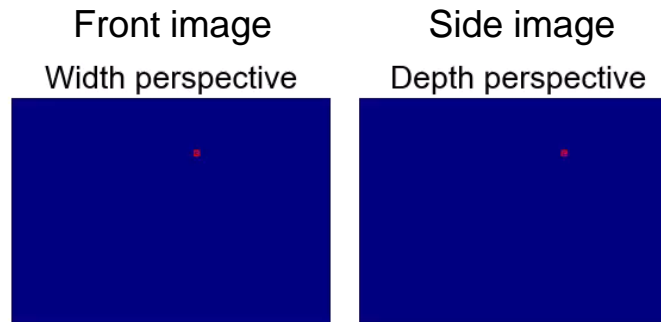
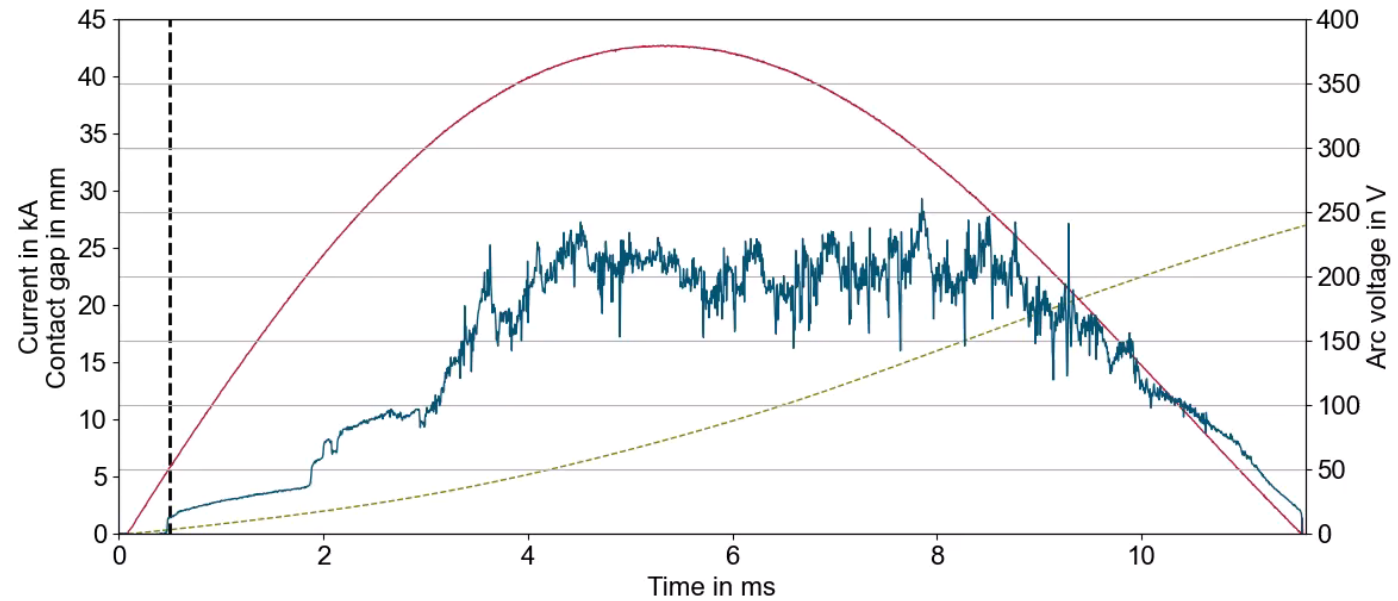
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Results

Performed tests

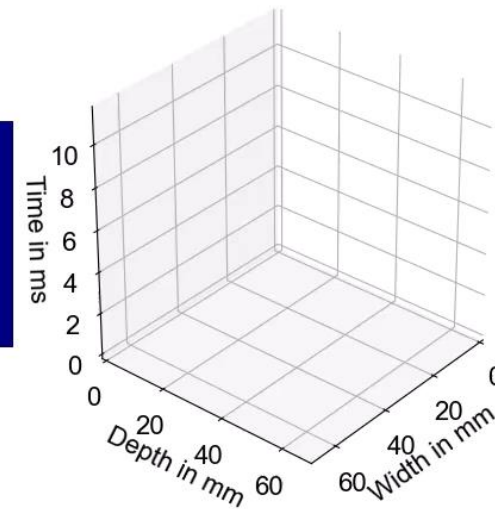
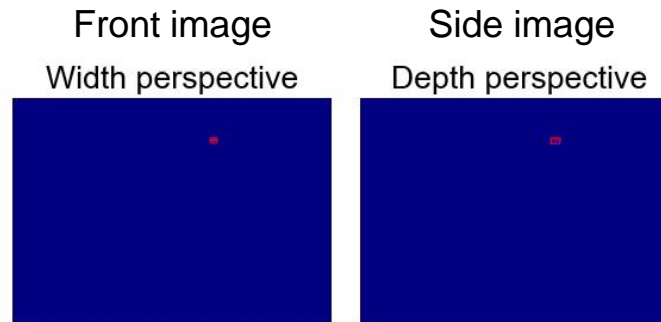
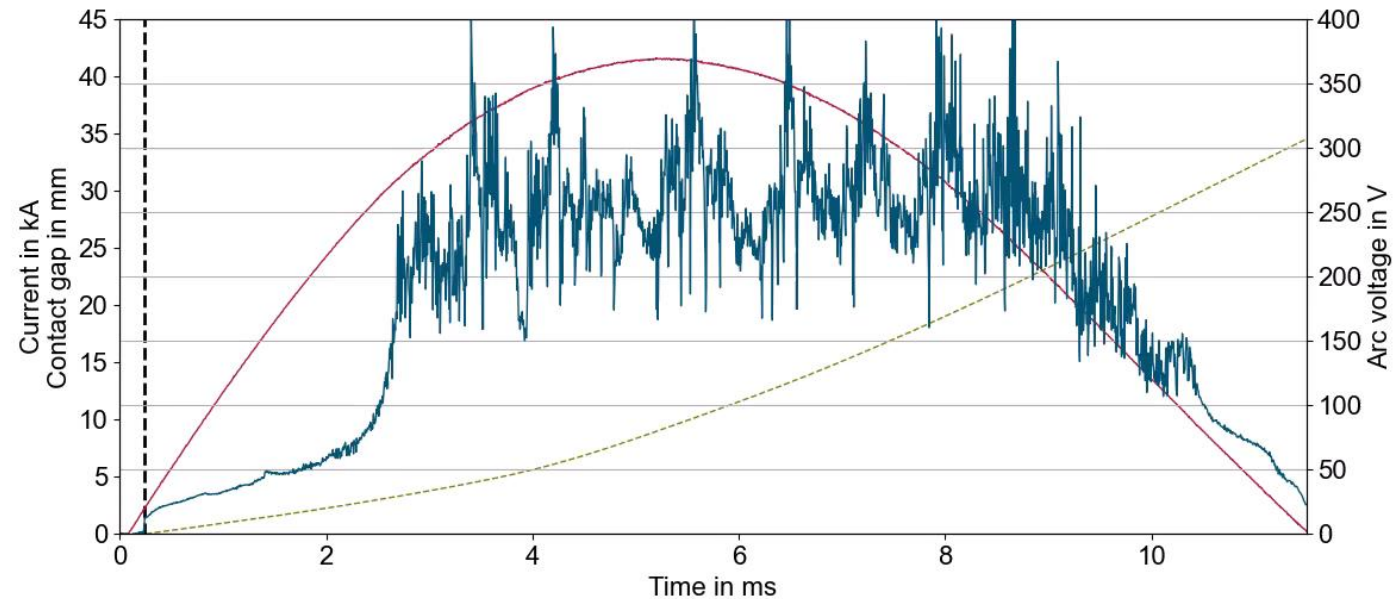
- 25 mm final gap
- 31.5 kA short-circuit current
- Material: CuCr25
- Contact diameter: 68 mm
- Arcing time: 11.5 ms
- Input charge: 308.7 As
- Rotations: 7



Results

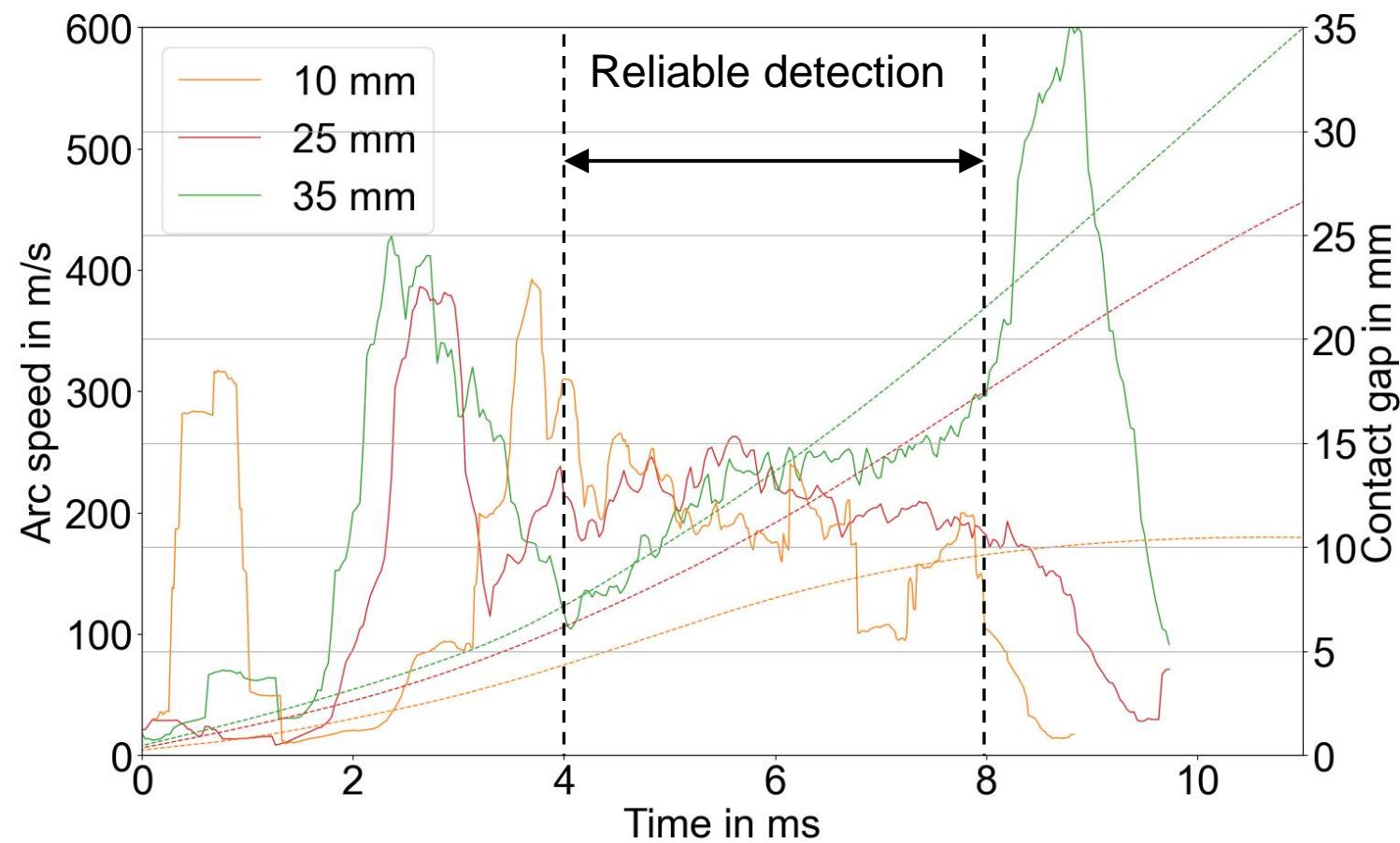
Performed tests

- 35 mm final gap
- 31.5 kA short-circuit current
- Material: CuCr25
- Contact diameter: 68 mm
- Arcing time: 11 ms
- Input charge: 295.43 As
- Rotations: 12



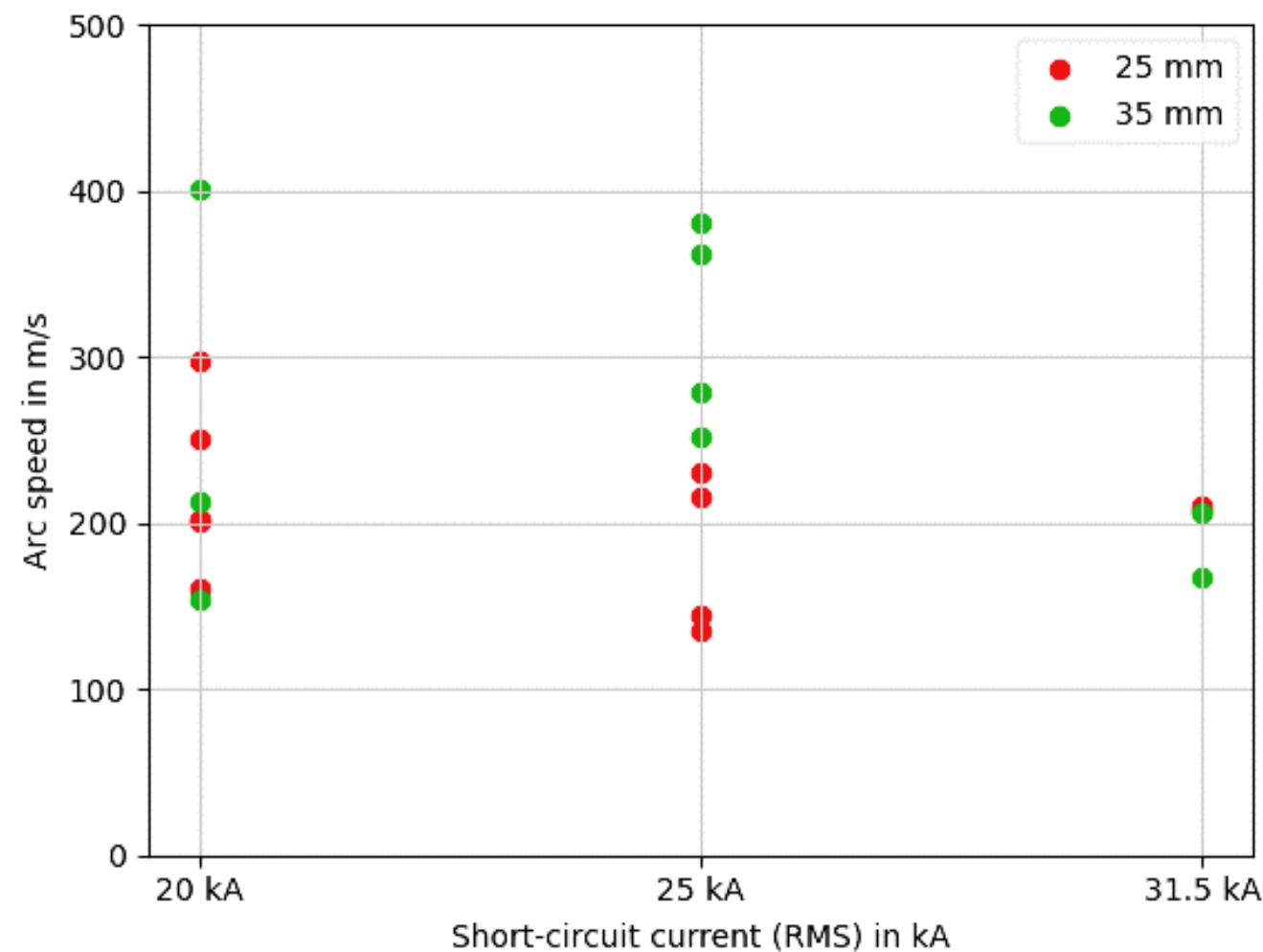
Results

Arc Speed - Comparison



Results

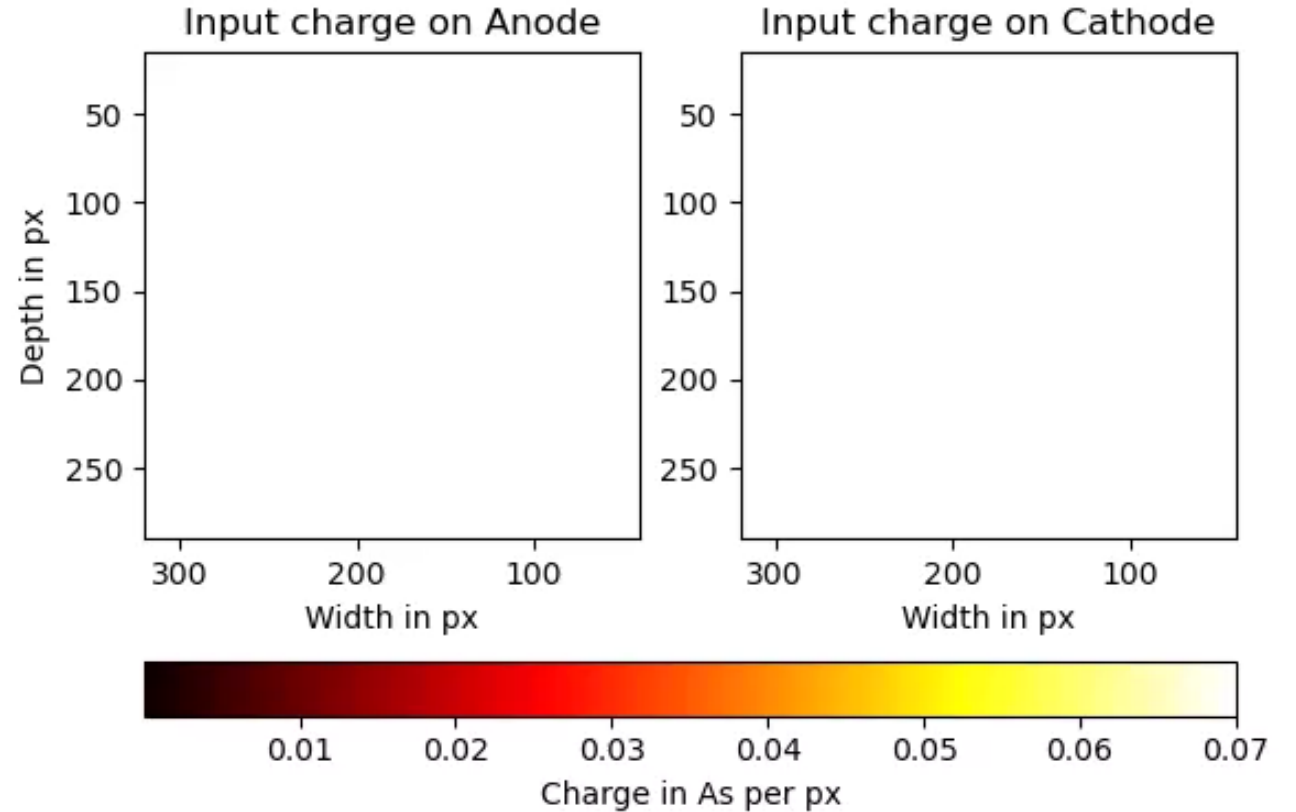
Average Speeds between 4 ms and 8 ms (early ignition <1.5 ms)



Evaluation Method

Arc Movement

- Per frame: footpoint
- Frame to frame: charge
- Measured charge through footpoints on contact surface

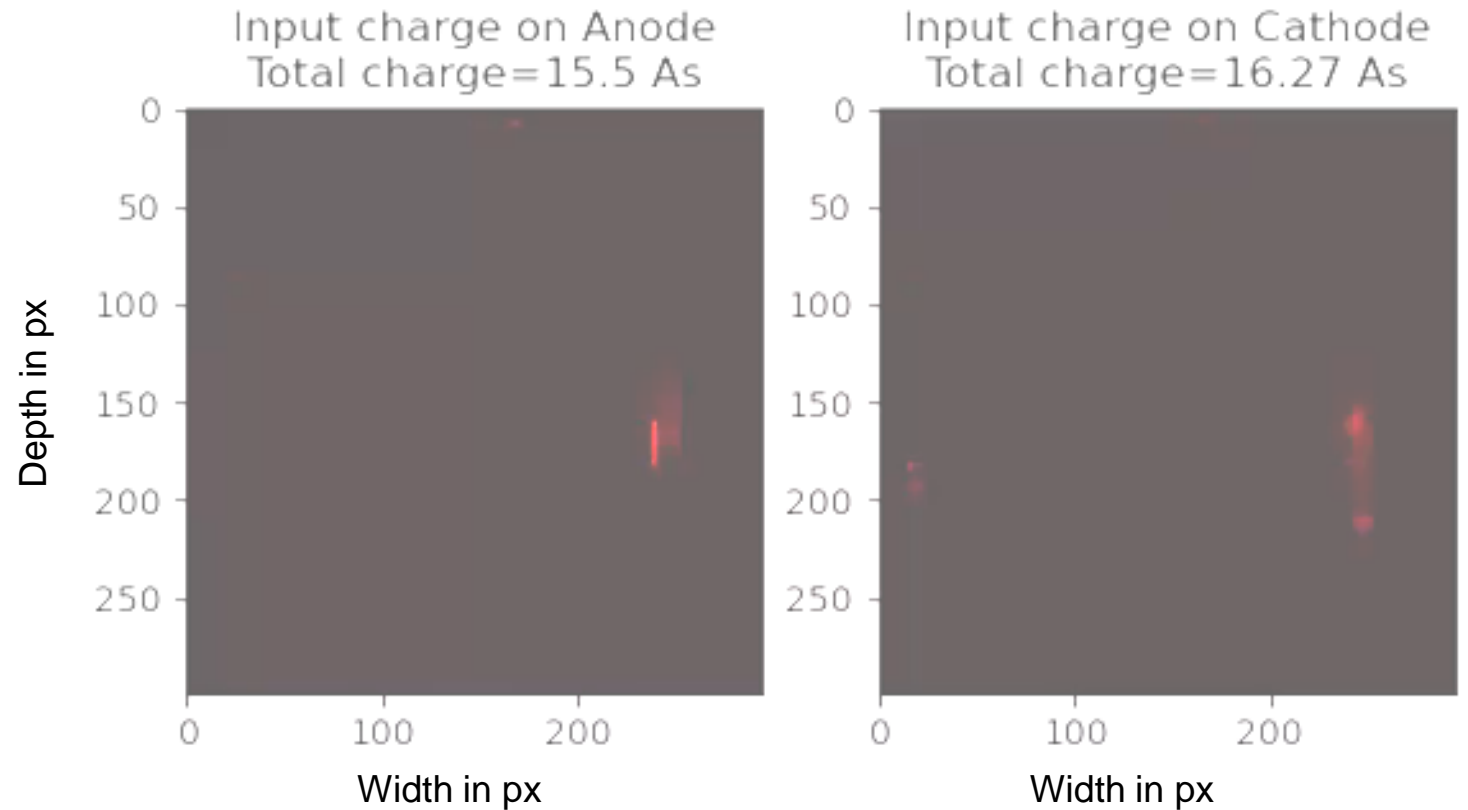


Results

Charge distribution over contact lifetime

- 35 mm Contact gap
- 3x 2 kA
- 5x 20 kA
- 5x 25 kA
- 3x 31,5 kA

→ Cumulative Charge



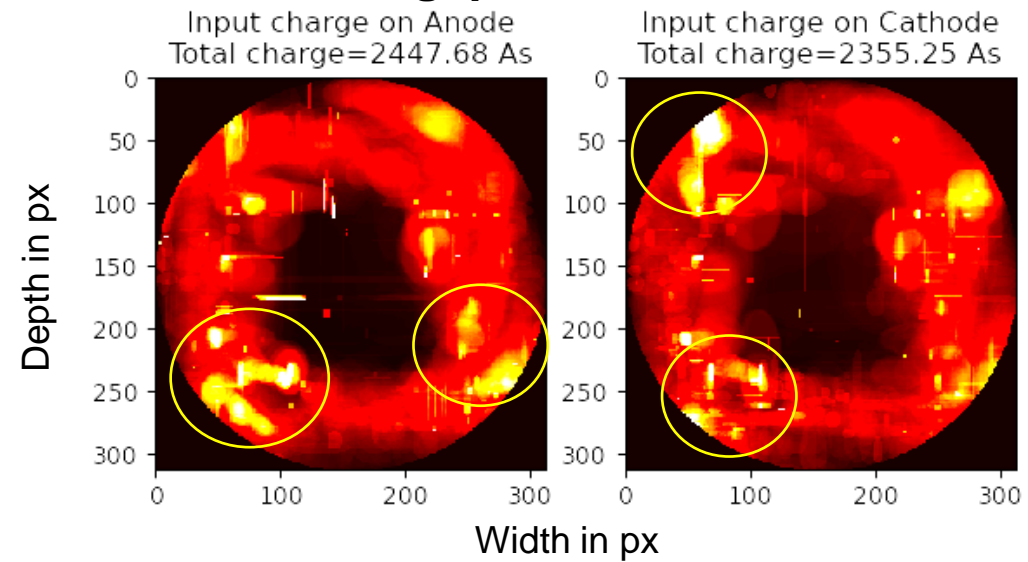
Results

Charge distribution over contact lifetime

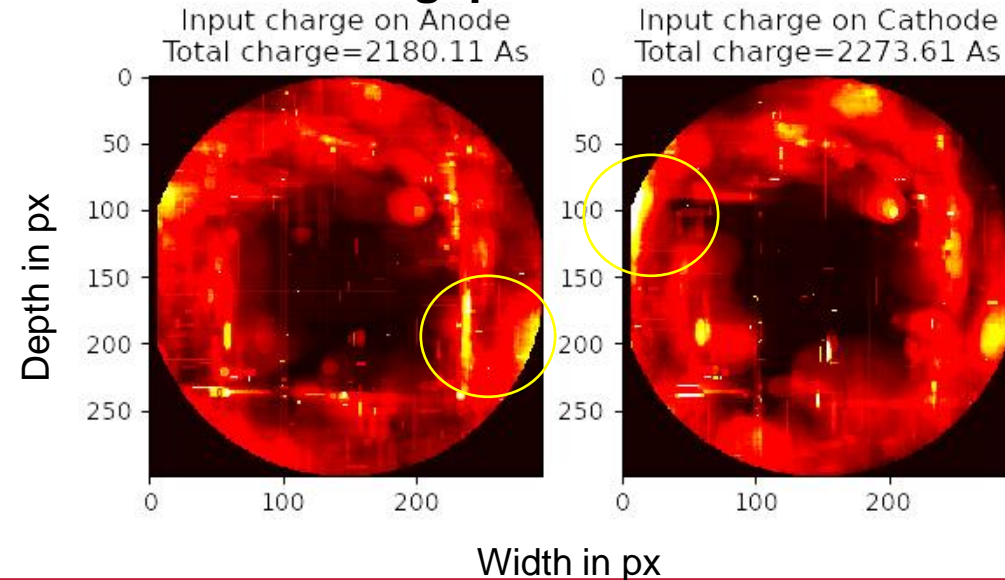
- Comparing same tests with different gaps
- 3x 2 kA
- 5x 20 kA
- 5x 25 kA
- 3x 31,5 kA

➔ New perspective for determine contact stress

25 mm Contact gap



35 mm Contact gap



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Conclusion

- A method for arc evaluation based on **automated arc detection** was presented
 - Individual observation of arc movement and footpoints
 - Consideration of electrical and optical data
- A programmable drive was used to vary gap distances **above 20 mm with TMF-contacts**
- The arc speed and charge distribution for all test were evaluated
 - ➔ The arc speed is not effected significantly by the contact gap
 - ➔ The charge distribution is helpful new display of contact stress, but the differences for longer gaps are minor



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Thank you for your interest

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References

[1] cf: <http://www.vpe.ch/html/umspannwerke.php>

[2] Burges, K. et al. Konzept zur SF6-freien Übertragung und Verteilung elektrischer Energie: Abschlussbericht. Ed. by Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit. 2018

Backup: ITG Vacuum Workshop

Electrical Circuit

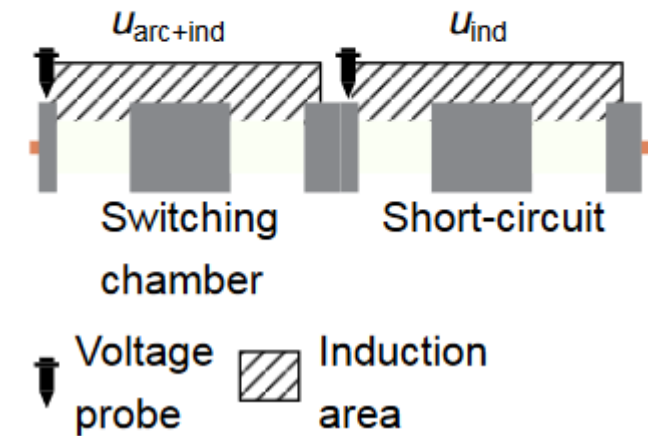
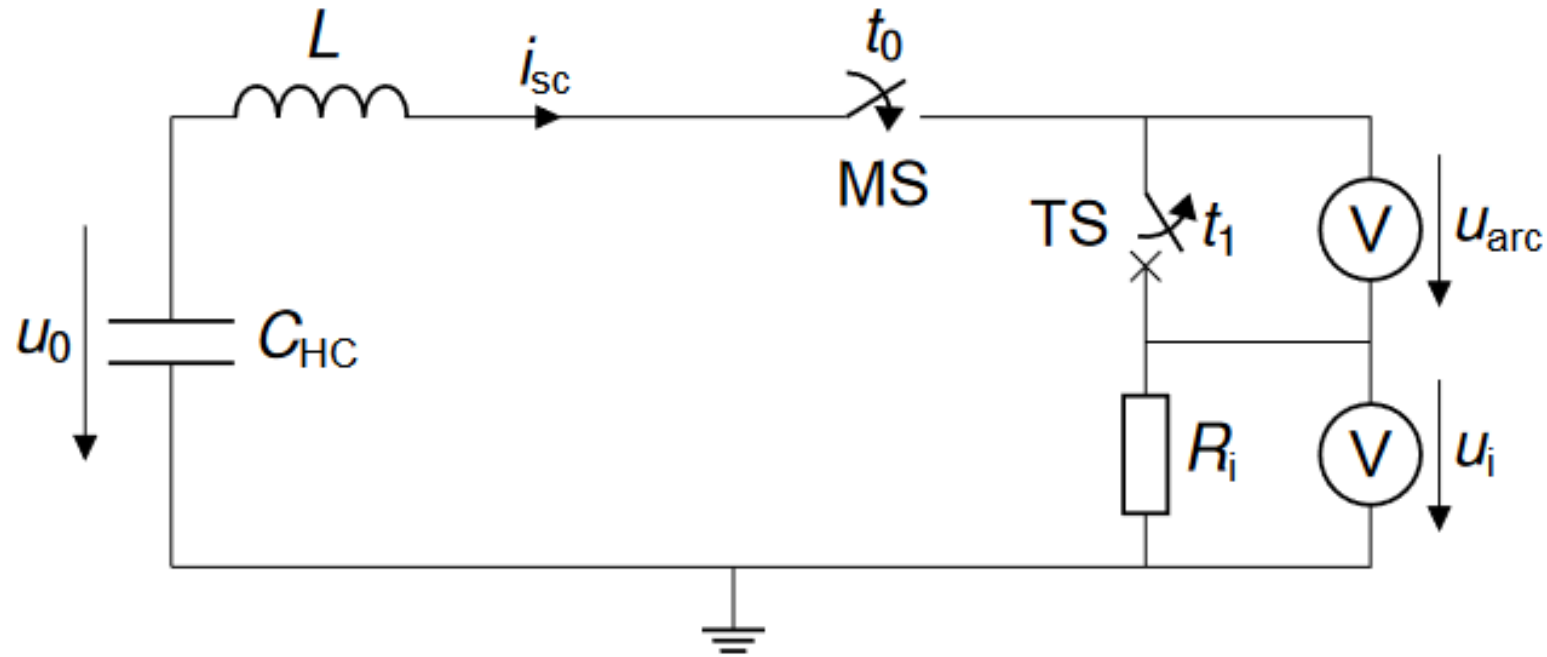
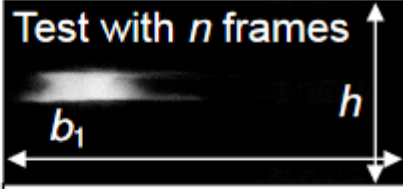
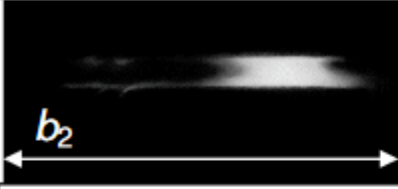


Image Processing

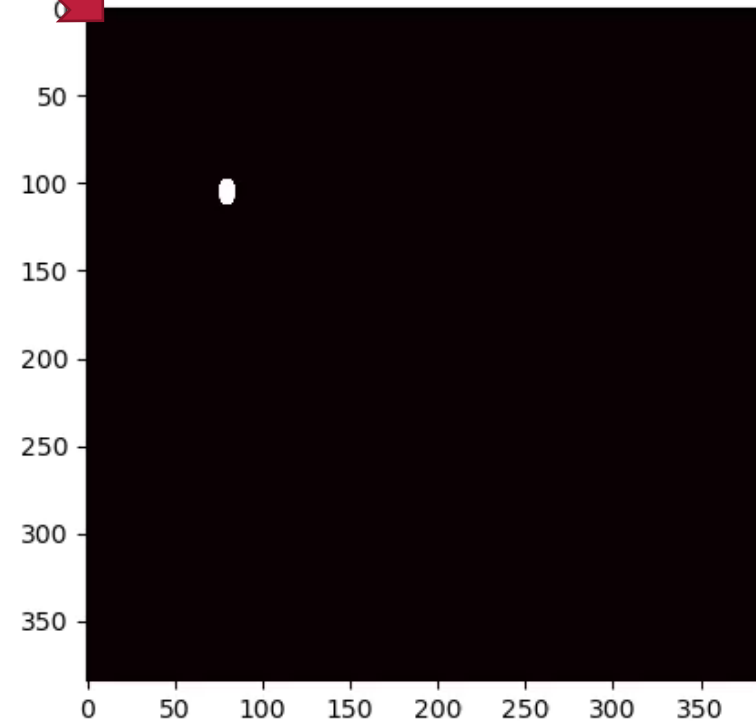
	Front Image	Side Image	
	 <p>Test with n frames</p>		n : Number of frames h : Image height b_i : Image width $\underline{A}, \underline{B}$: Image matrices with 12-bit values th_{Otsu} : Segmentation threshold X : Structuring element \oplus : Dilation \ominus : Erosion k : Correction factor F : Antidiagonal unit matrix
3D-Array read in	$n * \underline{A}_{i, h \times b_1} \subset \mathbb{N}$	$n * \underline{B}_{i, h \times b_2} \subset \mathbb{N}$	
Segmentation	$n * th_{Otsu, \underline{A}}$	$n * th_{Otsu, \underline{B}}$	
Morphological Opening	$\underline{A} \circ X = (\underline{A} \ominus X) \oplus X$	$\underline{B} \circ X = (\underline{B} \ominus X) \oplus X$	
Morphological Closing	$\underline{A} \bullet X = (\underline{A} \oplus X) \ominus X$	$\underline{B} \bullet X = (\underline{B} \oplus X) \ominus X$	
Frame correction	Correction factor $\underline{A} * k$	Mirror frame $\underline{B} * F$	

Arc-Programm

Realer Fußpunkt

- Matrix pro Frame mit binäre Ortsinformation

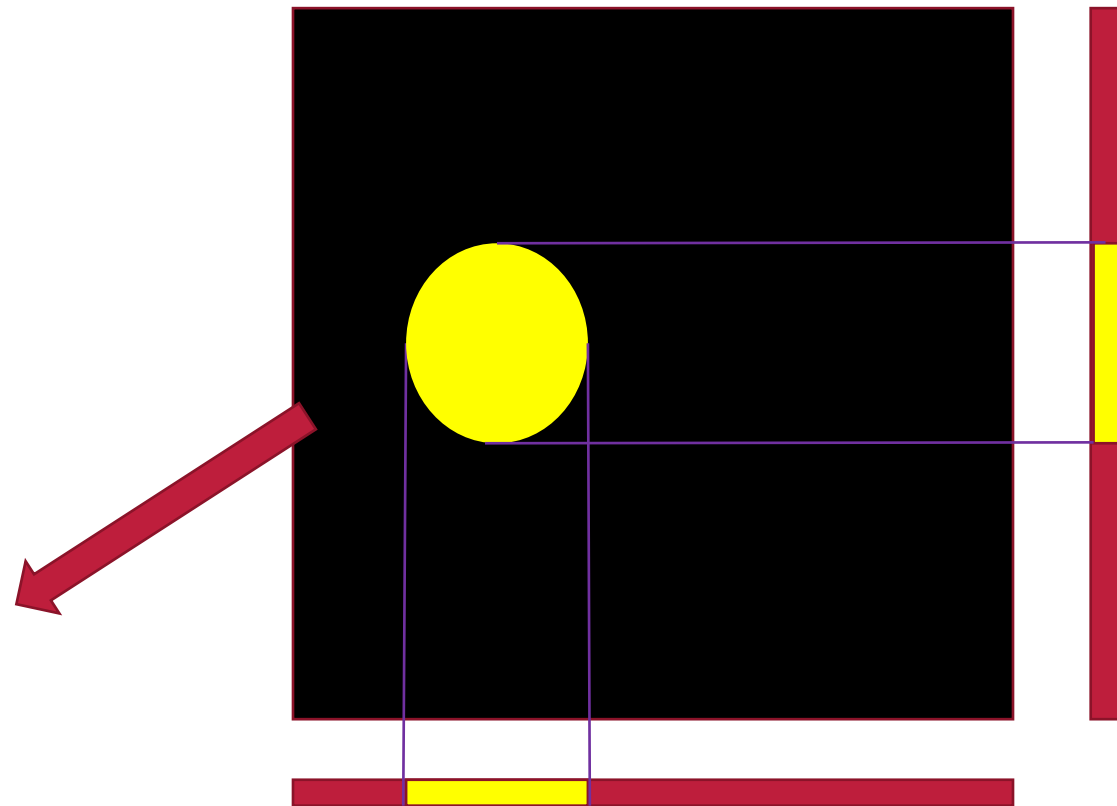
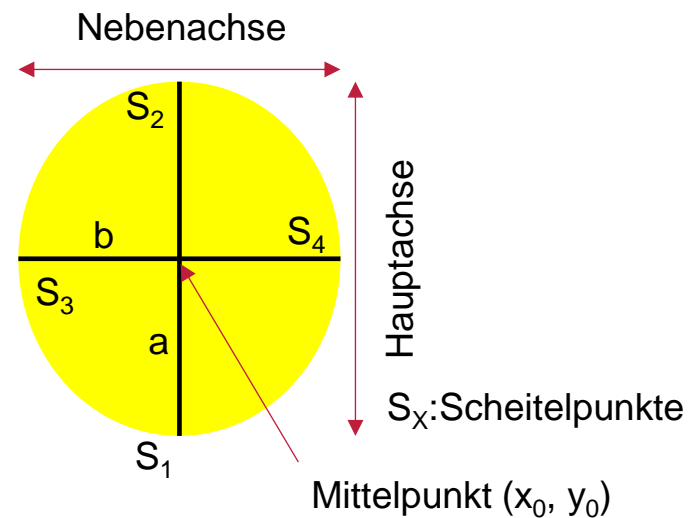
➔ Zeitverlauf einer Fußpunktbewegung



Arc-Programm

Optische Überlagerung

- 1D-Betrachtung der Perspektiven
- Für jeden Frame wird ein binäres Array mit Ellipse an den Fußpunkten bzw. Bogen berechnet



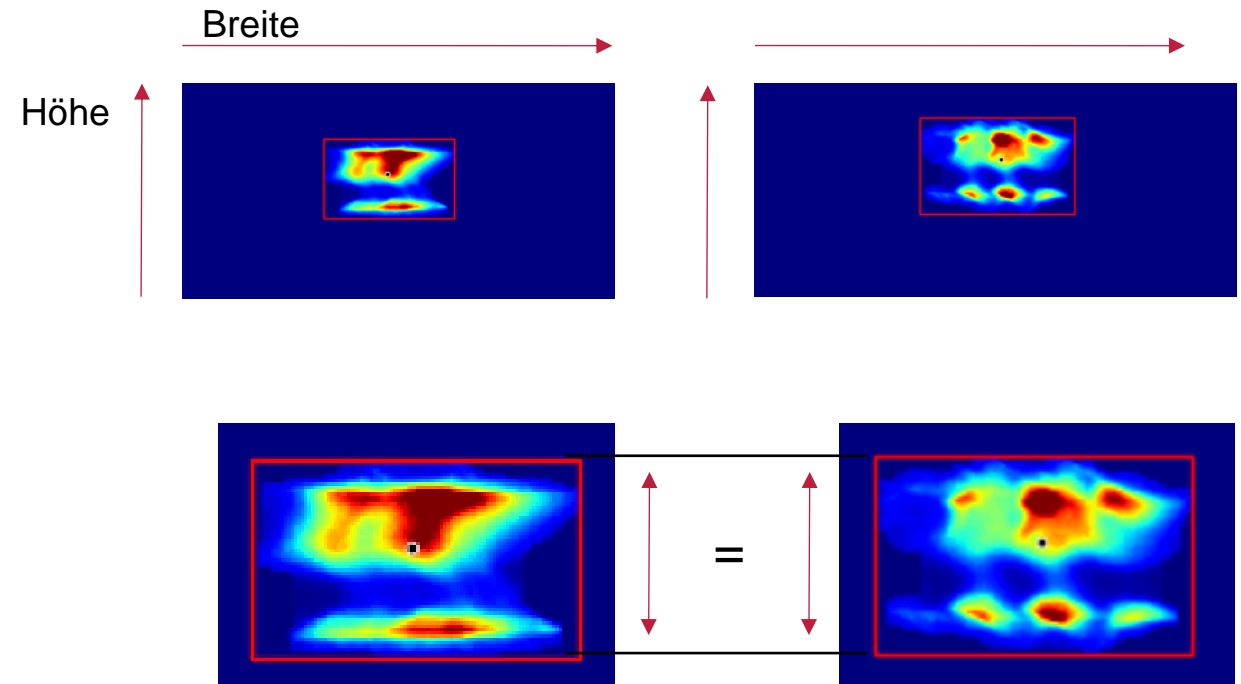
Ellipsengleichung

$$\frac{(x - x_0)^2}{a^2} + \frac{(y - y_0)^2}{b^2} = 1$$

Arc-Programm

Korrektur Höhe

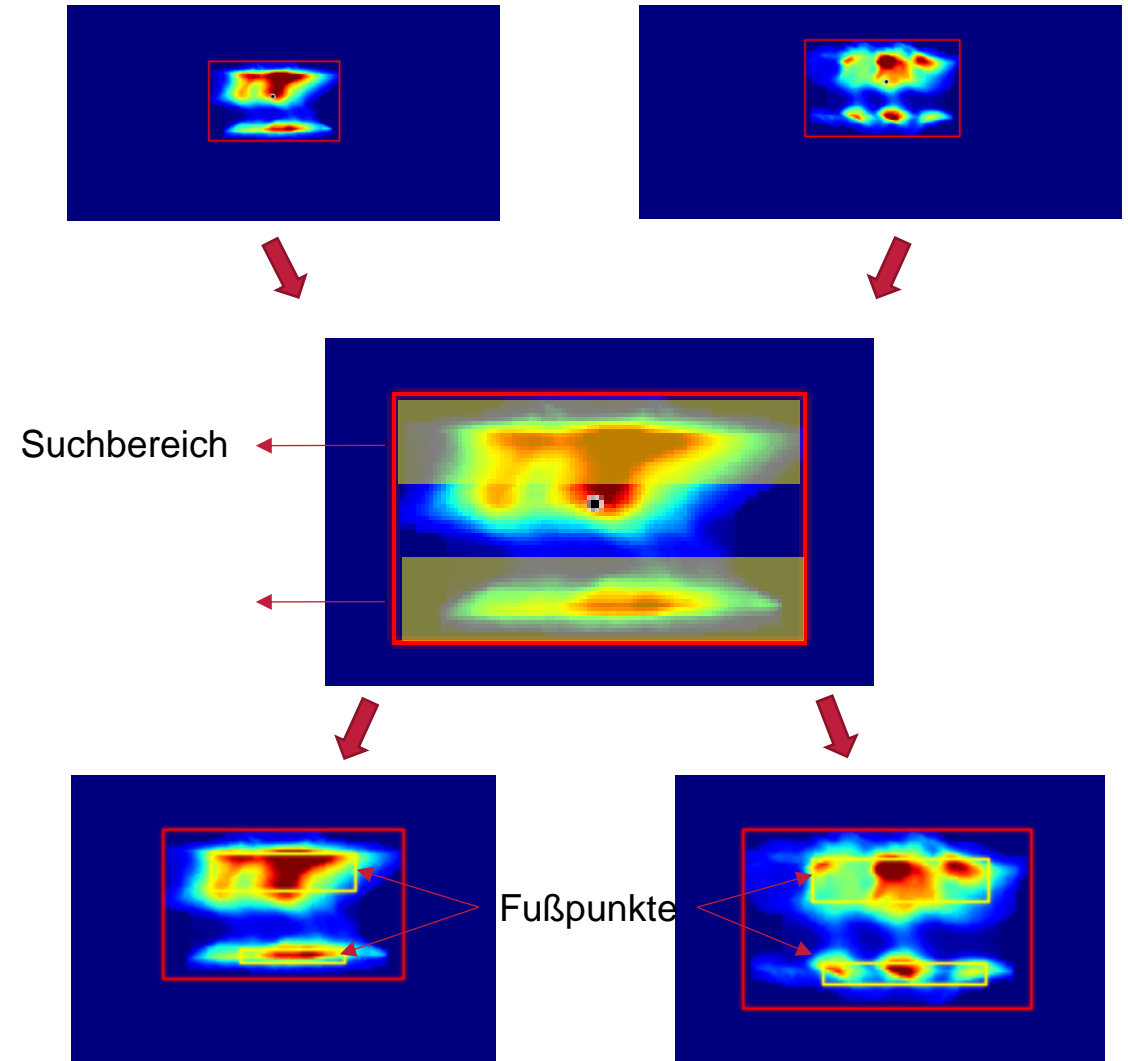
- Minimale Unterschiede (bis 5 px-Reihen typisch) in der jeweiligen Höhe
- Auswahl der kleineren Höhe → Anpassung der größeren Höhe an das kleinere Maß durch zuschneiden
 - Reduziert Überstrahlung
- Anpassung der festen Kontaktseite
 - Start bei gleicher Höhe
 - Ausgleich minimaler Fehler in Spiegelausrichtung
 - Achtung: nur vertikale Korrektur



Arc-Programm

Fußpunktdetektion

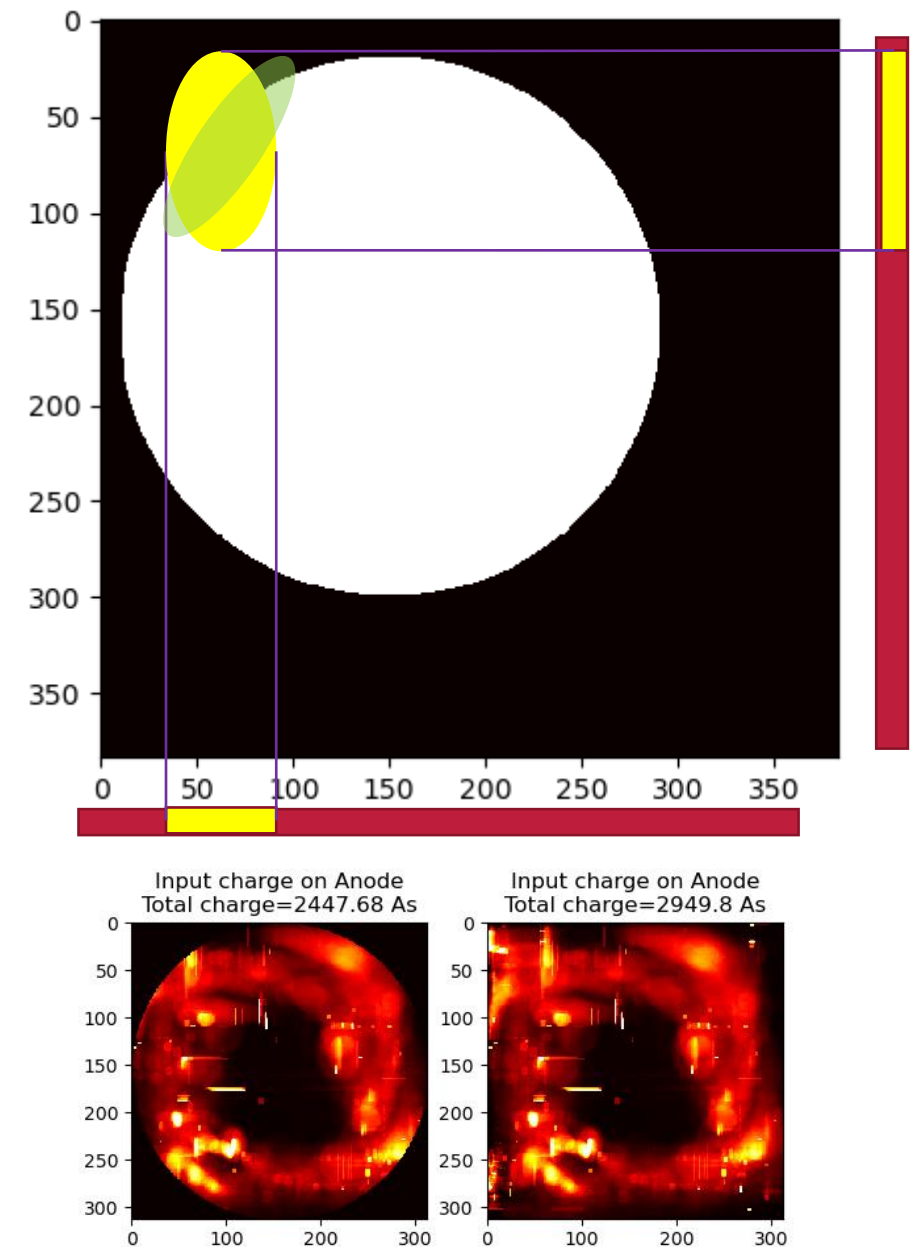
- Anpassung im ursprünglichen Programm für Fußpunkte
- Separater, adaptiver Suchalgorithmus innerhalb des Bogens nach Fußpunkten
- Innerhalb eines Suchbereichs (Elektrodenah) wird der intensive Kern (abhängig vom der Intensität im Suchbereich) detektiert
- Resultierend sind drei Bereich:
Fußpunkt 2x, Bogenbereich



Error in Evaluation

Main sources of error:

- Perpendicular perspective
 - By perspective the determination of the footpoint ellipses is always parallel to the image acquisition (major and minor axis are always aligned according to the images)
 - Possible solution: Alignment orthogonal to the radius
- Charge outside the contacts
 - Cutting off the contact area leads to a difference in measured introduced charge and distributed charge
 - here: 20 % difference
 - Possible solution: distribute charge only via contactTranslated



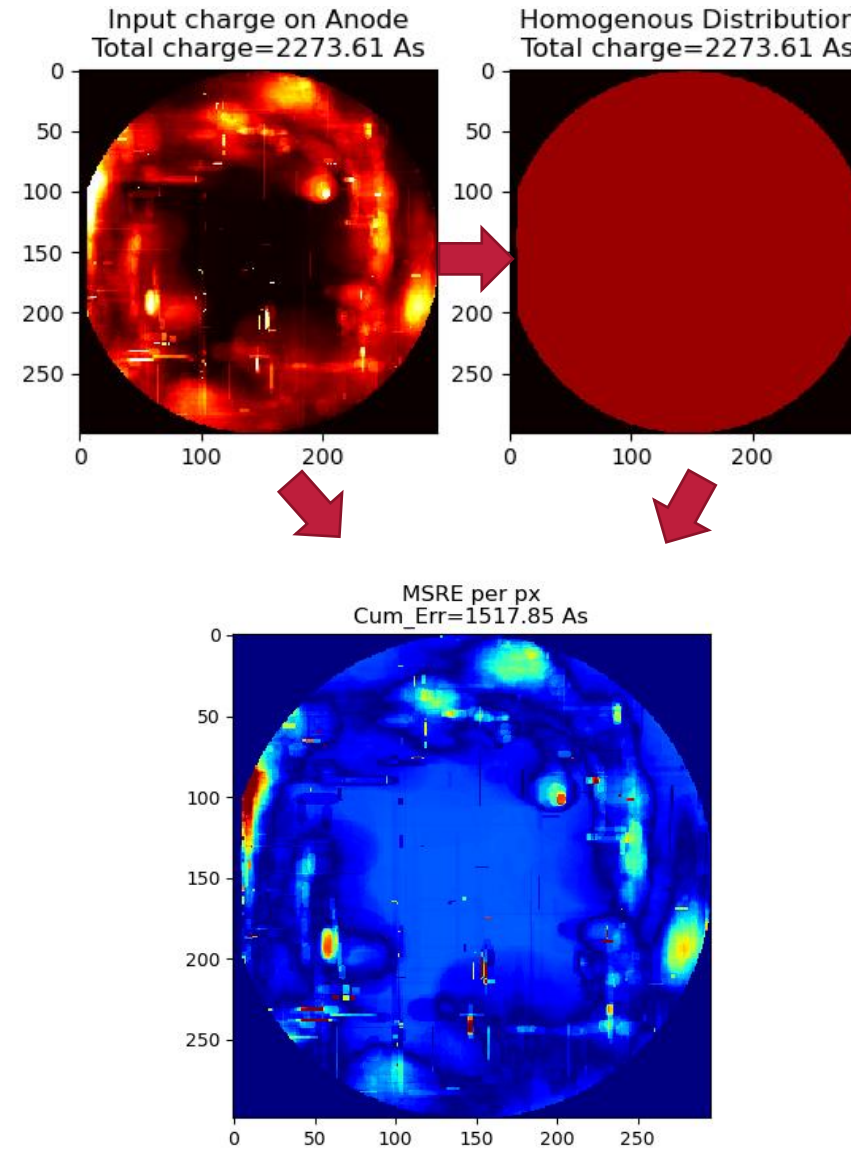
Results

Statement of the distribution?

- "Optimum" is a homogeneous distribution
- Difference to homogeneous distribution with MSR distance

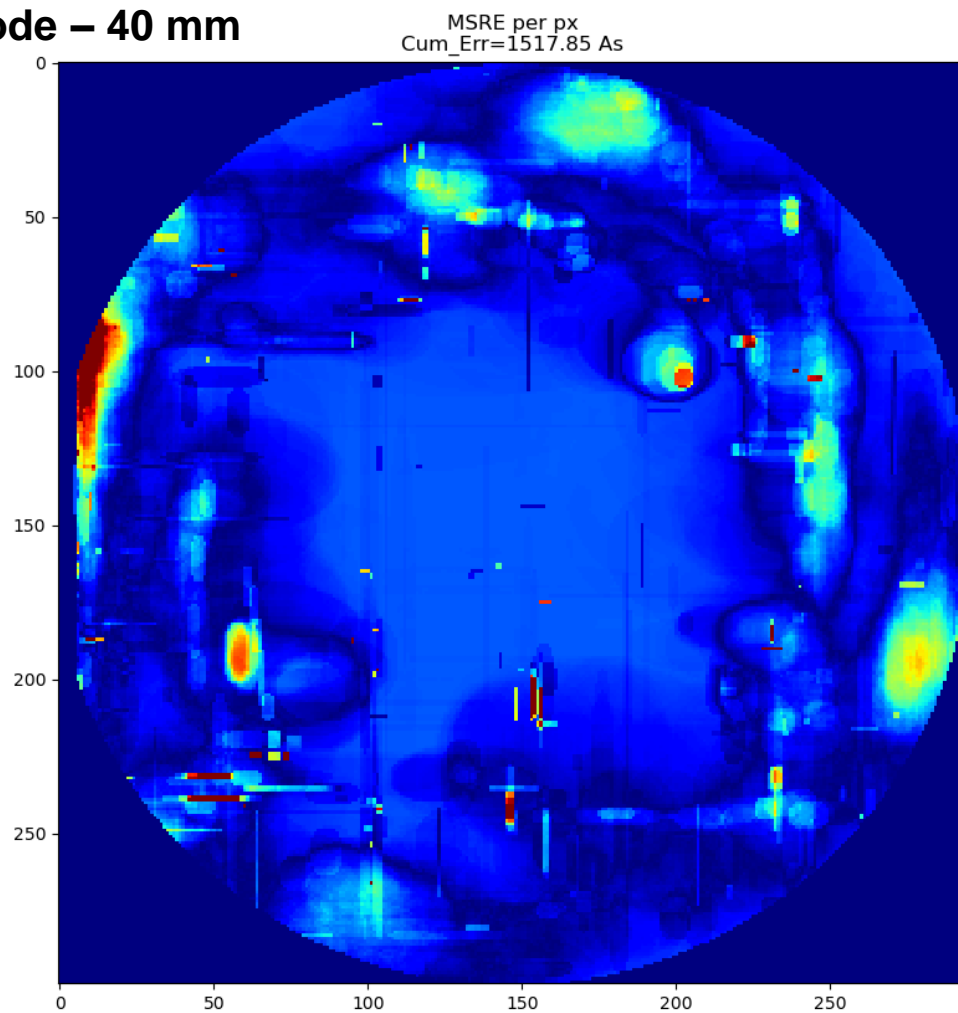
→ Intensive stress points are highlighted

→ Cumulated error is a parameter for the load distribution on a contact



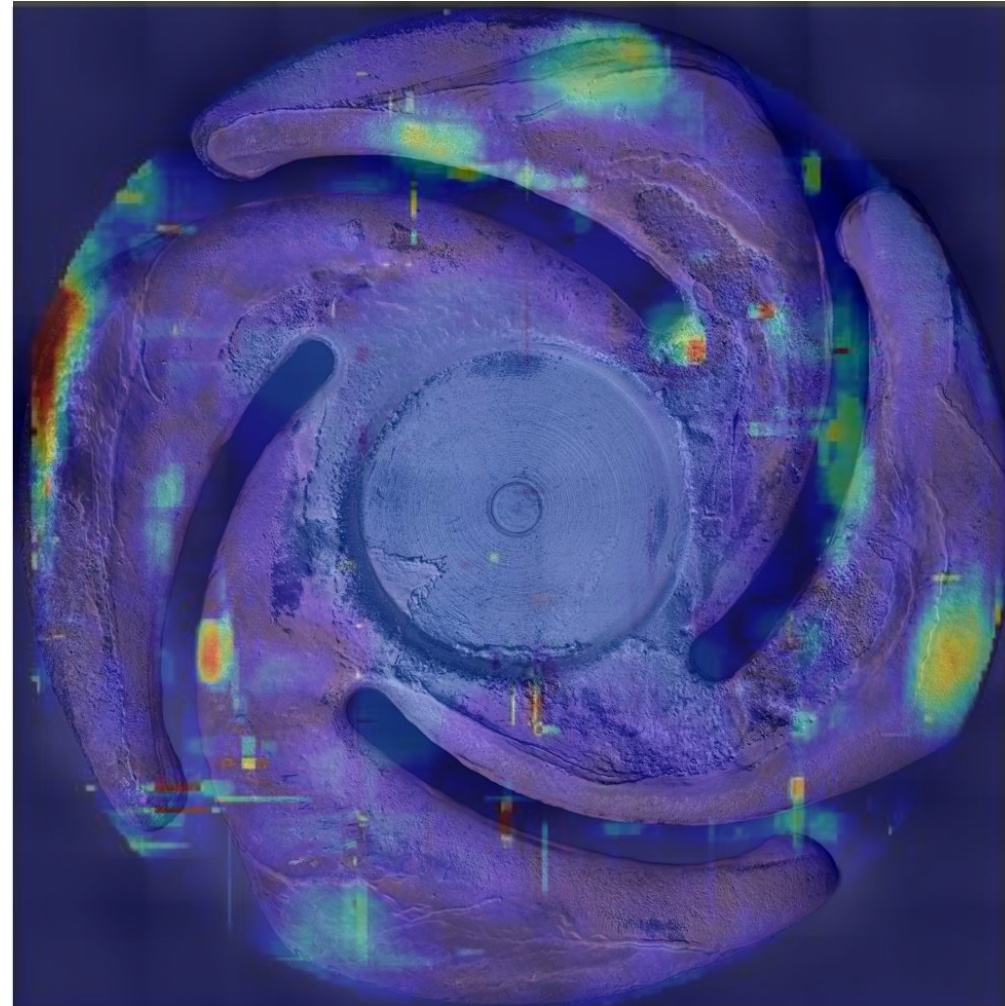
Vergleich mit der Kontaktfläche

Scan Anode – 40 mm



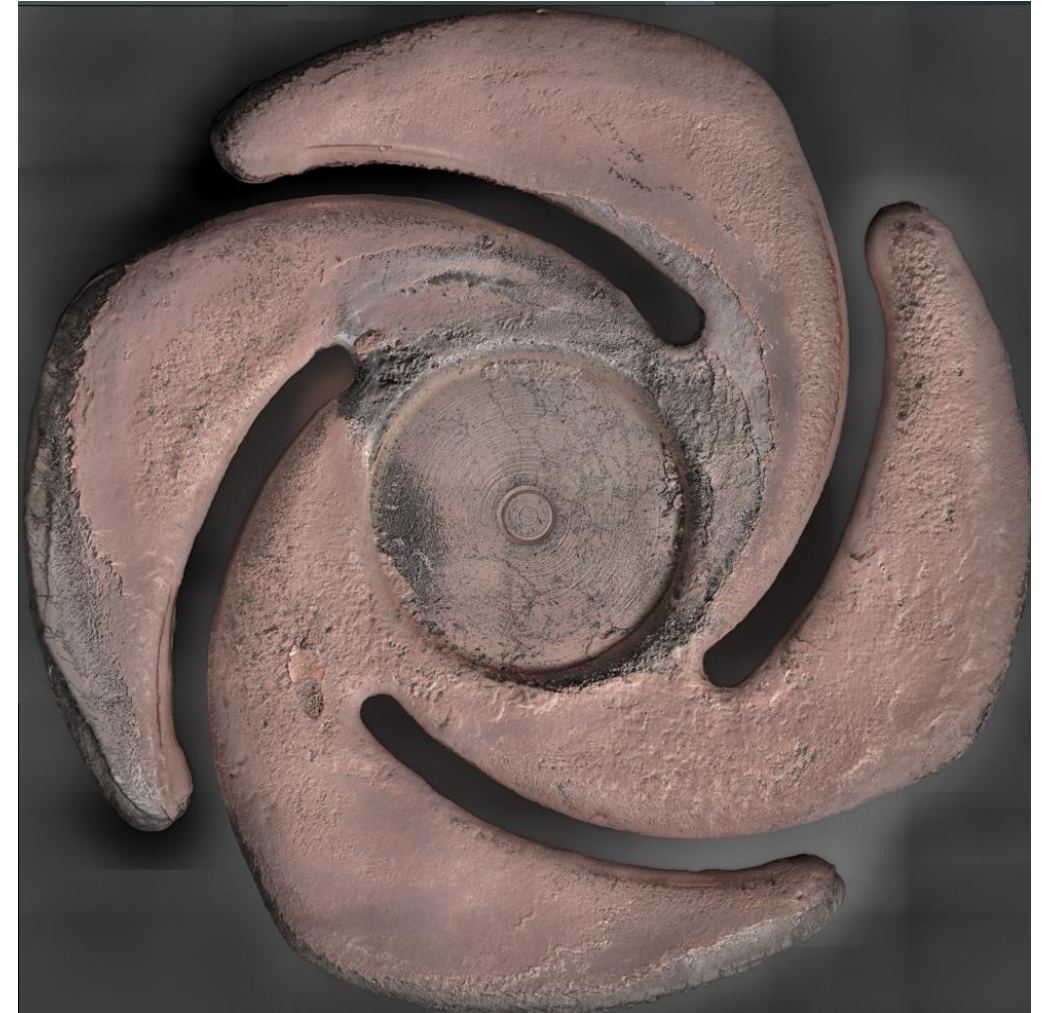
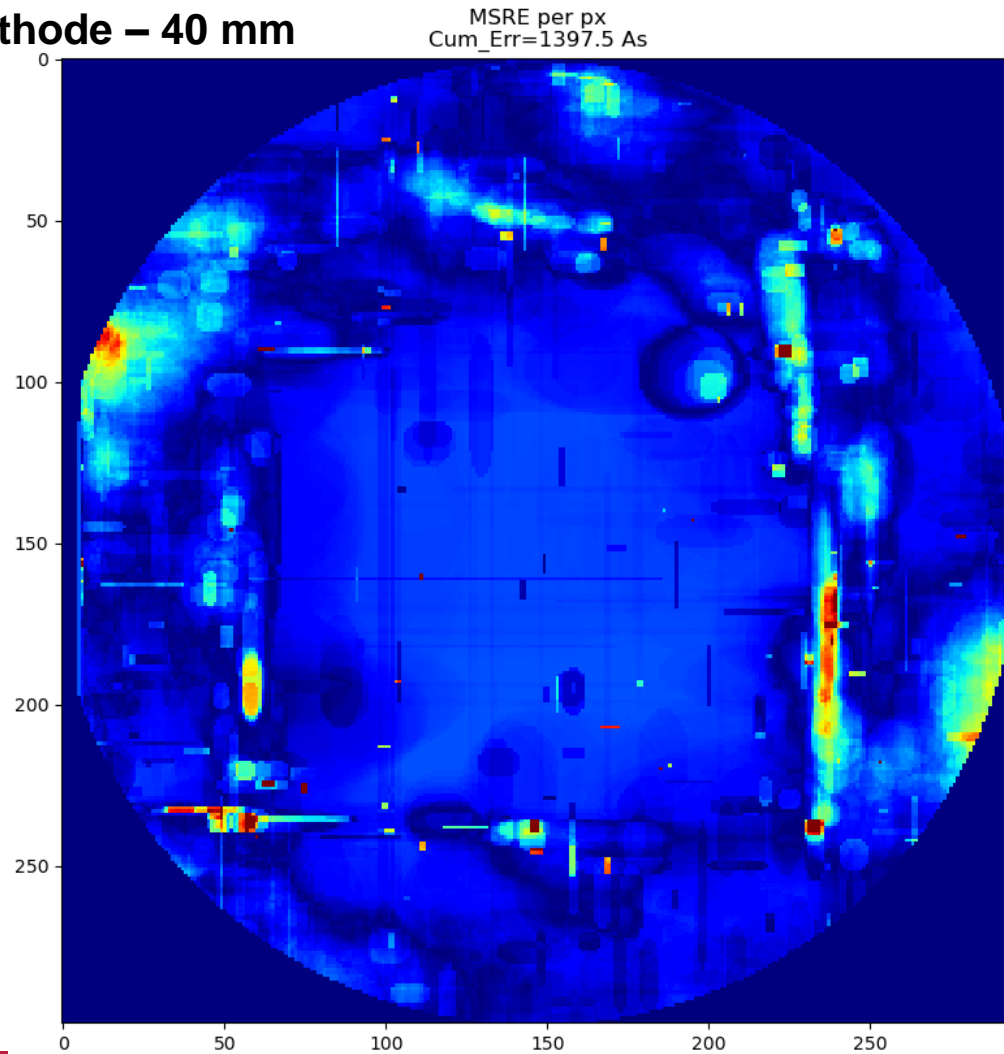
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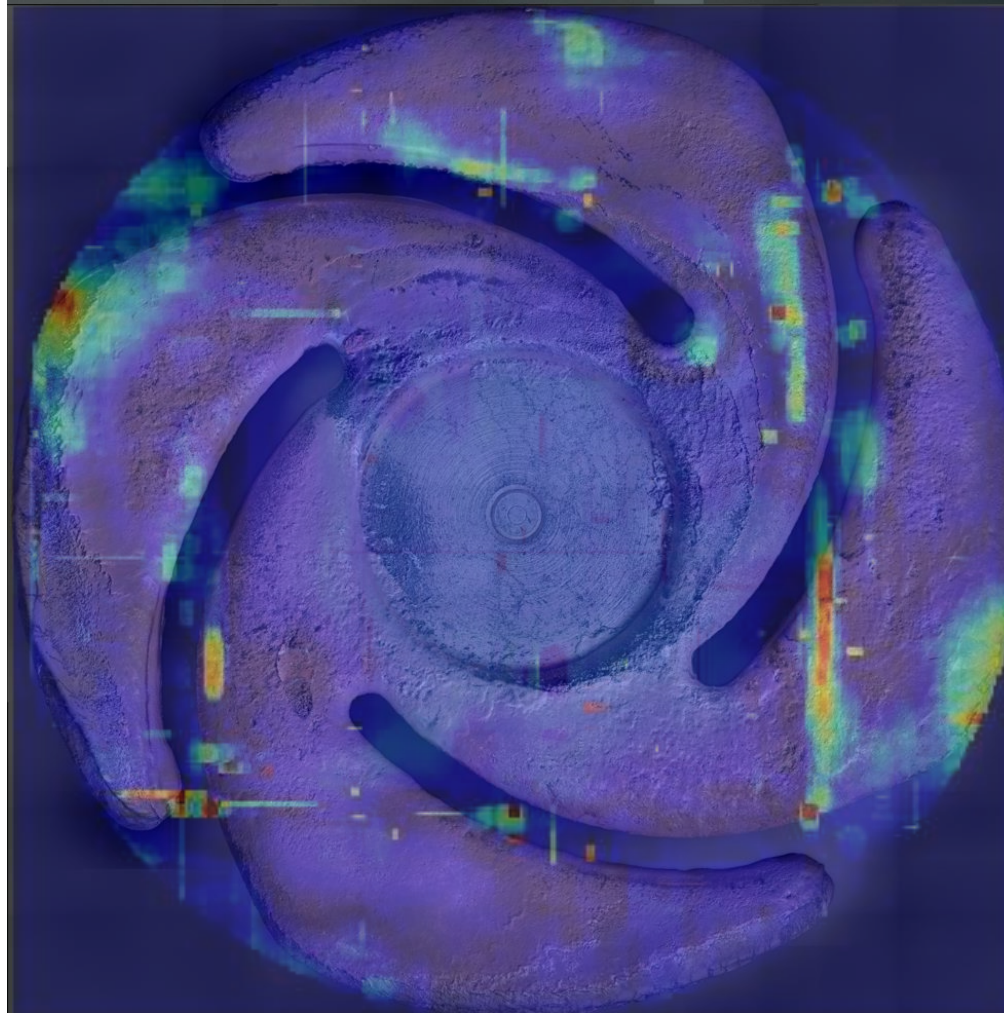
Vergleich mit der Kontaktfläche

Scan Kathode – 40 mm



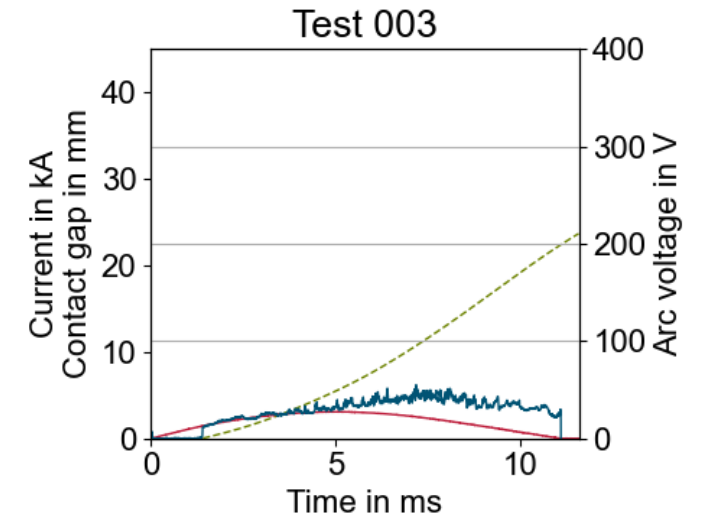
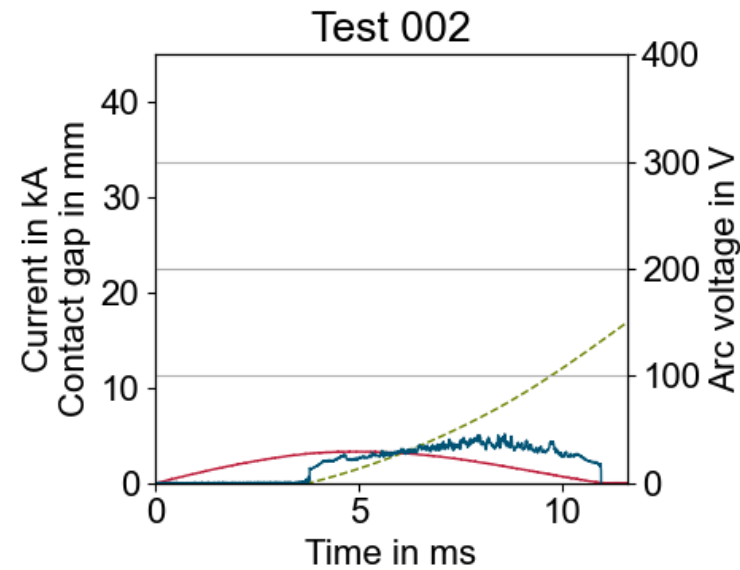
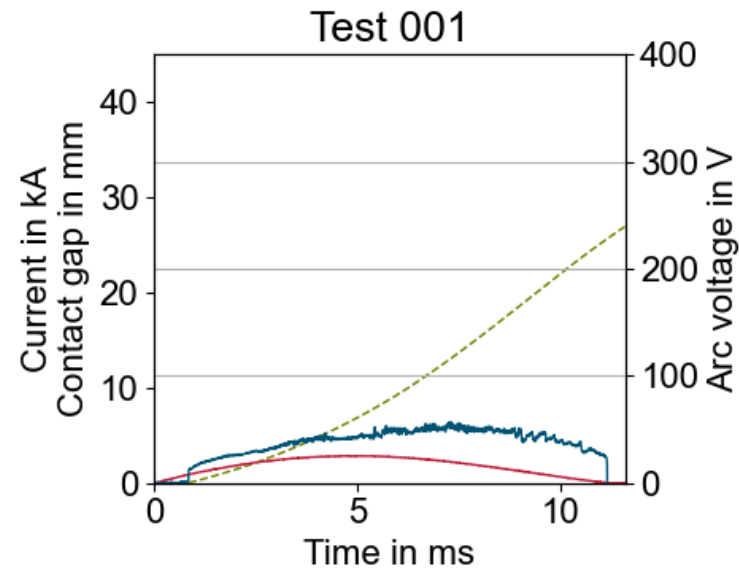
Vergleich mit der Kontaktfläche

Scan Kathode – 40 mm



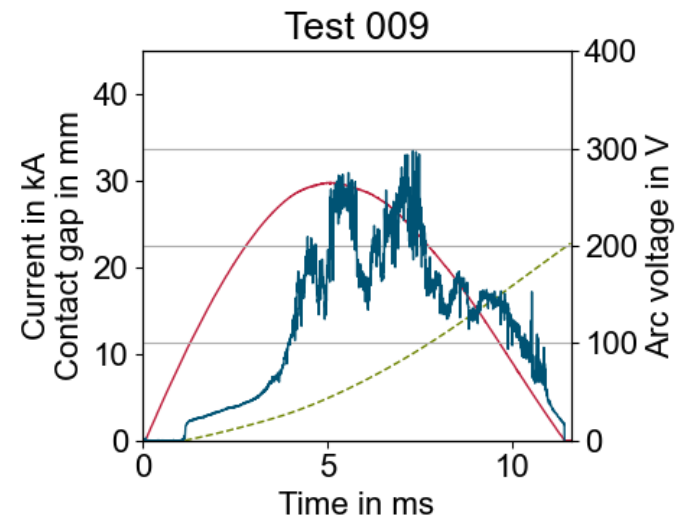
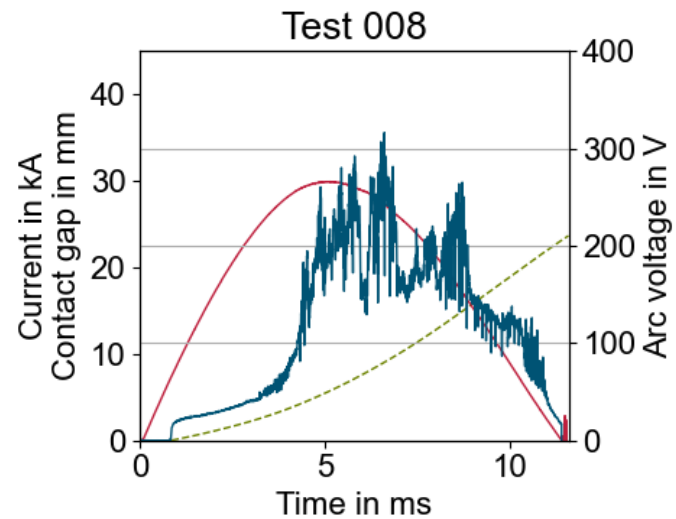
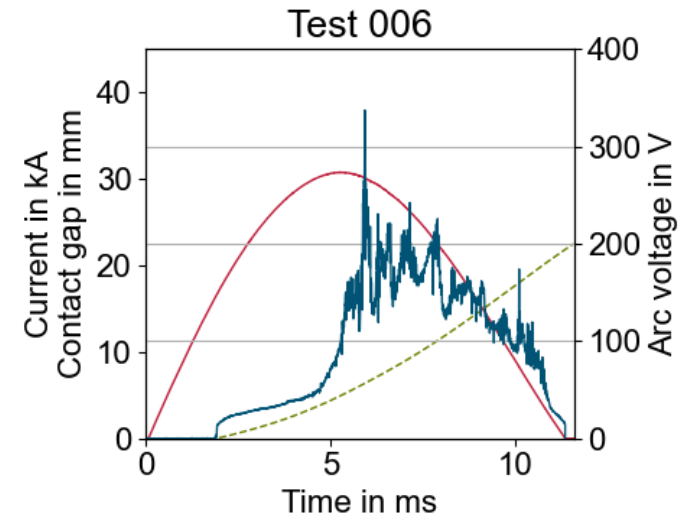
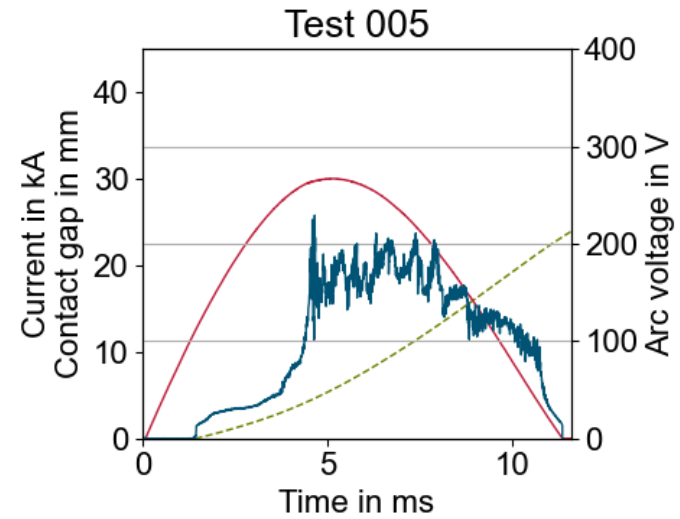
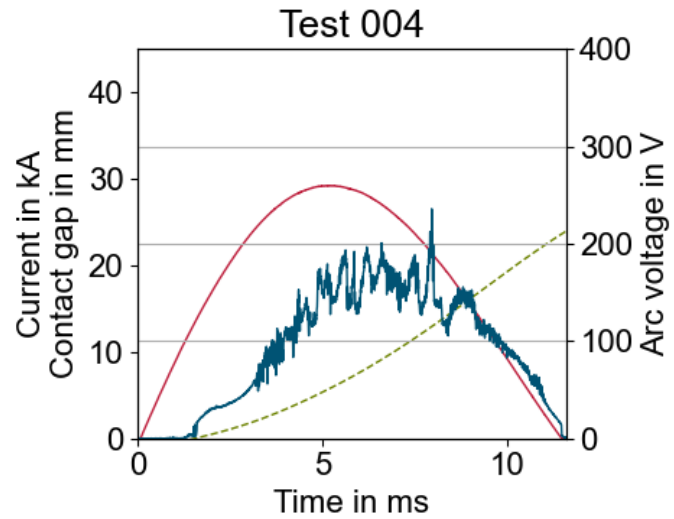
Tests 25 mm

2 kA



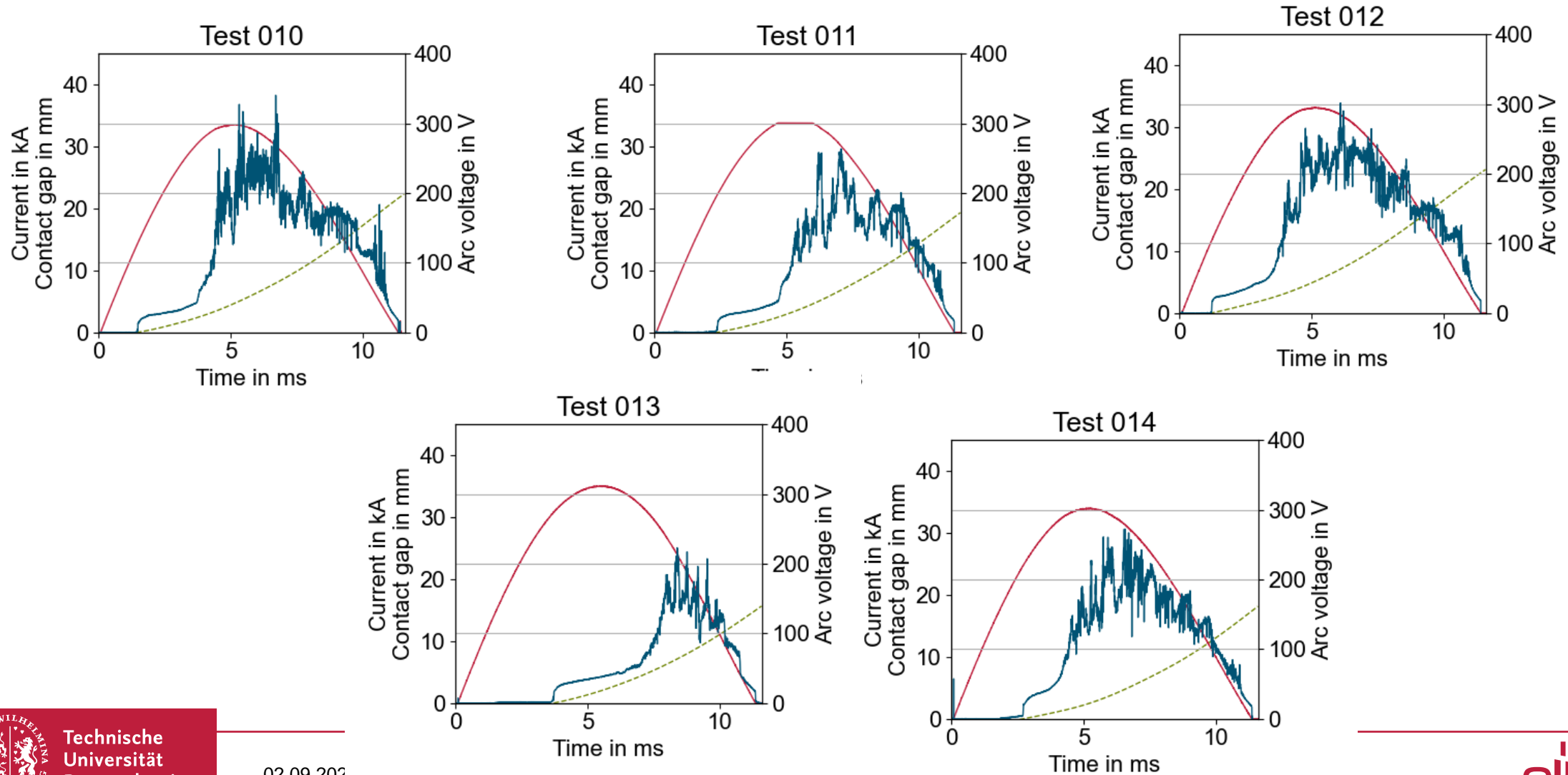
Tests 25 mm

20 kA



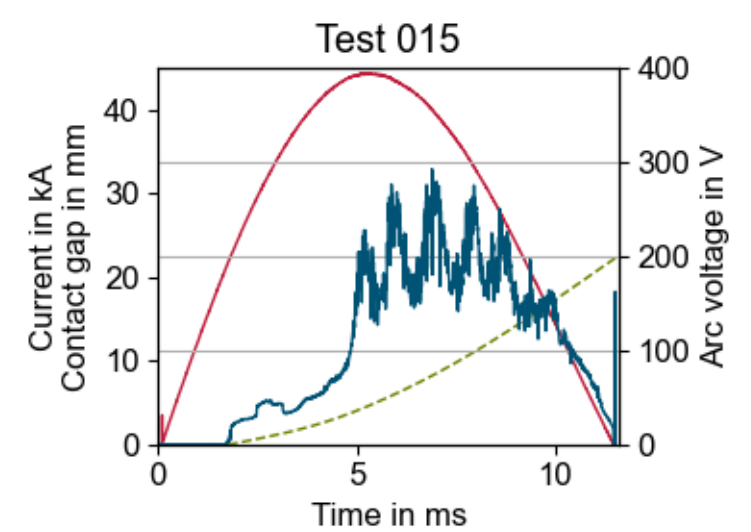
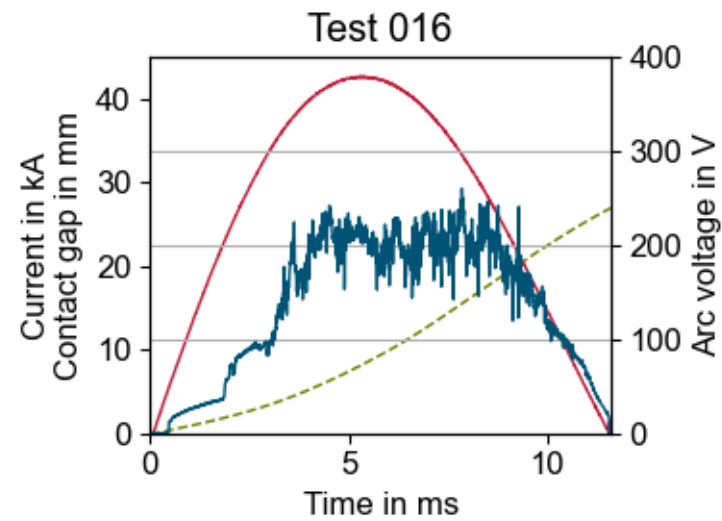
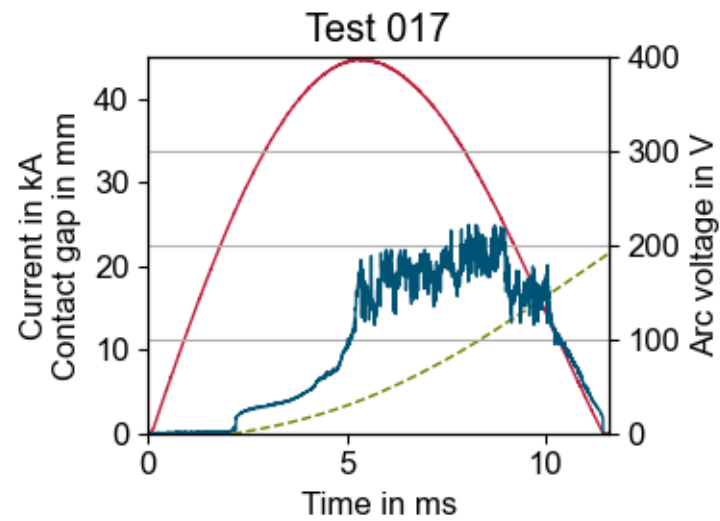
Tests 25 mm

25 kA



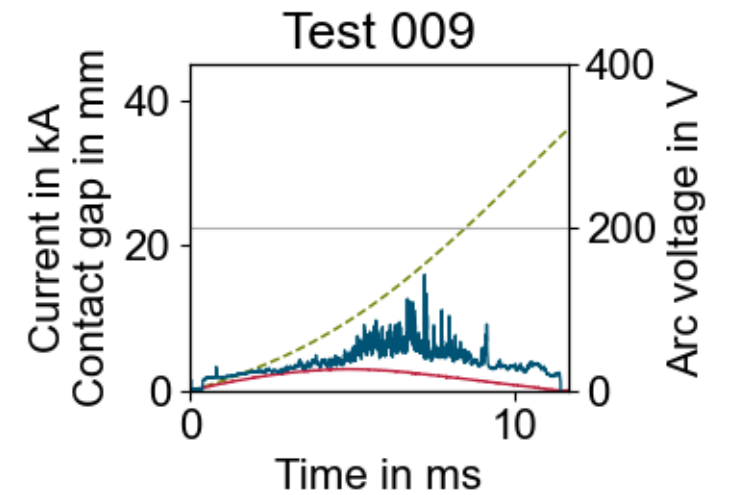
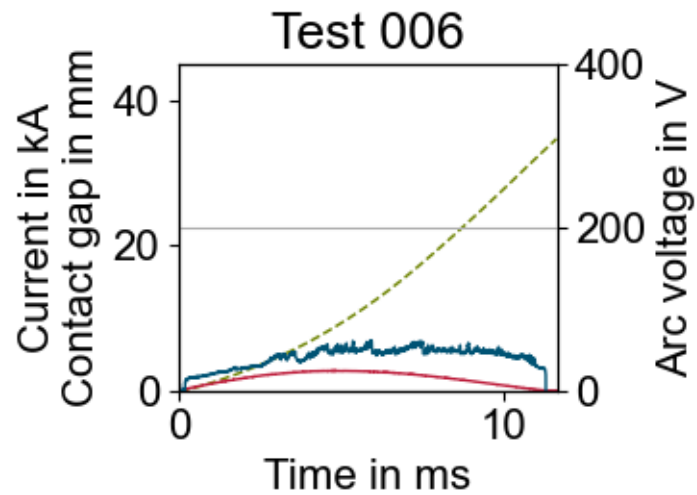
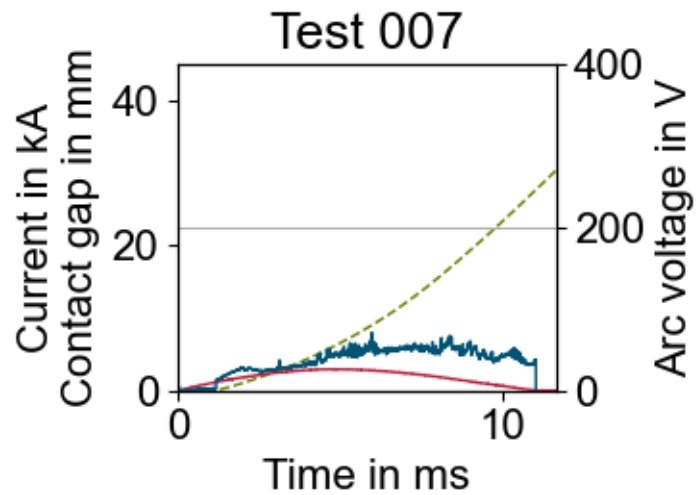
Tests 25 mm

31.5 kA



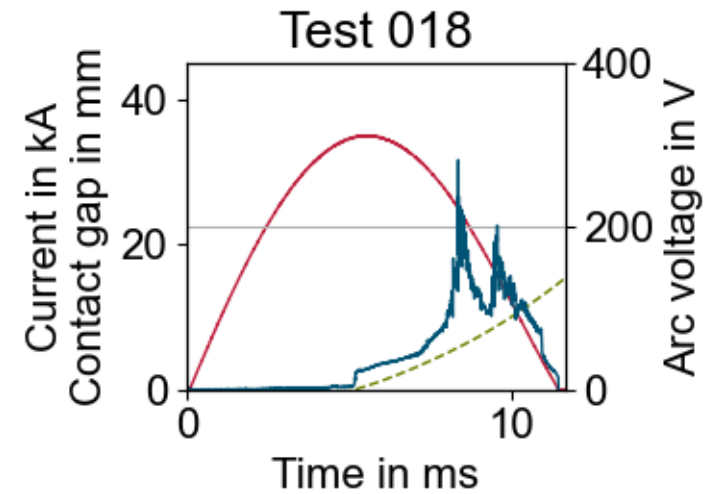
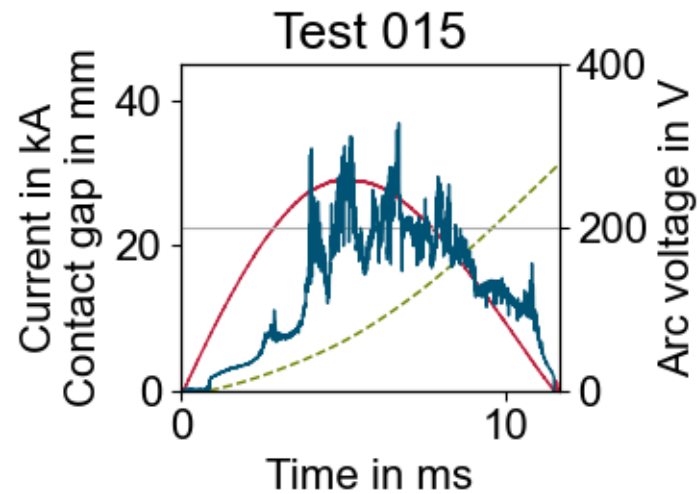
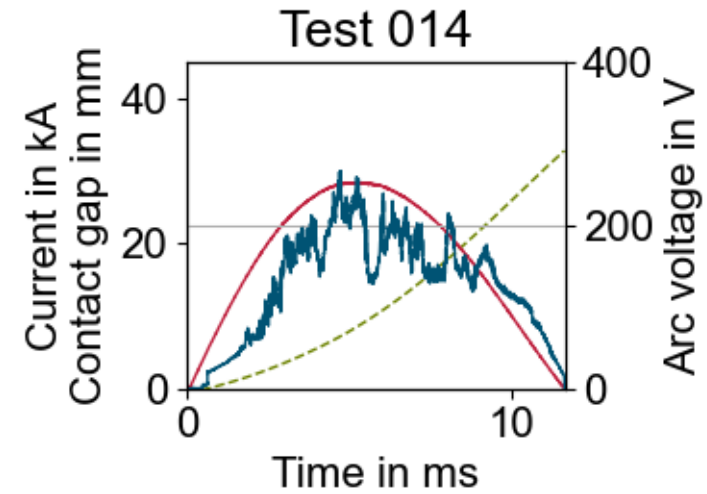
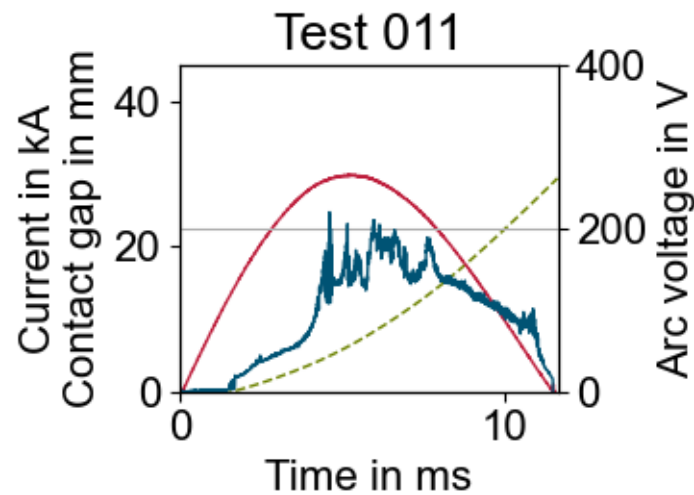
Tests 35 mm

2 kA



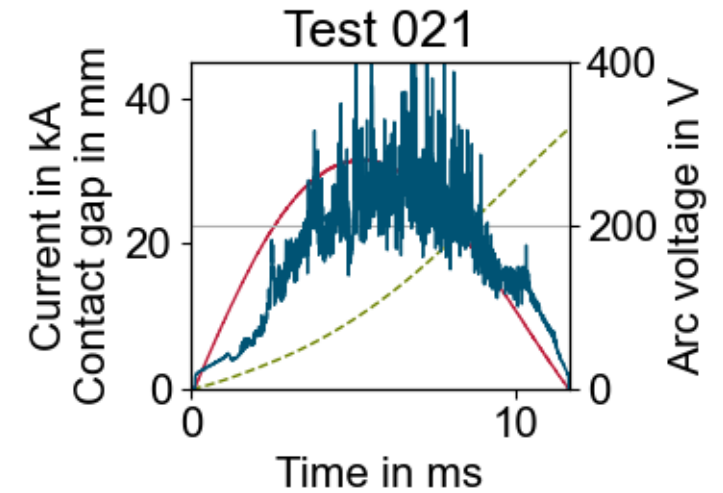
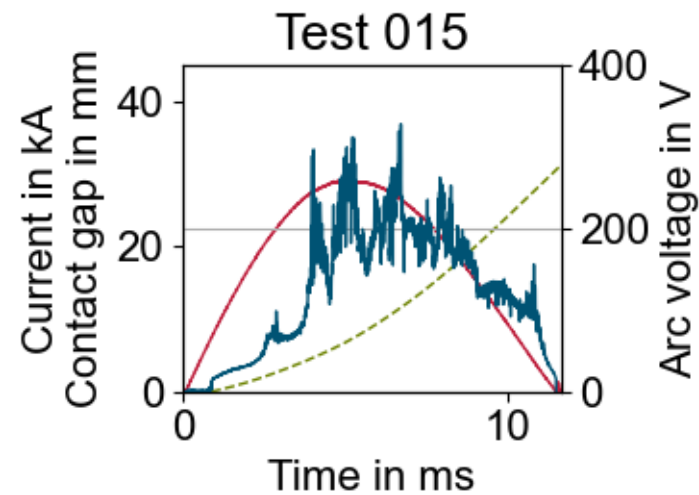
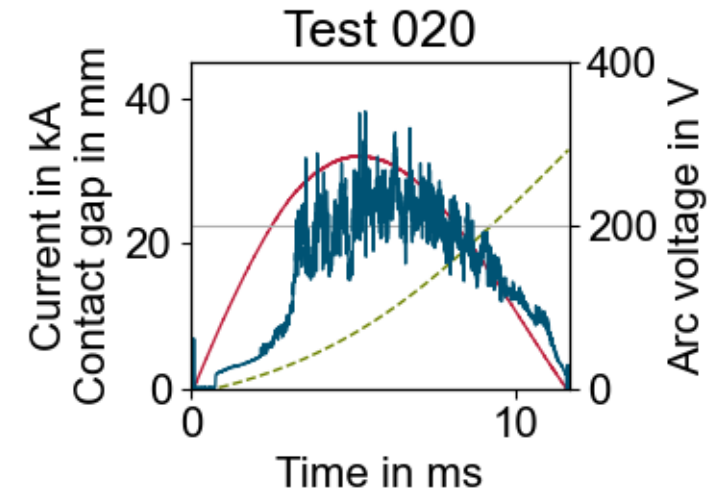
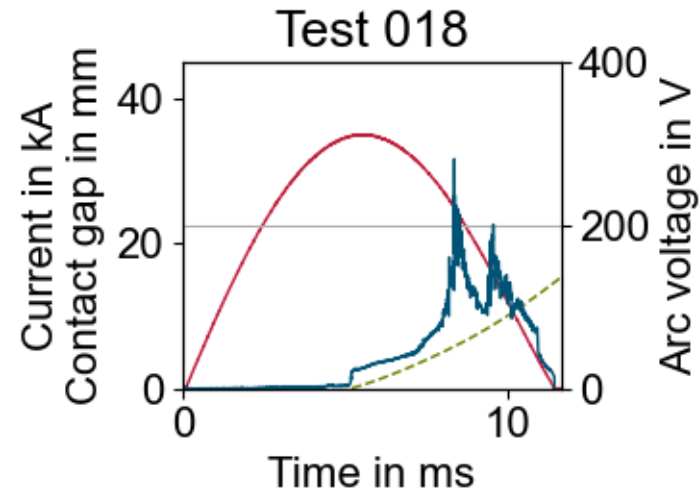
Tests 35 mm

20 kA



Tests 35 mm

25 kA



Tests 35 mm

31.5 kA

