Technische Universität Braunschweig

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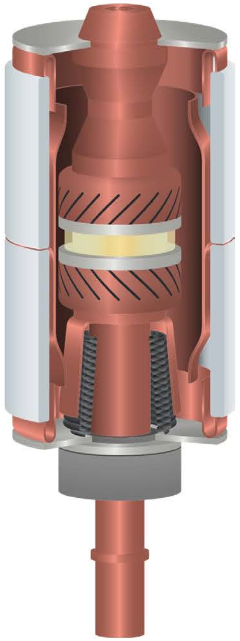
Comparison of different contact geometries for current interruption in vacuum using long gaps up to 45 mm

Marius Hinz, Dietmar Gentsch, Timo Meyer, Michael Kurrat | ITG Vacuum Workshop | 28.08.2026

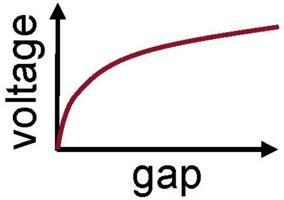
Motivation

Higher voltage levels require further fundamental approach for understanding arc behaviour for large gaps



Vacuum Interrupter

- State of the Art in medium voltage application
- Switching behaviour for small contact gaps well known



Requirement for higher contact gaps

- Necessary for high voltage applications
- No linear upscaling
- Higher thermal load, risk for breakdown

?

Understanding of arc dynamic

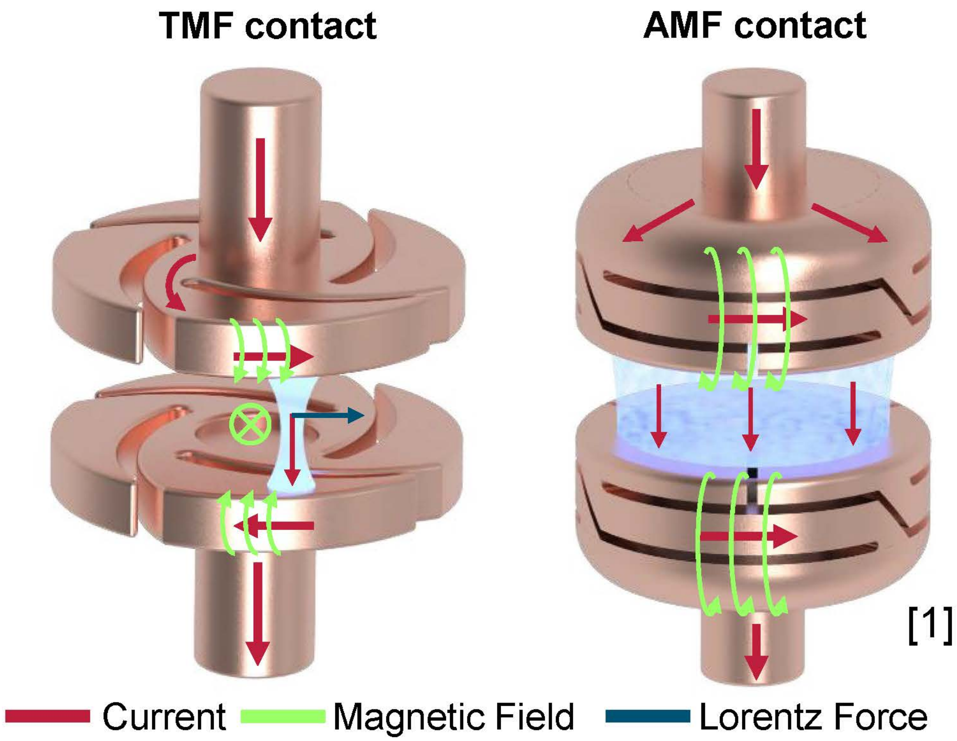
- For higher contact gaps
- Thermal load on electrode surface

The different contact geometries

TMF contacts feasible for HV VI, yet more research carried out into AMF contacts

- Transversal magnetic field (TMF) contact
  - Generated Lorentz force drives the vacuum arc in a circular motion
- Axial magnetic field (AMF) contact
  - An AMF counteracts the azimuthal magnetic field and create a diffuse arc over a wide contact surface
- Both contacts aim to distribute the arc heating homogenous on the surfaces

- *Evaluation parameters:*
  - *Number of arc rotations (TMF)*
  - *Surface of arc appearance and contact erosion (TMF & AMF)*

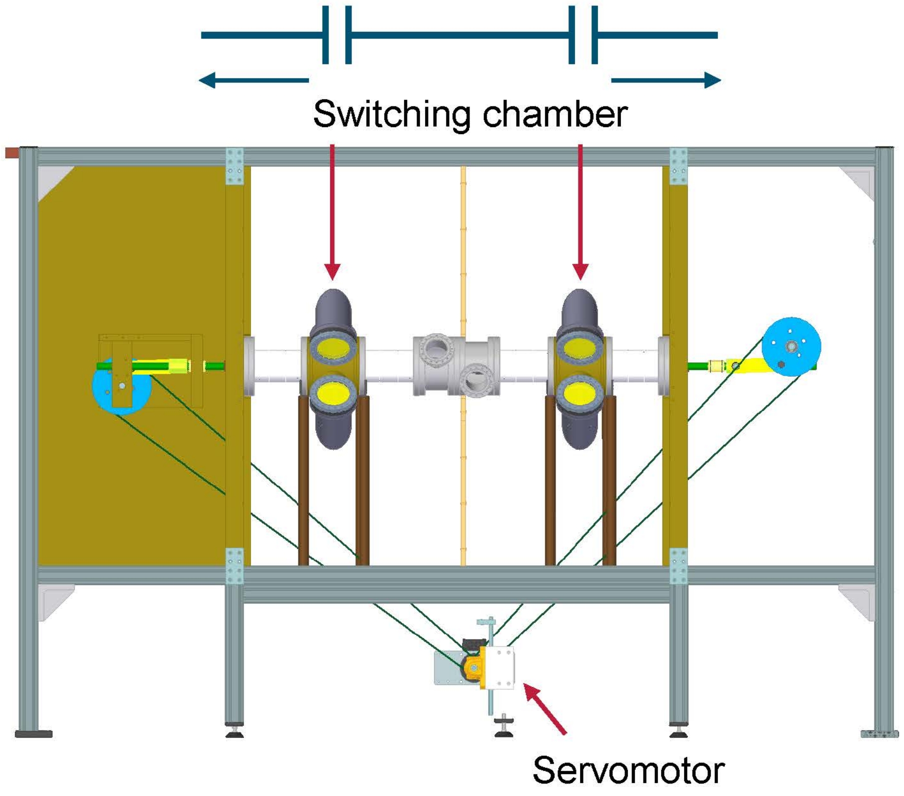


Problem with higher contact gaps:
Instable and lower magnetic field density could lead to degradation in successful interruption

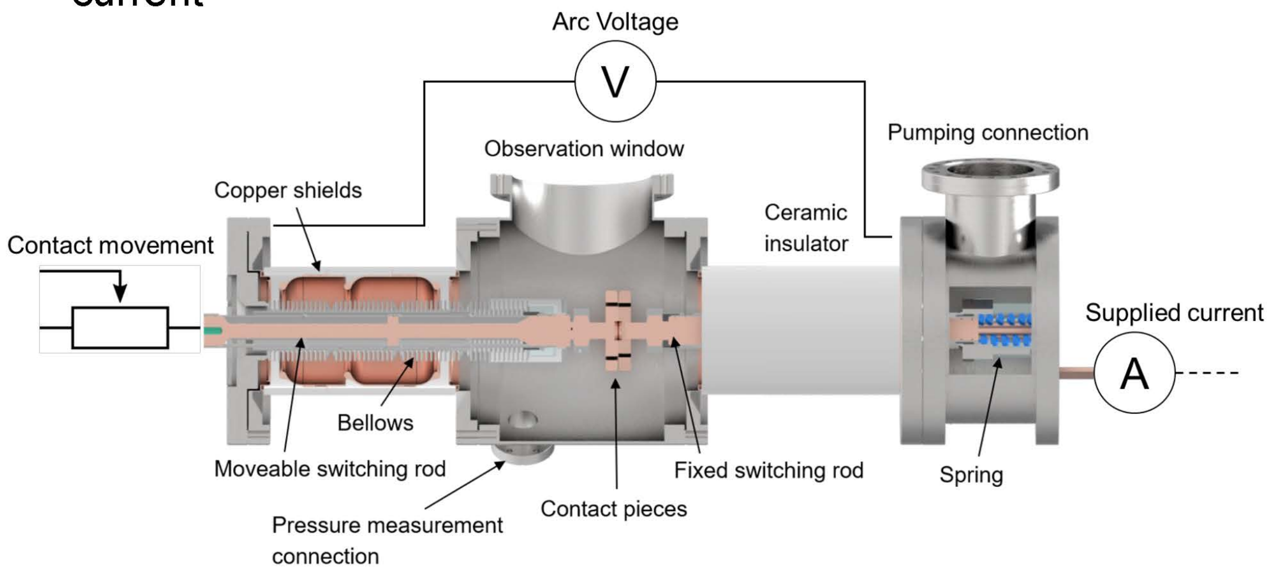
Experimental setup – Vacuum interrupter

Vacuum interruption for single and double break

Motivation | Fundamentals | **Test setup** | Results | Conclusion



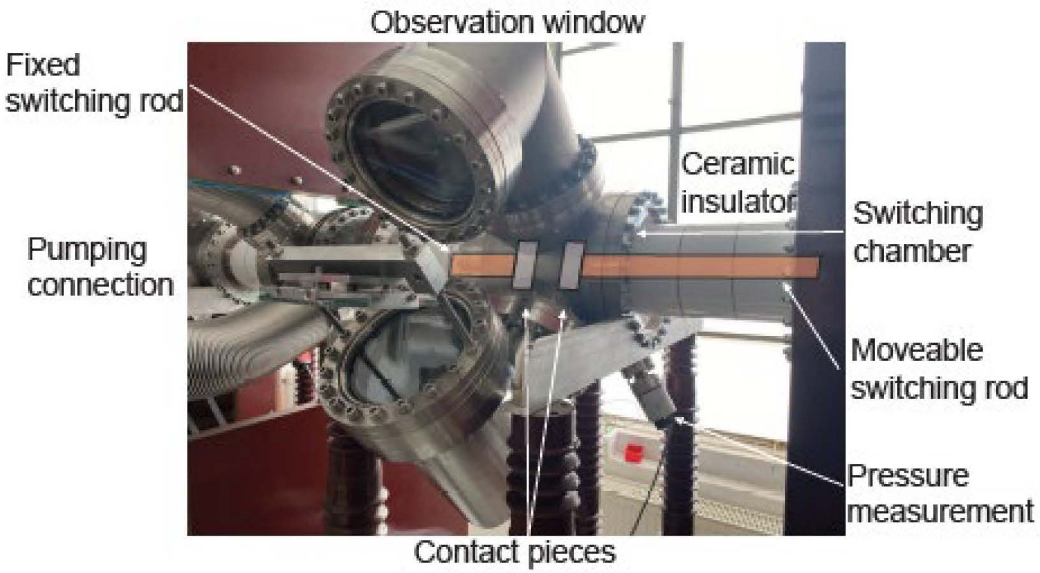
- Servo motor with a programmable gap trajectory
- Measuring of arcing voltage, contact gap and short-circuit current

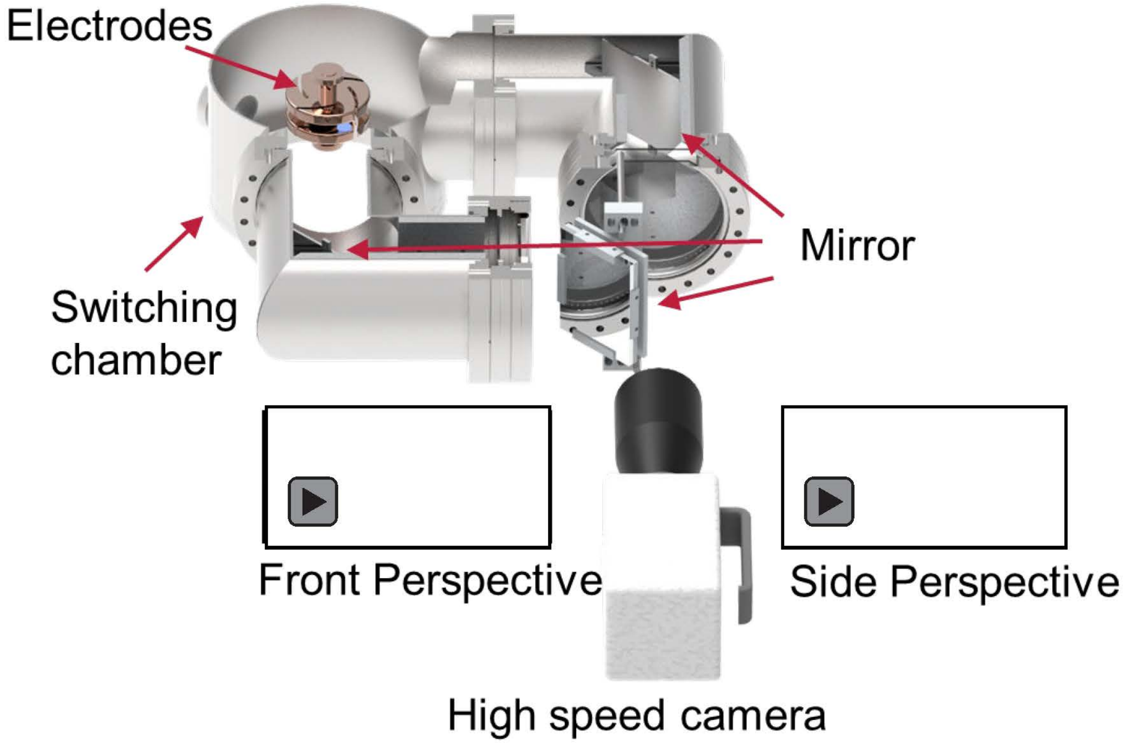


Experimental setup – mirror arrangement

The arrangement allows a 3D-model of the vacuum arc

- Mirror arrangement for a 3D-Model of the arc
- Evaluation of arc speed and rotation
- 12-bit high-speed-camera records 30k frames per second (fps)





Investigation

Design of Experiments

Motivation | Fundamentals | **Test setup** | Results | Conclusion

Contact gap at CZ

[20;30;45] mm

Short circuit current

[15;20;31,5] kA_{rms}

Contact material

CuCr25 & CuCr35+

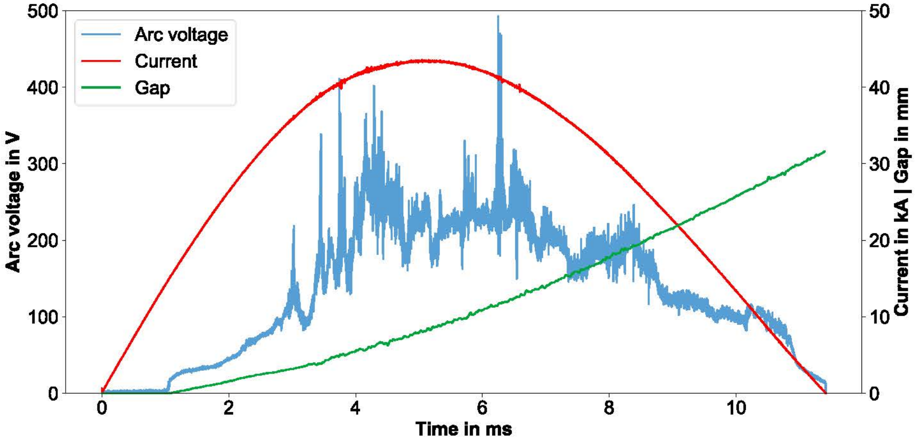
Contact geometry

TMF & AMF

80 measurements in total

Video of interruption with TMF contact

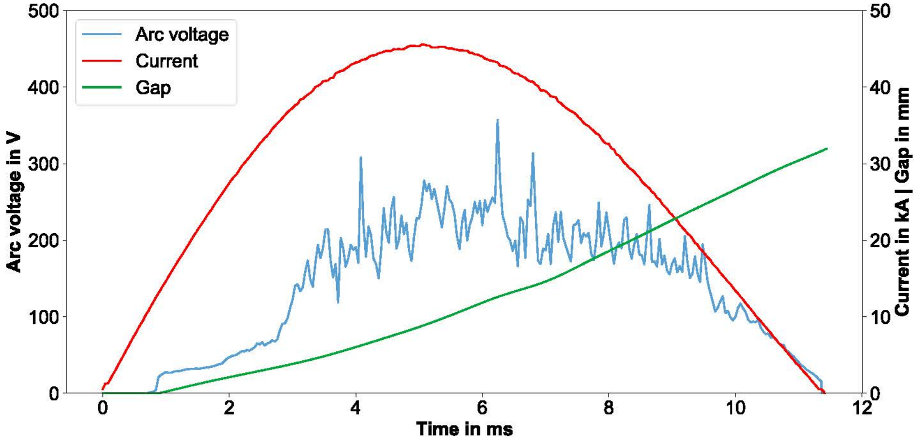
TMF, CuCr25, 31.5 kA_{rms}, positive polarity (moved cathode)



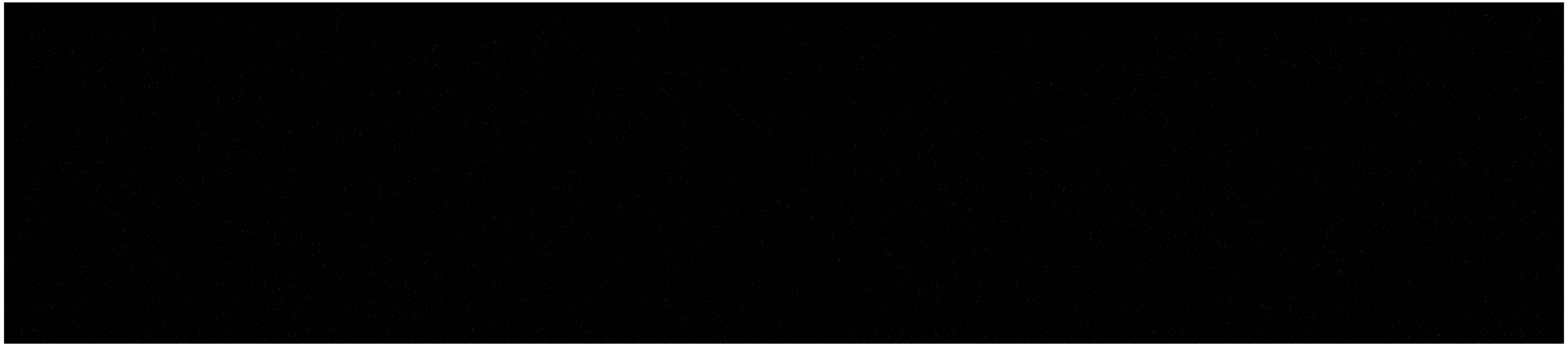
	Specs
Rotations	5
Arcing Time	10,4 ms
Gap at CZ	30,3 mm
Average speed	2,91 m/s

Video of interruption with TMF contact

TMF, CuCr35+, 31.5 kA_{rms}, positive polarity (moved cathode)

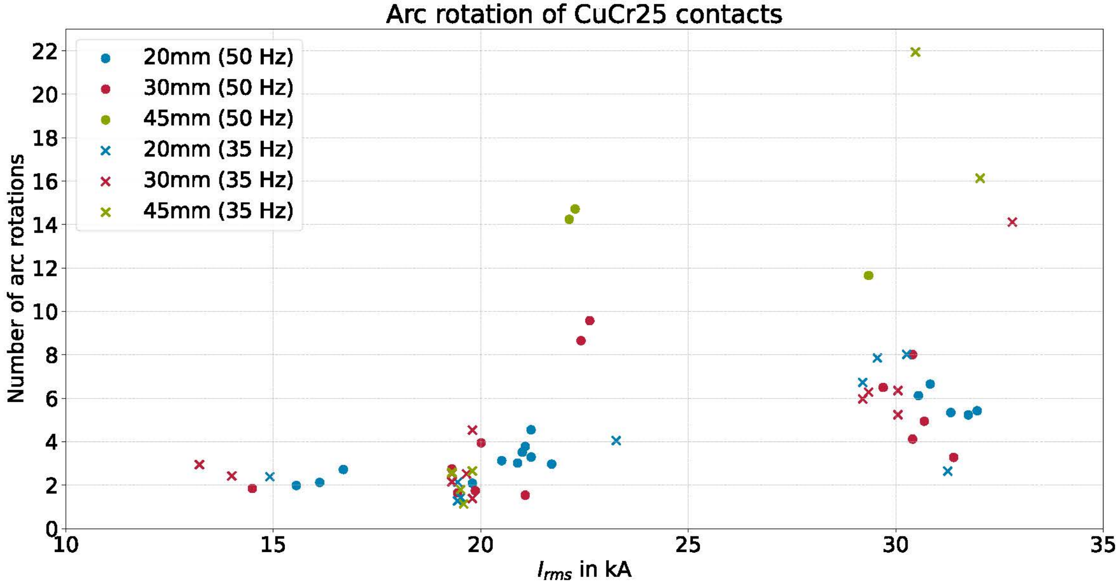


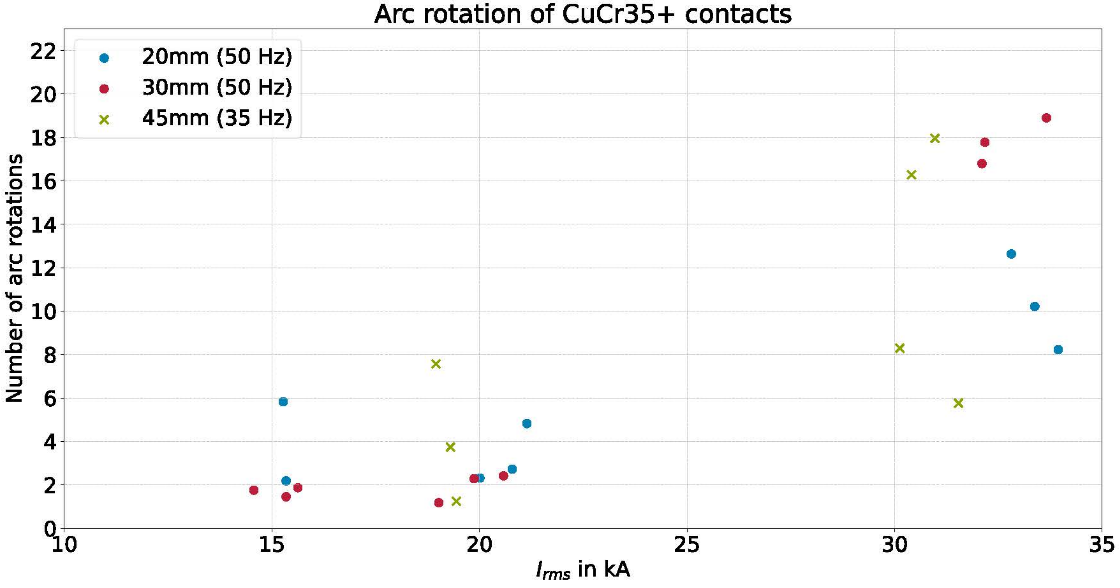
	Specs
Rotations	17
Arcing Time	10,5 ms
Gap at CZ	31,8 mm
Average speed	3,03 m/s



Number of arc rotation for TMF contacts

Both contact materials work for long gap interruptions



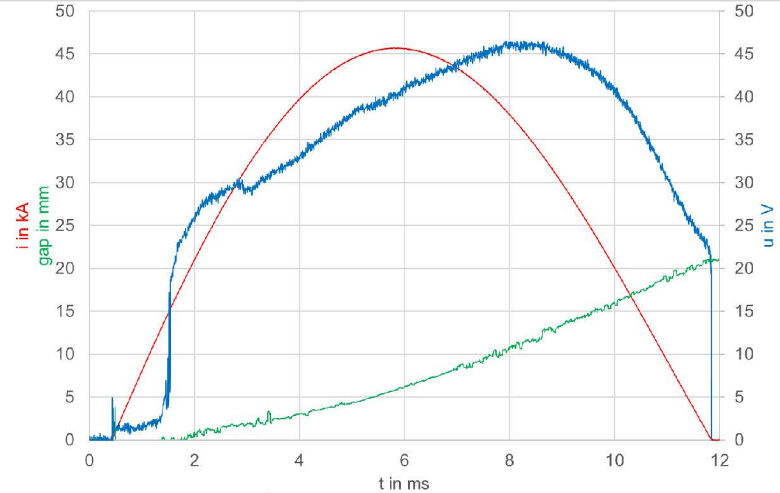


Current (RMS)	Contact gap		
	20 mm (50 Hz)	30 mm (50 Hz)	45 mm (35 Hz)
15 kA	2.3 ± 0.39	-	-
20 kA	3.3 ± 0.71	4.3 ± 3.43	2.1 ± 0.66
31.5 kA	5.8 ± 0.61	5.4 ± 1.90	19.03 ± 4.11

Current (RMS)	Contact gap		
	20 mm (50 Hz)	30 mm (50 Hz)	45 mm (35 Hz)
15 kA	4.0 ± 2.58	1.7 ± 0.21	-
20 kA	3.3 ± 1.33	2.0 ± 0.71	4.2 ± 3.19
31.5 kA	10.4 ± 2.20	17.8 ± 1.00	12.1 ± 5.96

Video of interruption with AMF contact

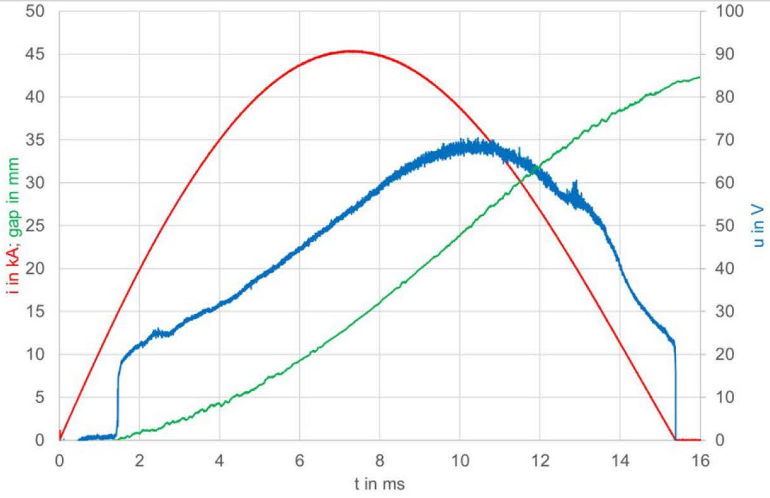
AMF, <u>CuCr35+</u>, 31.5 kA$_{rms}$, positive polarity (moved cathode)



	Specs
Frequency	50 Hz
Arcing Time	10,31 ms
Gap at CZ	21 mm
Average speed	2,23 m/s

Video of interruption with AMF contact

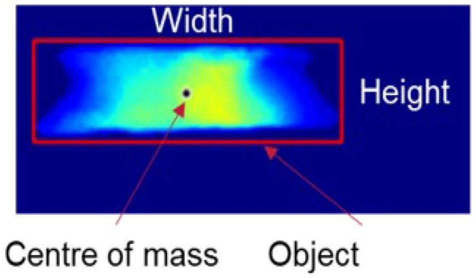
AMF, CuCr35+, 31.5 kA_{rms}, positive polarity (moved cathode)

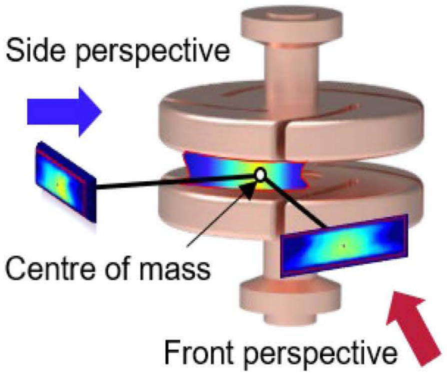


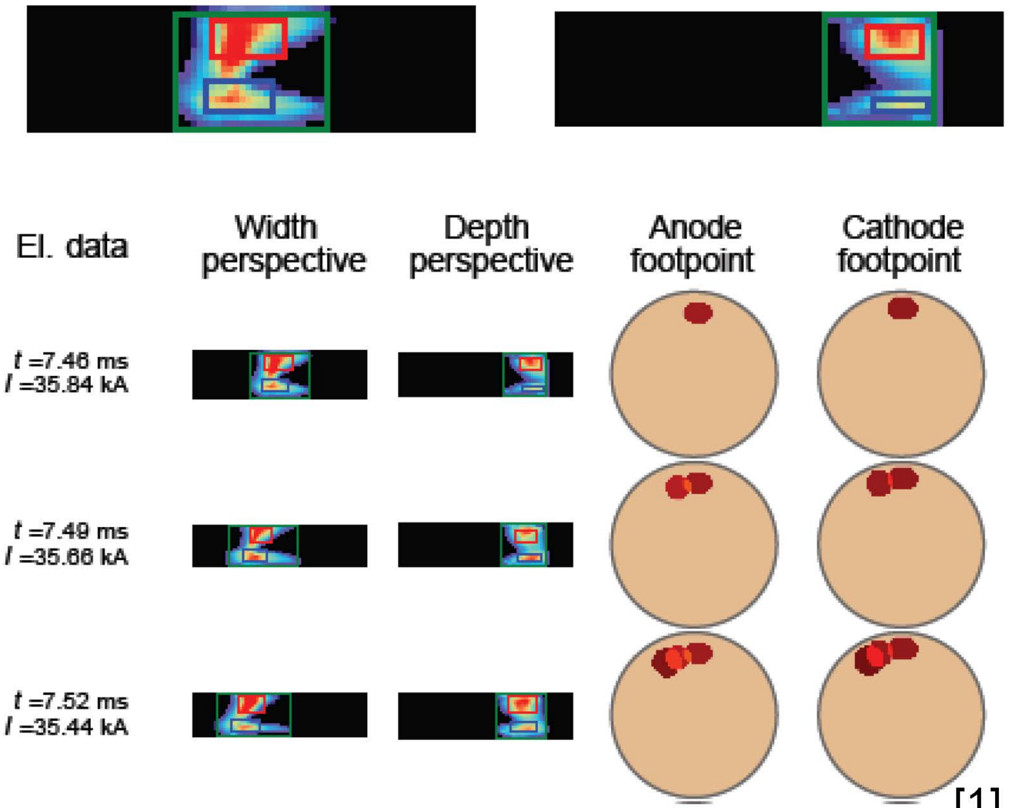
	Specs
Frequency	35 Hz
Arcing Time	13,90 ms
Gap at CZ	43 mm
Average speed	3,09 m/s

Post processing of videos

The 3D-model of the vacuum arc allows the estimation of the contact erosion







[1]

- Transfer in pseudo-colors and determination of arc center & foot points at electrodes

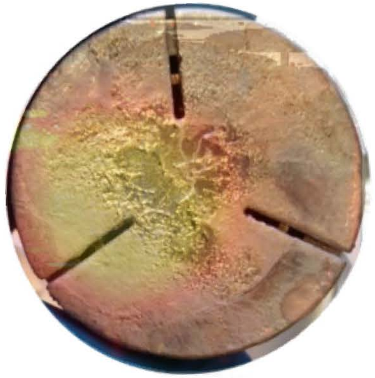
Indicator for contact erosion

- Charge input, determined by the current and arc intensity
- Colour scale determined by the transferred charge

Contact erosion

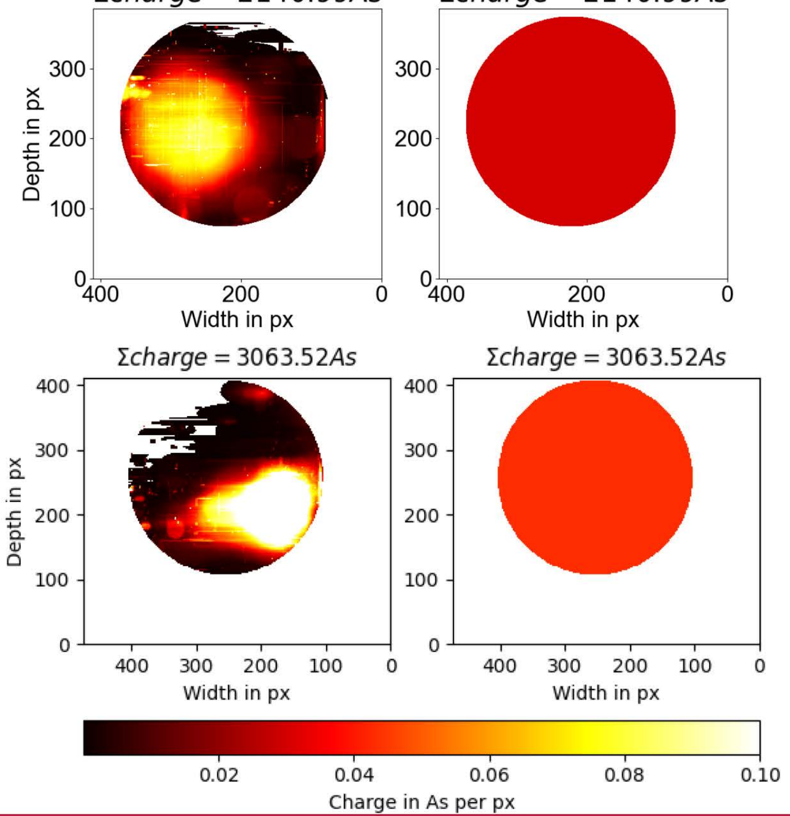
Estimation of contact erosion works with calculation of charge input on contact surface

50 Hz, 20 mm

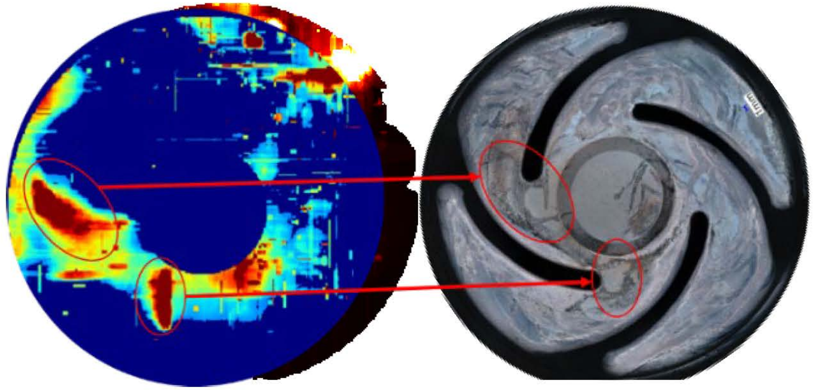


35 Hz, 45 mm

Input charge on Anode | Theoretical homogenous distribution



50 Hz, 20 mm

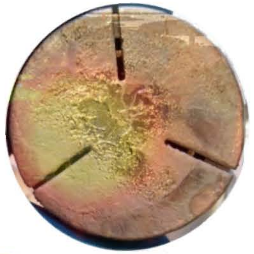


- One big spot at AMF contacts
- Multiple little spots at TMF contact

Conclusion and Outlook

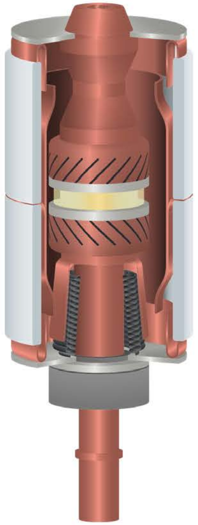
Conclusion

- Both contact geometries look feasible for larger contact gaps
  - **High number of rotations** for **TMF** contact and **wide area of arc appearance** for **AMF**
- Contact material showed little impact on the number of arc rotations for higher gaps
  - Bigger effect of the higher current and contact gap



Outlook

- Serial arrangement of two contact pairs
  - Evaluation of arcing behaviour during double interruption
- Adding transient recovery voltage after CZ
  - Investigation of interaction with interruption process
- Consideration of metal vapour shield
  - Assessment of influence on the arc dynamics



Contact

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FORSCHUNG

- Experimental investigations of breaking process in a vacuum double interrupter
- Influence of long contact gaps above 20 mm in a vacuum interrupter

VERÖFFENTLICHUNGEN (Auswahl)

- Meyer, T., Flügel, K., Cziumplik, D., Hinz, M., Kurrat, M.: **Optical and electrical parameters for classifying arc mode and movement using TMF-contacts**, 12th International Workshop on the Mechanisms of Vacuum Arcs (MeVArc 2025), Uppsala, Sweden, 1.- 6. Juni 2025

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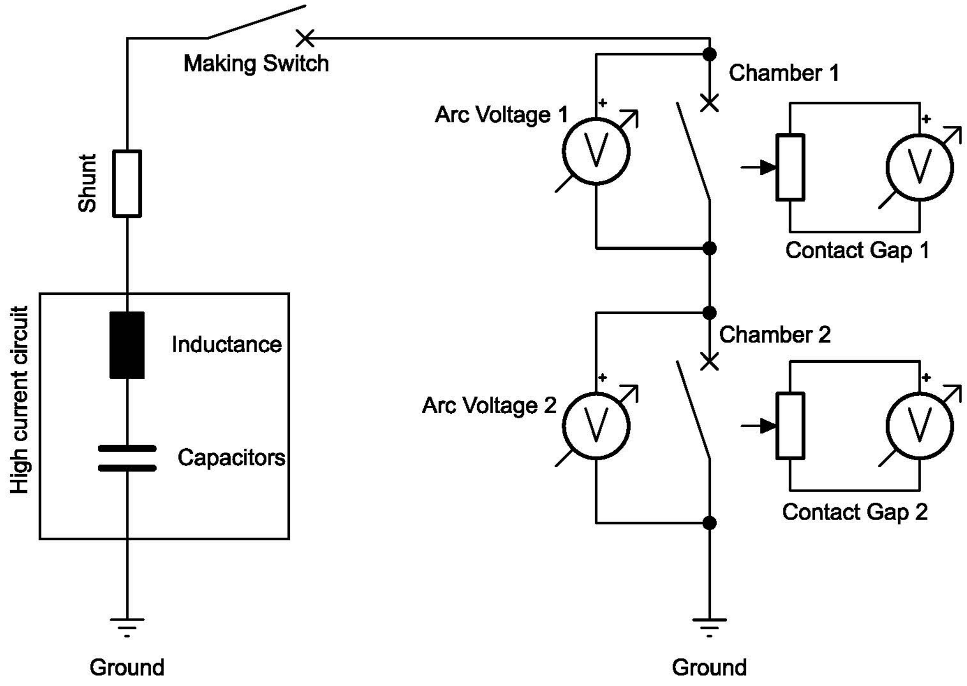
Appendix

Measurement circuit

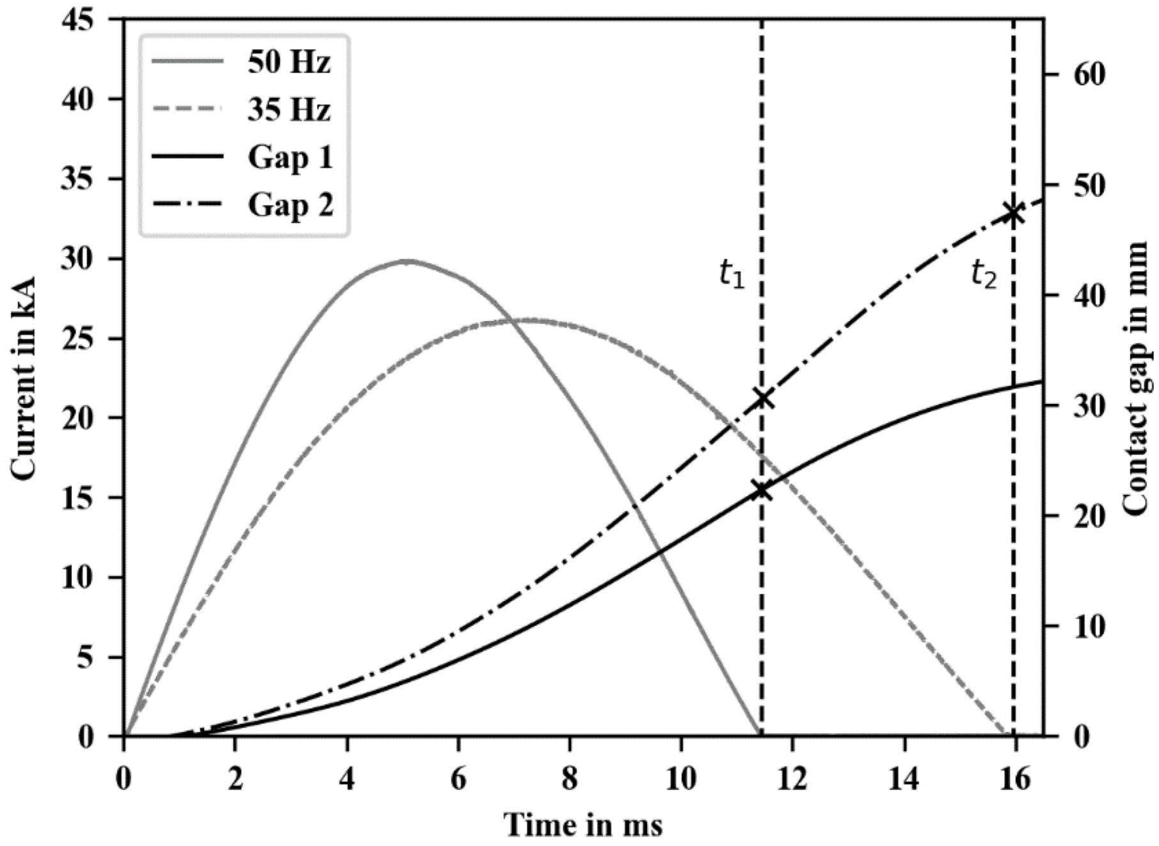
- Frequency of breaking current: $f_r = \frac{1}{2\pi\sqrt{LC}}$
- Resistance of shunt: 25 µΩ
- Making switch: ABB VM1
- Voltage probe for arc voltage: PMK PHV 661-L
- Potentiometer for contact gap: Megatron RC13

- Transformation of electrical signals in optical signal and transmission with HBM HV6600 Transmitter



Opening trajectories

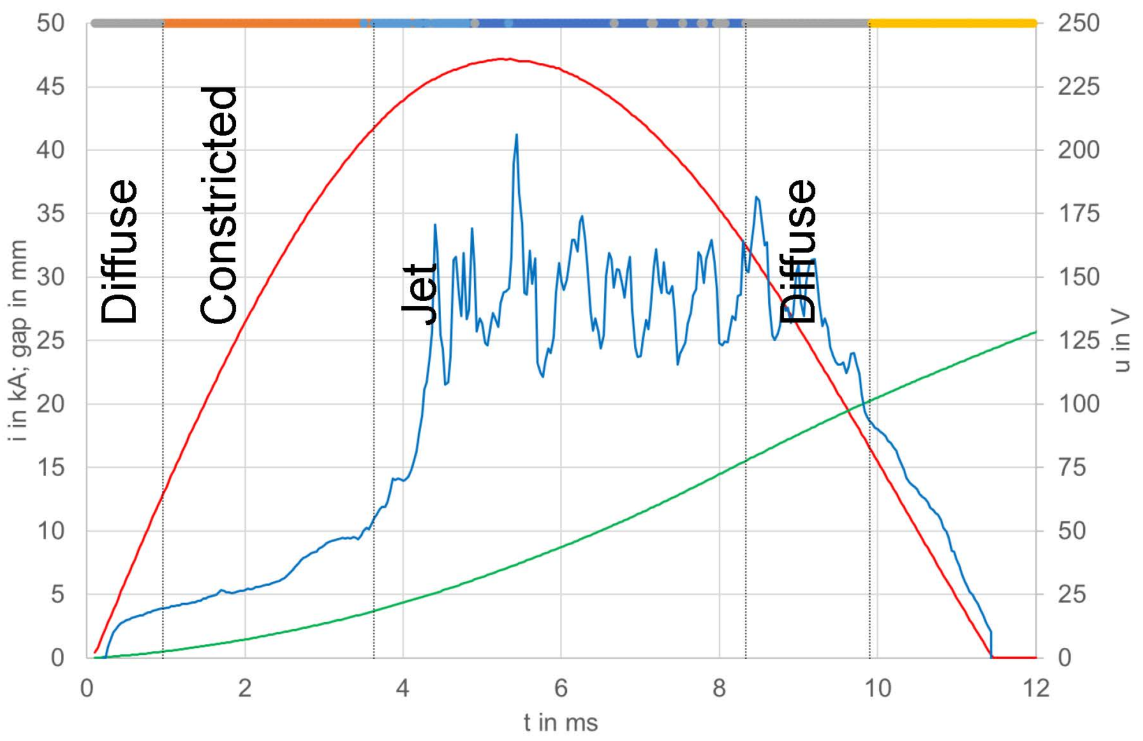
- Contact gaps of approx. 20 mm, 30 mm (t1) and 45 mm (t2) at current zero are tested
- For 45 mm, the frequency is lowered to 35 Hz
- Two materials were tested: CuCr25 & CuCr35+
- Gap 1 velocity approx. 2.4 ms & Gap 2 velocity 3 or 3.7 ms
- Current interruption up to 31.5 kA

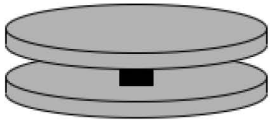
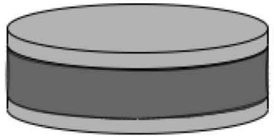
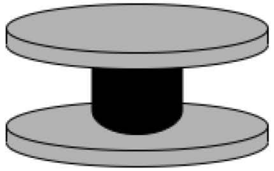
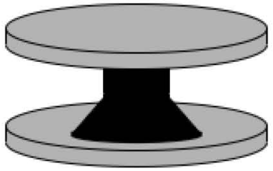
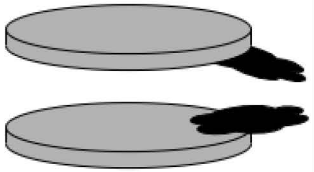


The arc mode

The time course of the arc mode

- During the emergence of arc, different modes are detectable
- Detected with High-Speed-Camera

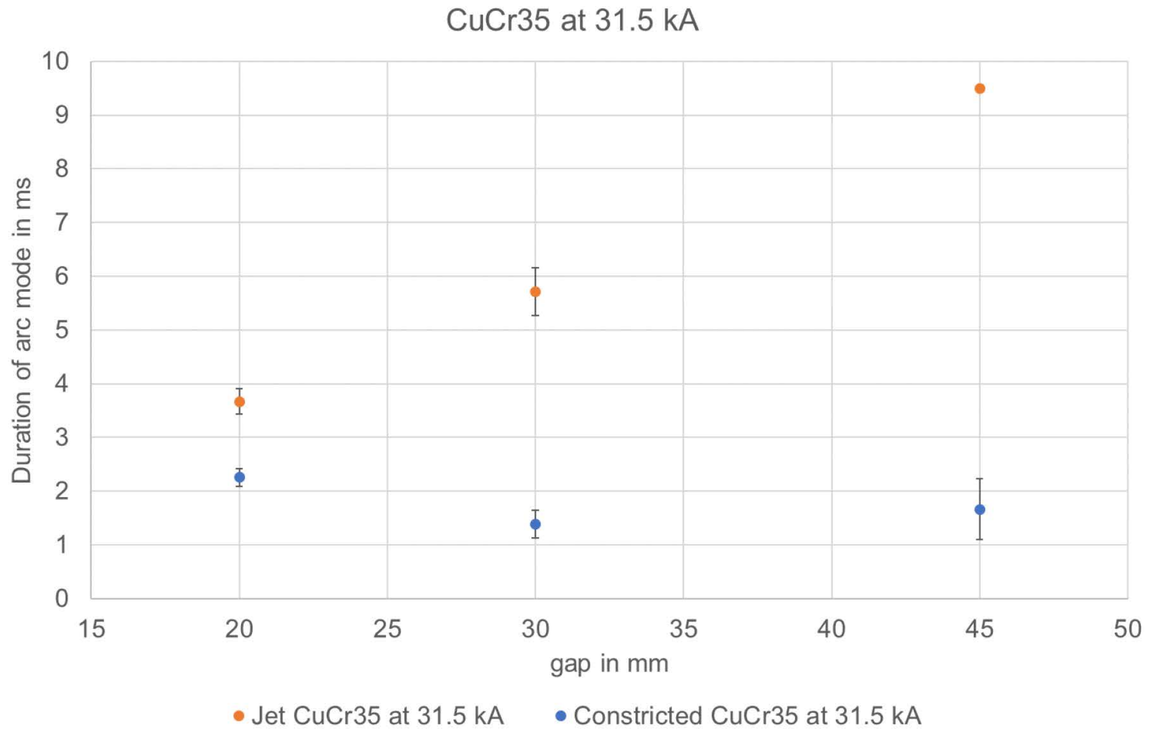


arc mode	bridge column	diffuse	constricted	Jet column	Anode Jet
arc mode on pin electrodes					

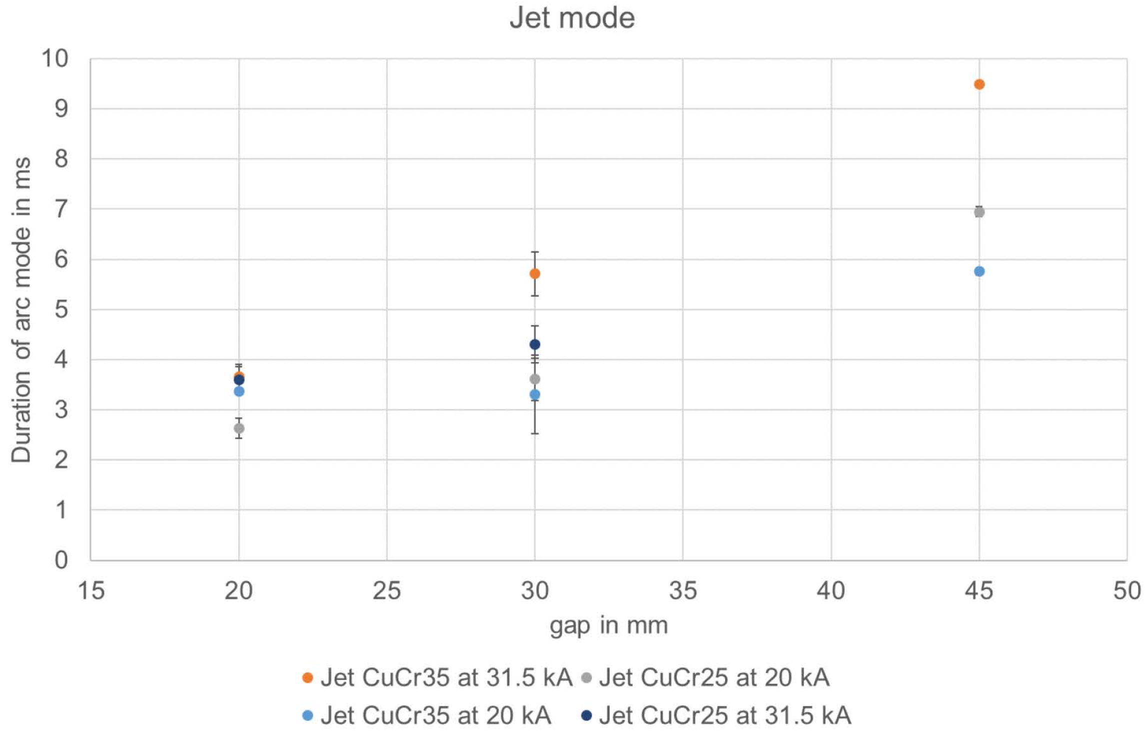
Jet mode

Duration of jetmode increases by gap

- Jet mode increase by higher contact gap, while constricted mode nearby constant



- Jet mode by different material and current
- Increasing gap shows a longer duration of Jet mode



References

- [1] Weber, Benjamin (2023): Automated Multivariate Analysis of Vacuum Arcs between TMF-Contacts. Technische Universität Braunschweig, Braunschweig. Institut für Hochspannungstechnik und Energiesysteme.