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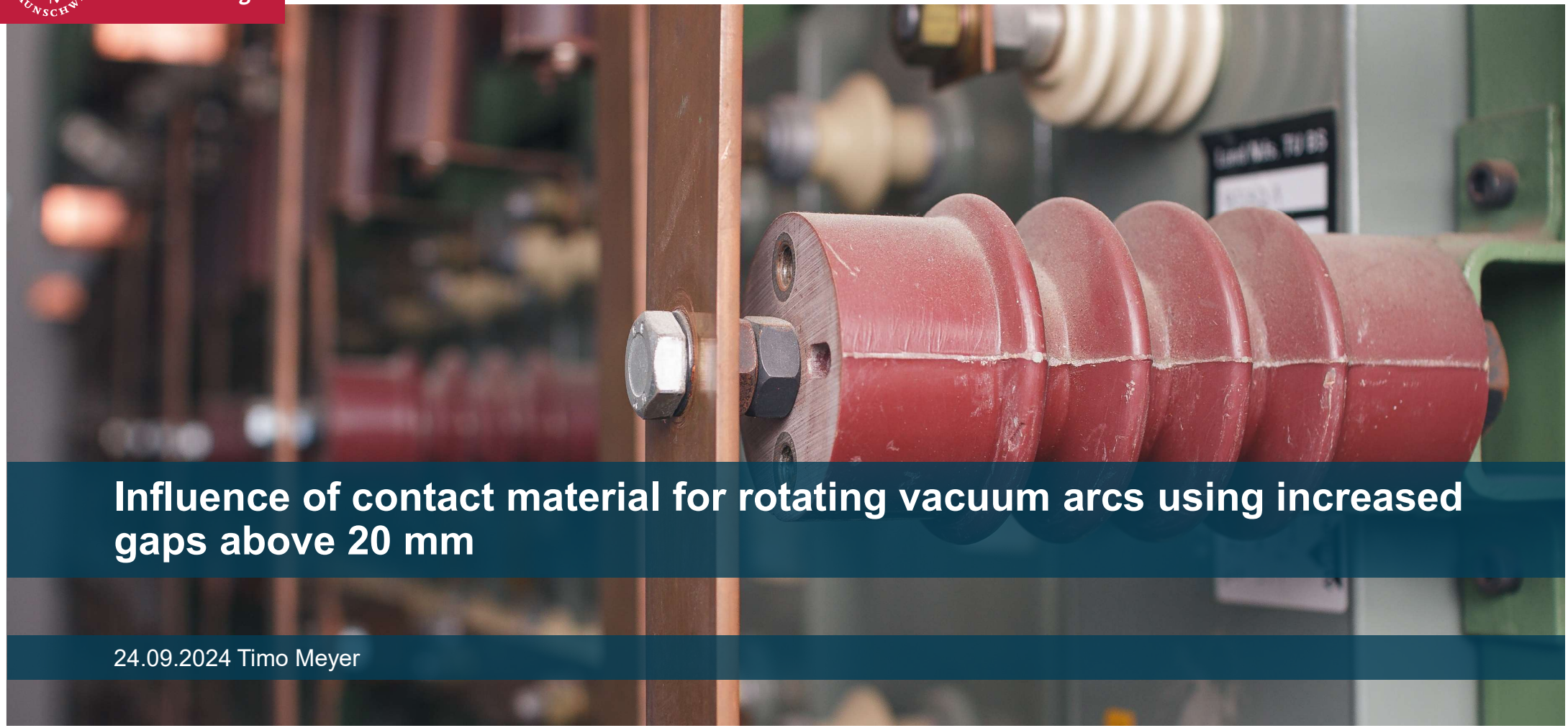
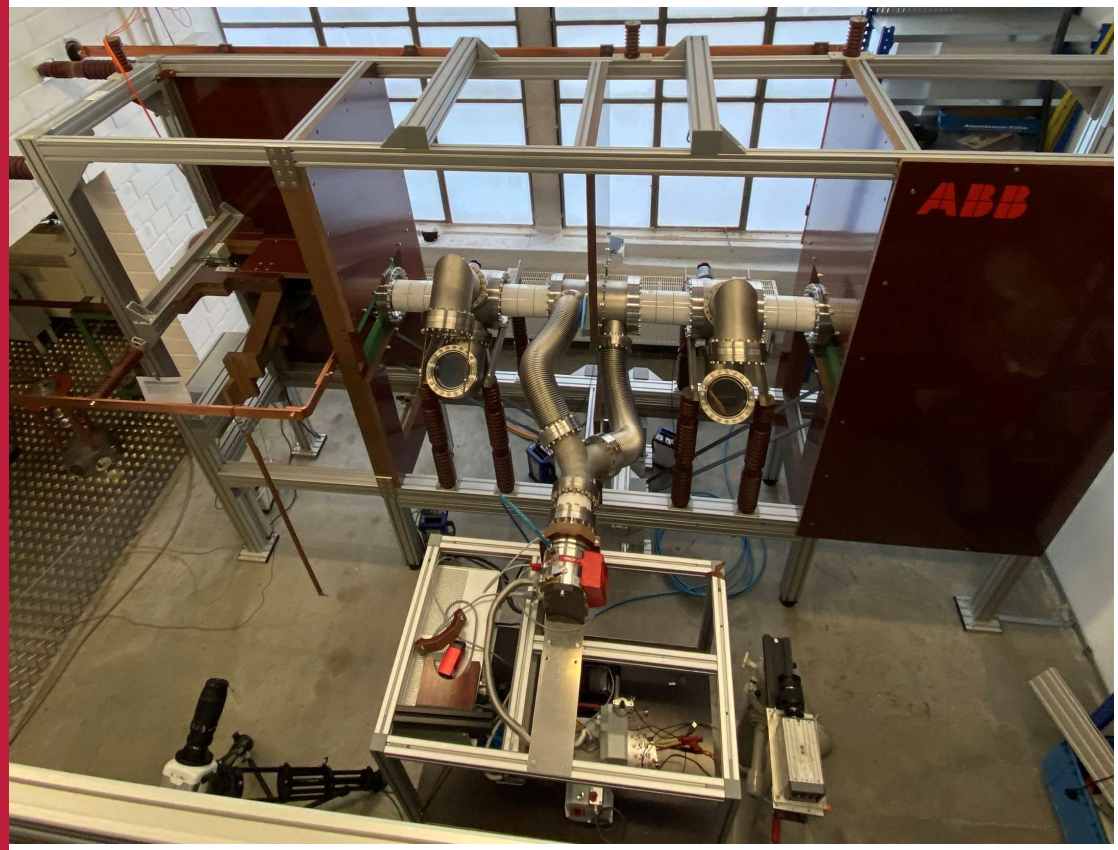


Influence of contact material for rotating vacuum arcs using increased gaps above 20 mm

24.09.2024 Timo Meyer

Agenda

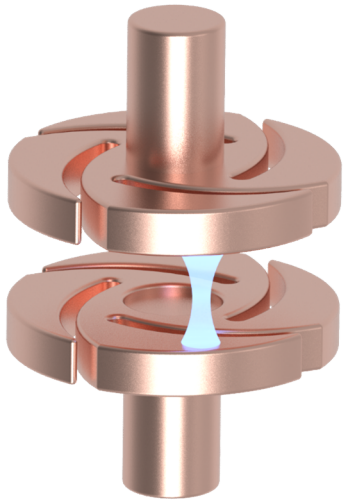
1. Motivation
2. Experimental setup
3. Investigation
4. Results
5. Conclusion



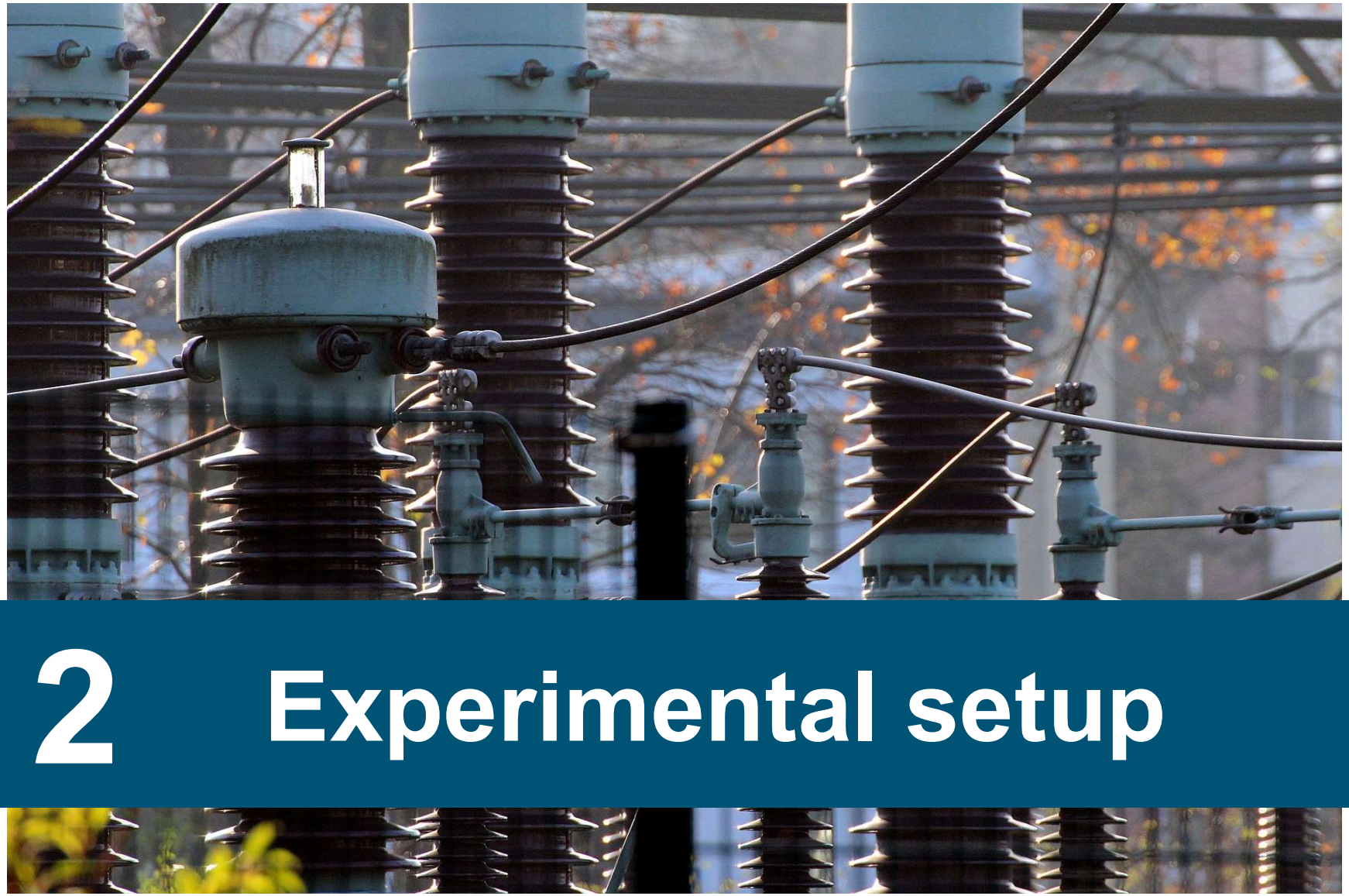
1 Motivation

Motivation

TMF contacts using for higher gaps



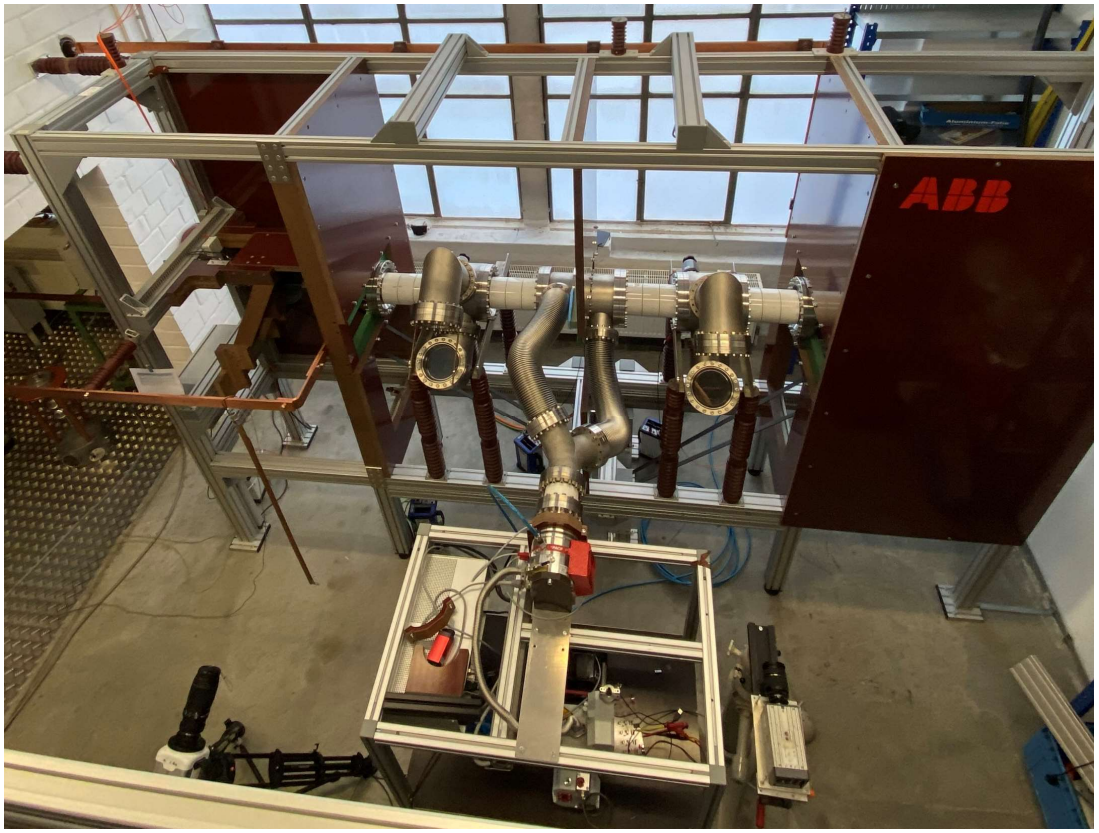
- Vacuum circuit breaker as SF6-free technology
- Long gap distance for higher voltage level: Most of them focus on AMF
- But TMF common uses in medium voltage level, because more inexpensive and show lesser contact resistance in closed position
- The aim is to test the highest possible gap for TMF contacts, where the TMF effect can be further explored
- Therefore, Optical and electrical investigation for evaluation of arc voltage, mode and movement carried out
- Gaps up to 45 mm and current of 31.5 kA rms (45 kA peak) with two different materials CuCr25 and CuCr35+



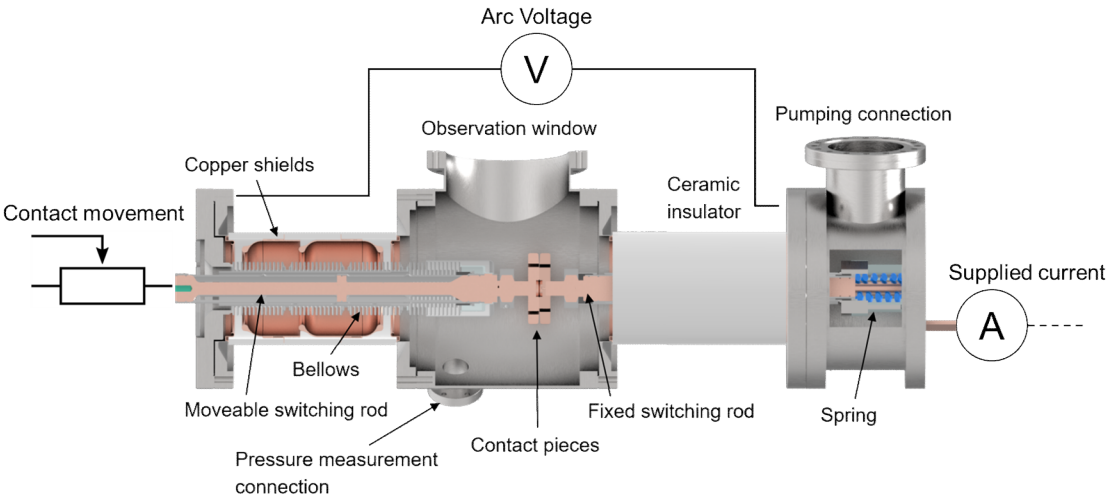
2 Experimental setup

Experimental setup

Vacuum interruption for single and double break



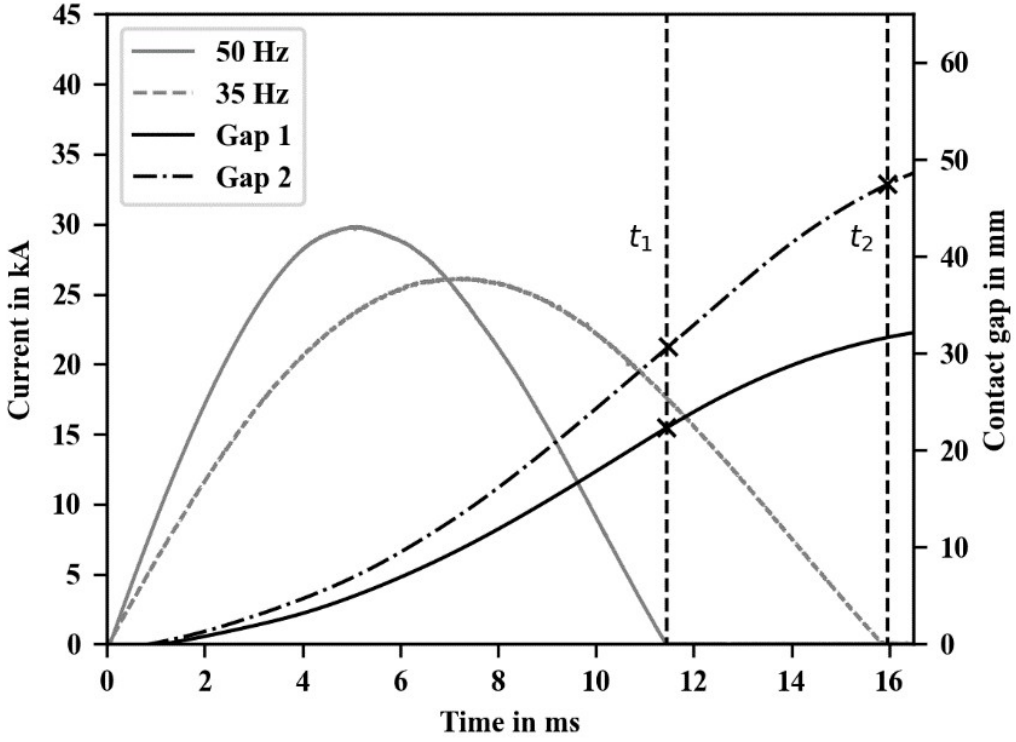
- Servo motor with a drive for programmable gap trajectories
- High-speed camera for optical investigation of the arc



Experimental setup

Methodology

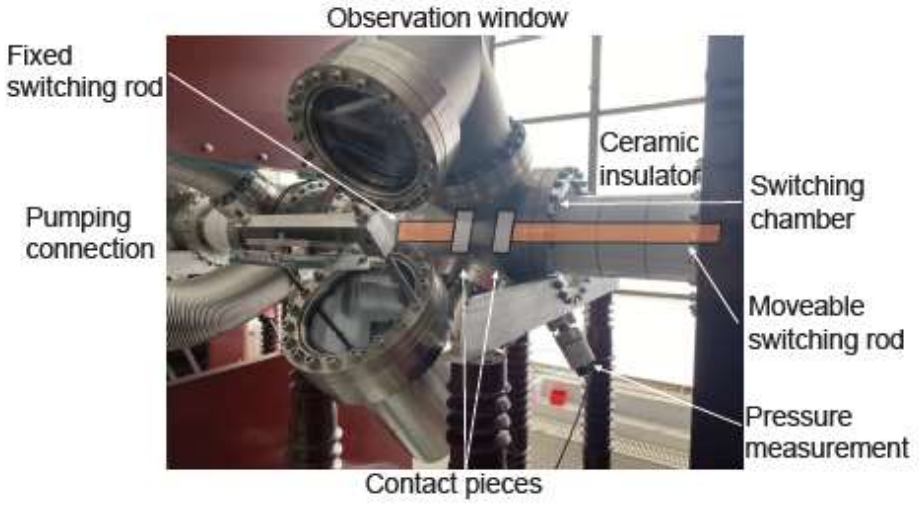
- Contact gaps of approx. 20 mm, 30 mm (t1) and 45 mm (t2) at current zero are tested
- For 45 mm, the frequency is lowered to 35 Hz
- Two materials were tested: CuCr25 & CuCr35+
- Gap 1 velocity approx. 2.4 ms & Gap 2 velocity 3 or 3.7 ms
- Current interruption up to 31.5 kA

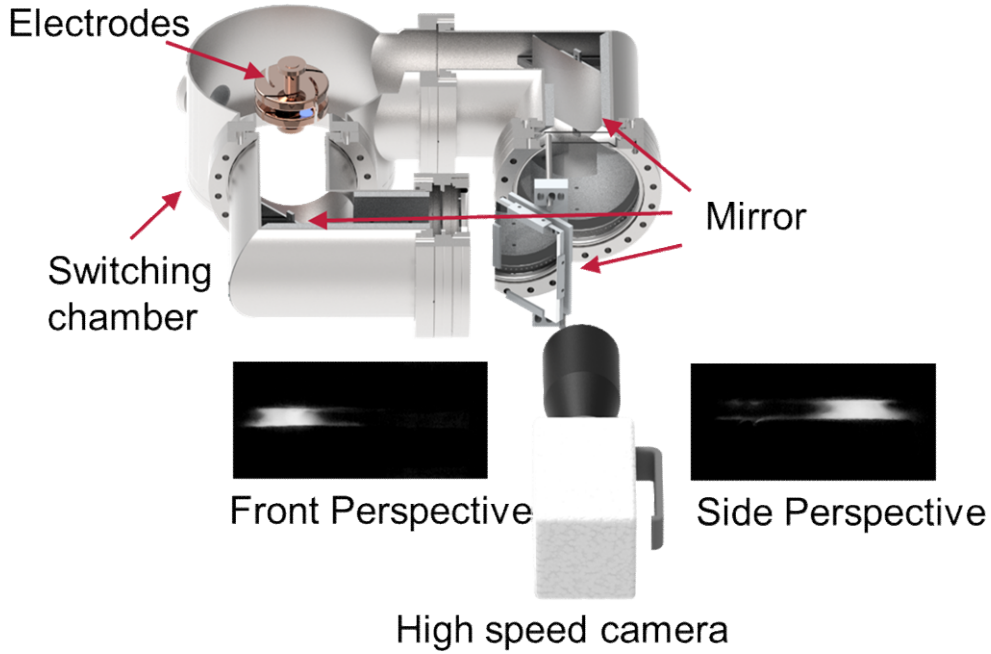


Experimental setup

Mirror arrangement

- 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)





3 Investigation

Investigation

Design of Expermients

- For each gap distance (20/30/45 mm) one contact pair up to 31.5 kA rms
- Two materials CuCr25 & CuCr35+
- 80 experiments carried out

n=2*

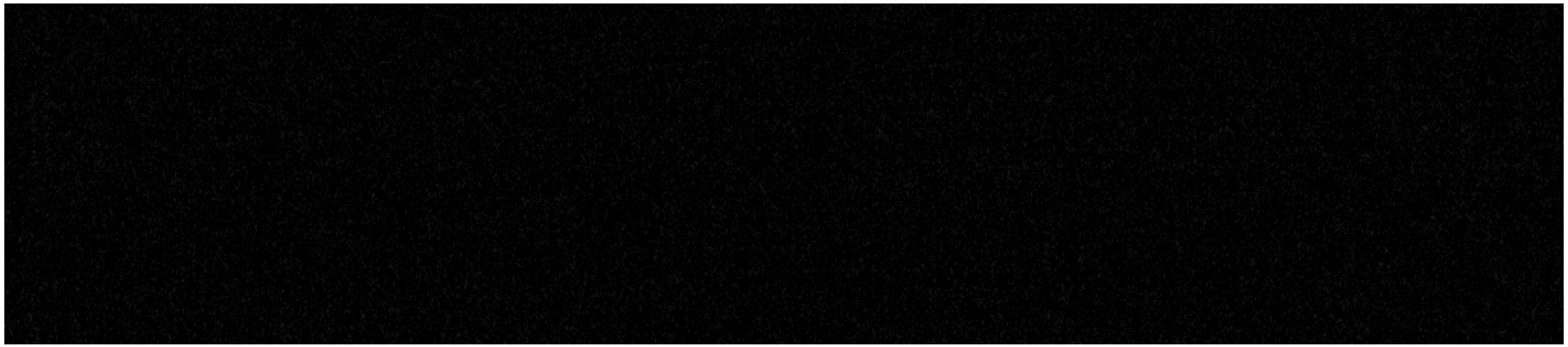
Current in kA (rms) / gap in mm		TMF / 50 Hz			TMF / 35 Hz	
		15	20	31,5	20	31,5
Gap at CZ	20	5	5	5		
	30	5	5	5		
	45				5	5
ΣTests		30			10	

=80

Long gap as single interruption

Equipped with CuCr35+

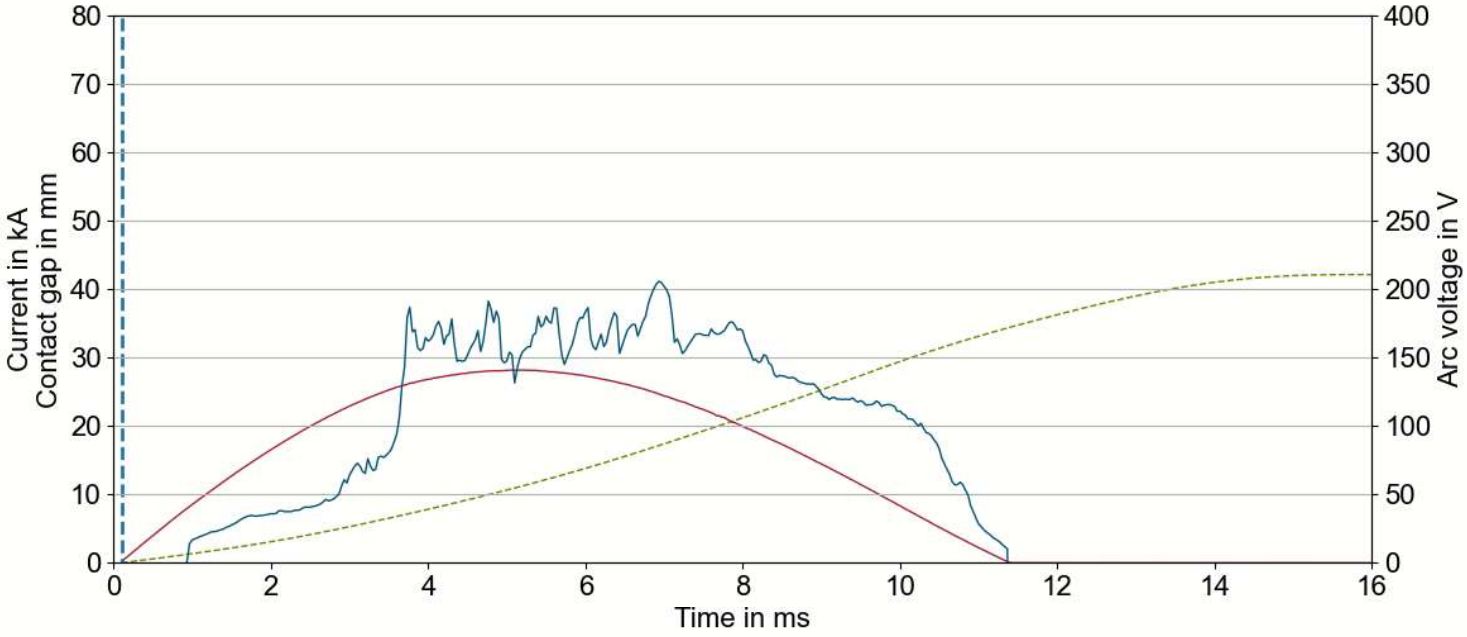
- 20 kA rms & 34 mm at 50 Hz

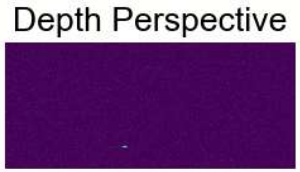


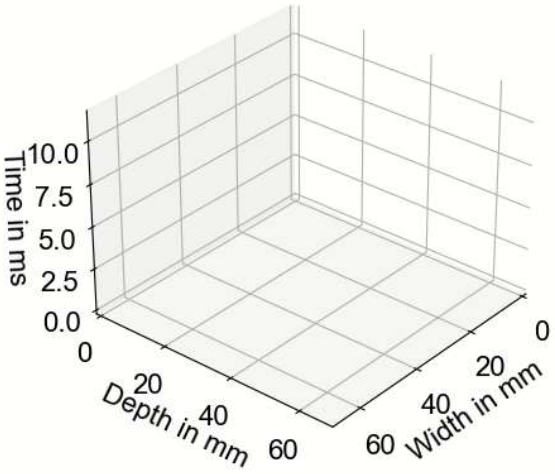
Long gap as single inte

Equipped with CuCr35+ (No. 019)

- 20 kA rms & 34 mm at 50 Hz



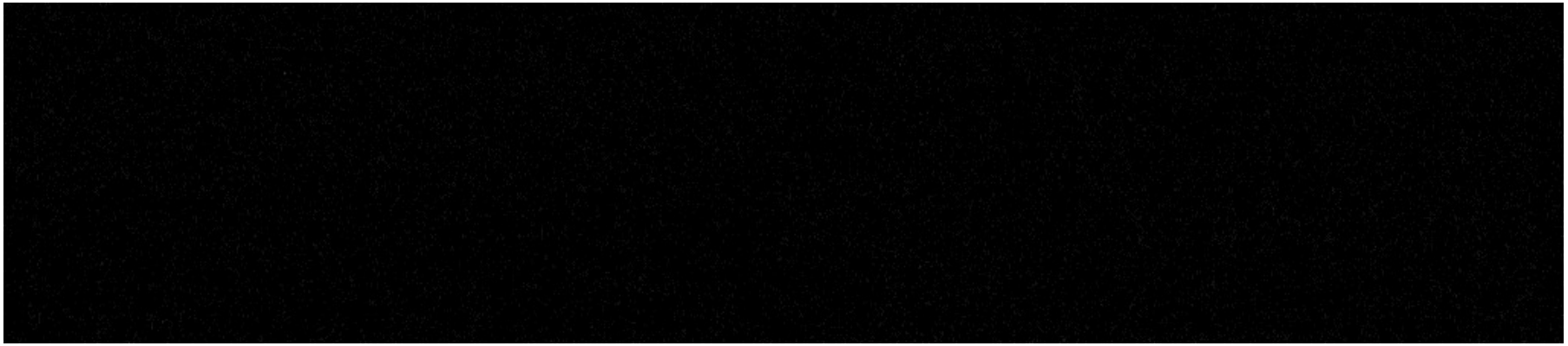




Long gap as single interruption

Equipped with CuCr35+

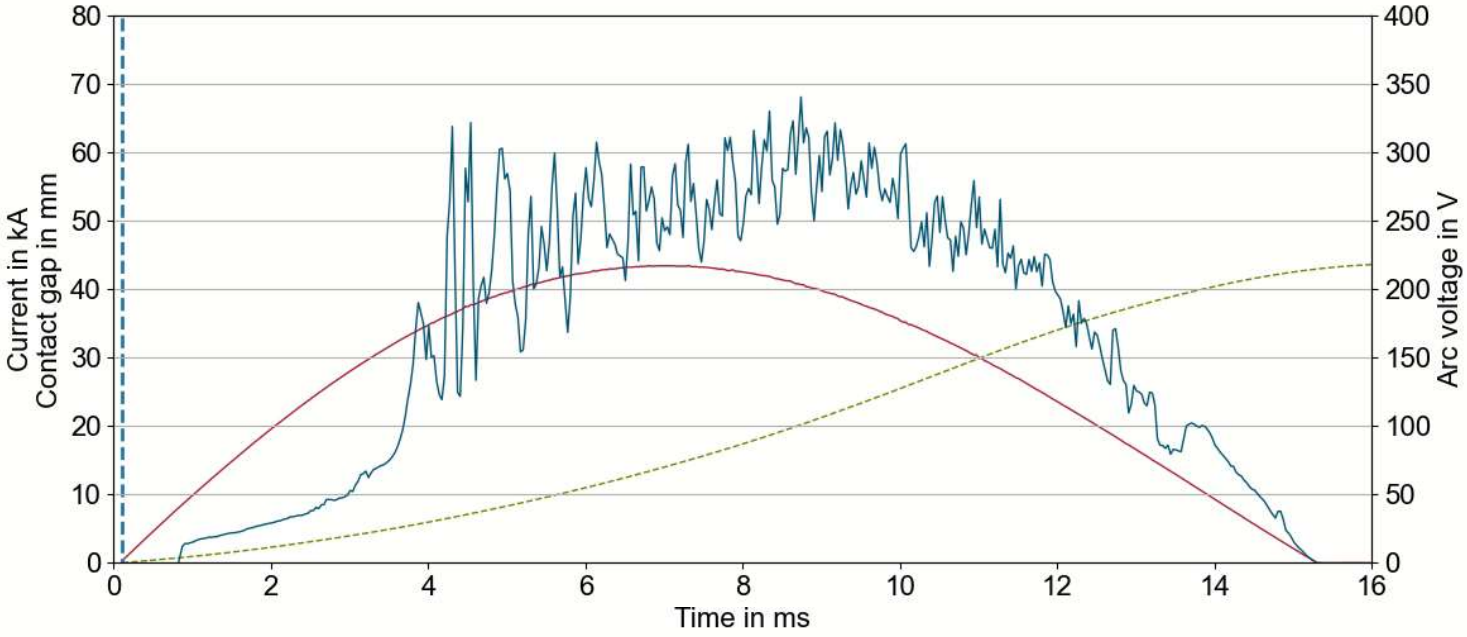
- 31,5 kA rms & 44 mm at 35 Hz

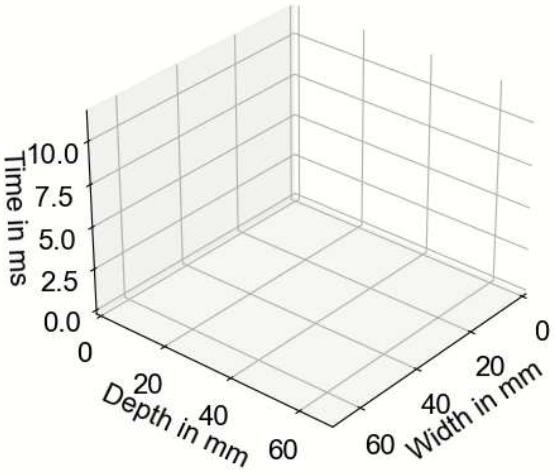


Long gap as single inte

equipped with CuCr35+ (No. 009)

- 31,5 kA rms & 44 mm at 35 Hz

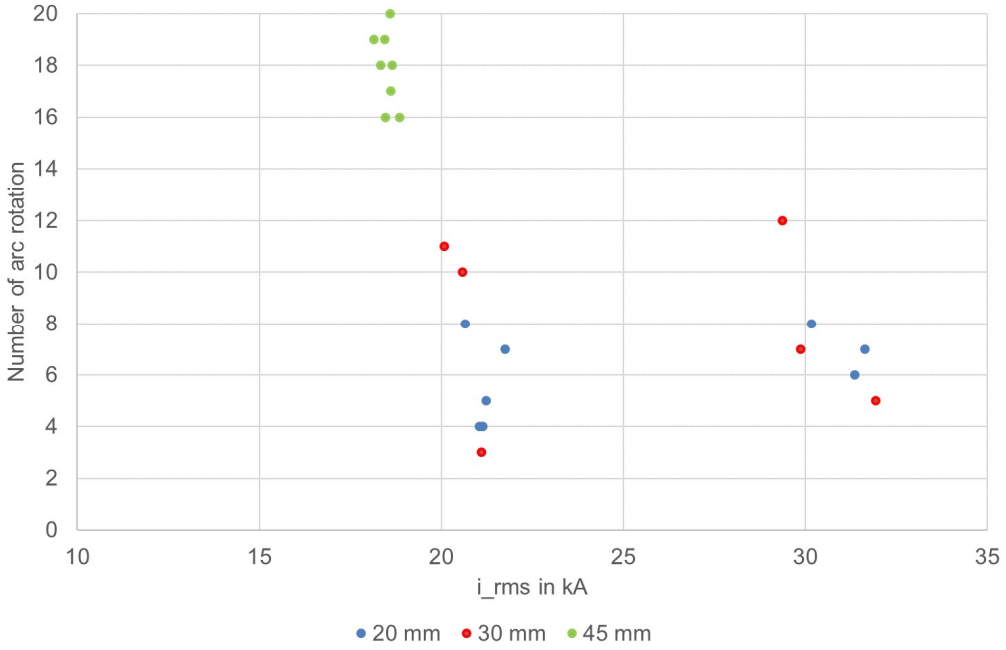




4 Results

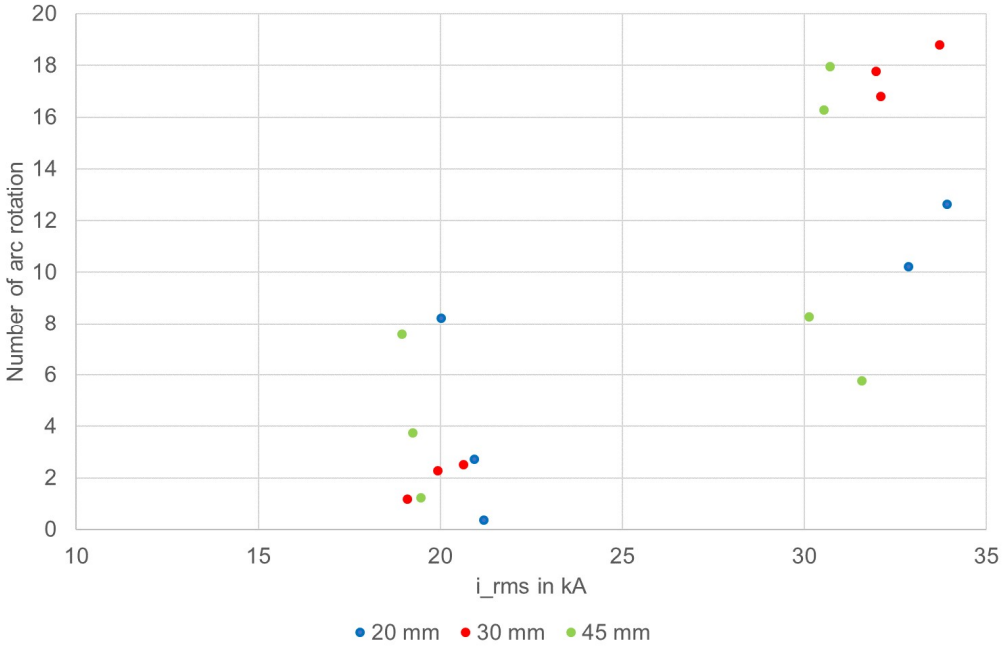
Number of arc rotation

- Number of arc rotation CuCr25



Current (RMS)	Contact gap		
	20 mm (50 Hz)	30 mm (50 Hz)	45 mm (35 Hz)
20 kA	5.2 ± 1.17	5 ± 2.45	18.86 ± 1.26
31.5 kA	7 ± 0.82	8 ± 2.94	-

- Number of arc rotation CuCr35+

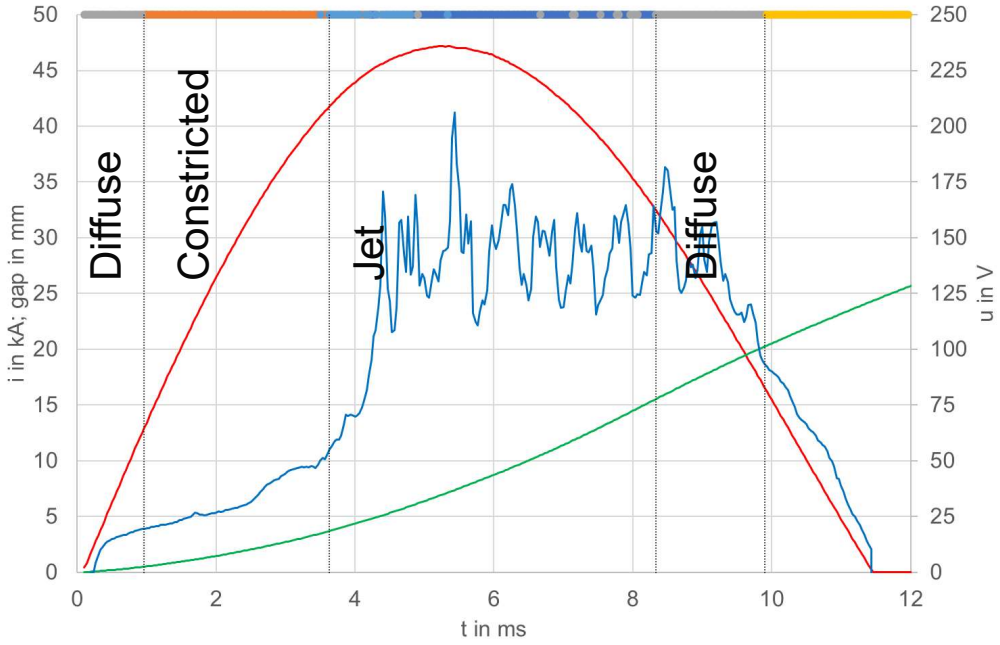


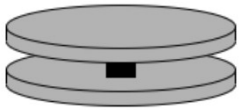
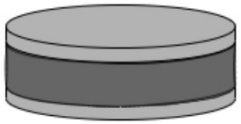
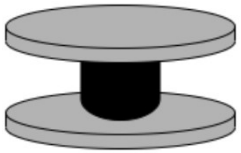
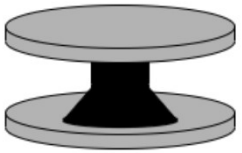
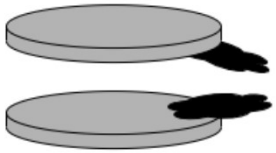
Current (RMS)	Contact gap		
	20 mm (50 Hz)	30 mm (50 Hz)	45 mm (35 Hz)
20 kA	1.80 ± 0.51	1.99 ± 0.29	4.19 ± 1.30
31.5 kA	10.36 ± 0.90	17.79 ± 0.41	14.18 ± 2.11

The arc mode

The time course of the arc mode

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



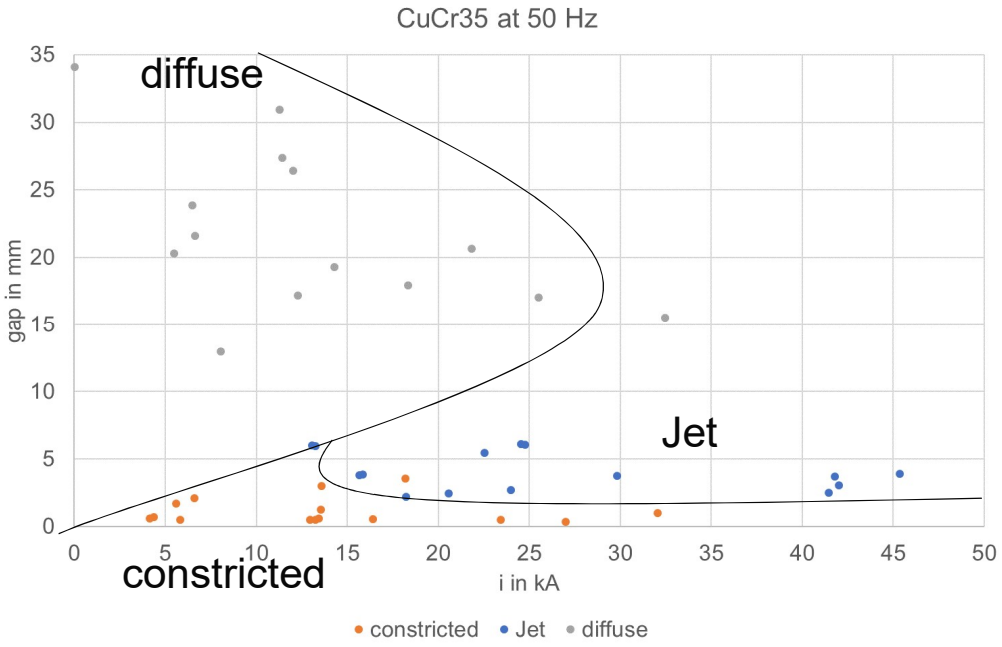
Bogenform	Brückensäule	diffuser Bogen	kontrahierter Bogen	Jetsäule	Anoden- u. Kathodenjet
Bogenbild bei Pinkontakten					

Arc appereance diagram

Why using an arc appereance diagram?

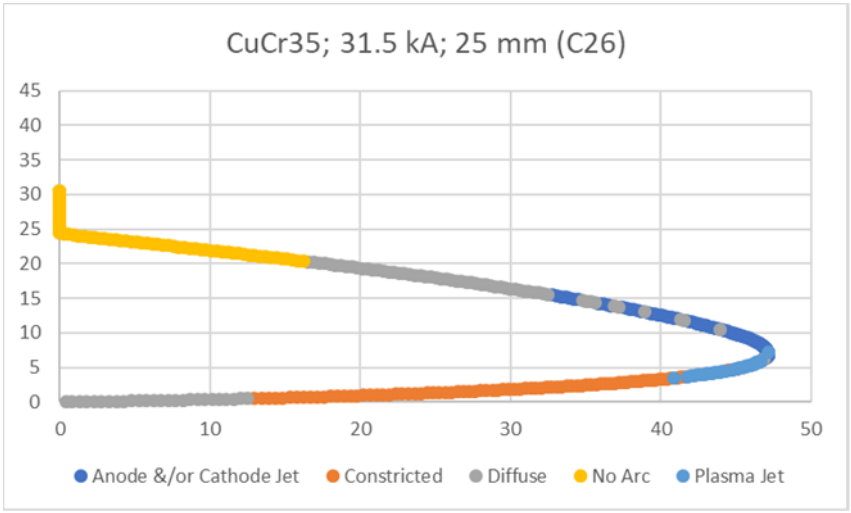
- The arc appearance diagram used to classify the arc mode by instantaneous gap and current
- The change of mode marks a point in the diagram
- Aim
  - Determination of the required mode (avoidance of strong contact erosion)
  - Additional examination of the contact trajectories to investigate the higher gaps

- Automated evaluation with python

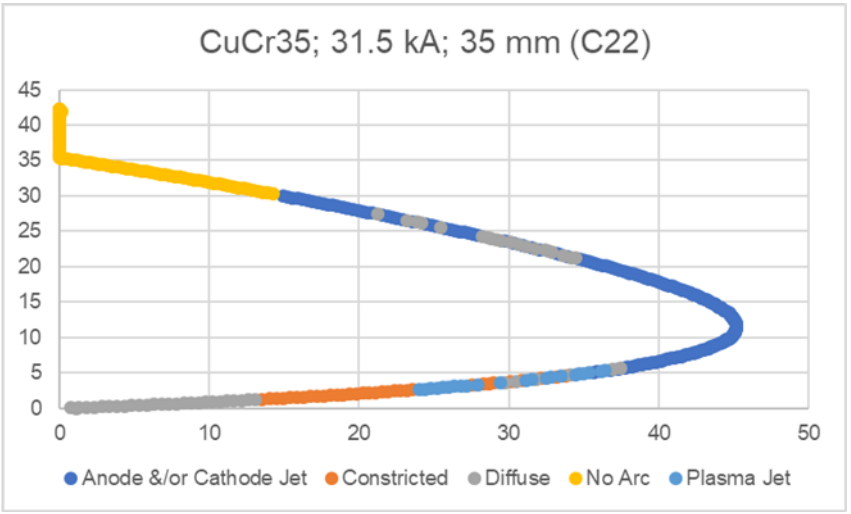


Arc appereance diagramm by each frame

- The automated evaluation enable an evaluation of each frame
- Every 30 µs detected the arc mode



Anode &/or Cathode Jet: 3.17 ms

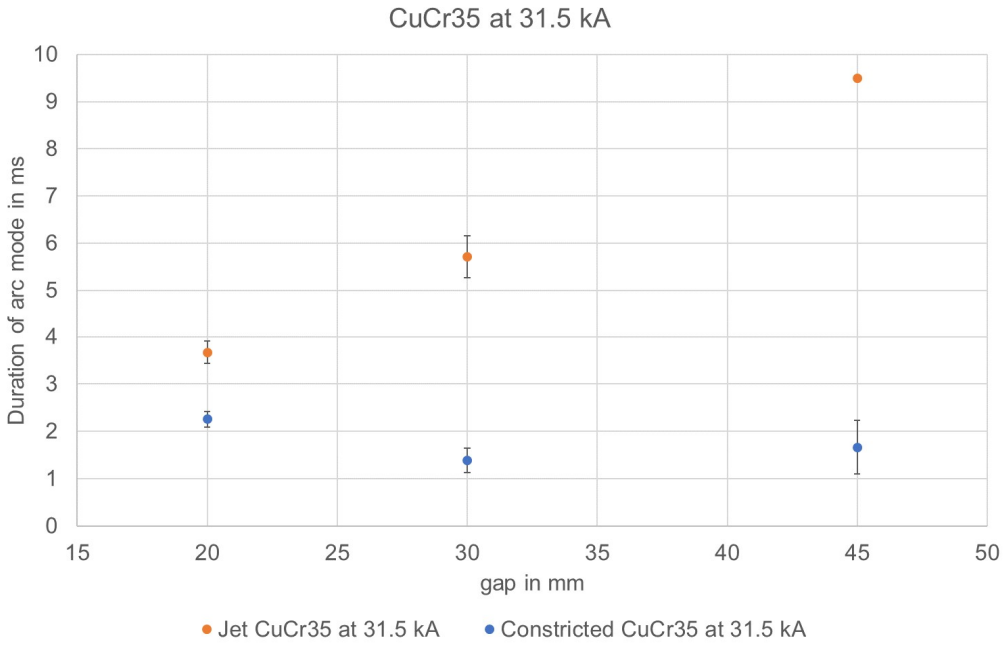


Anode &/or Cathode Jet: 6.23 ms

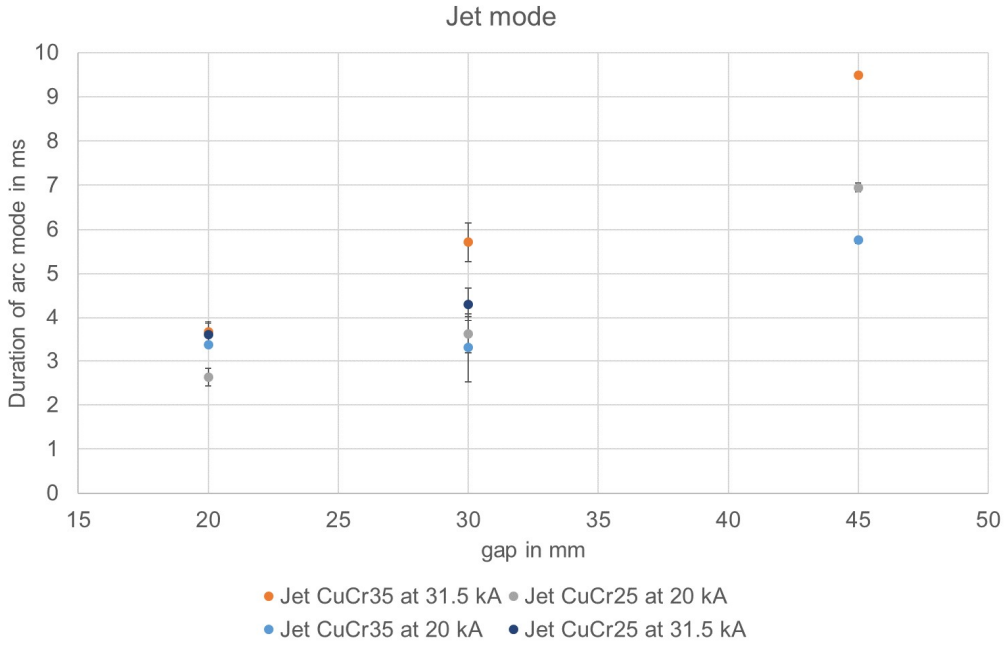
Jet mode

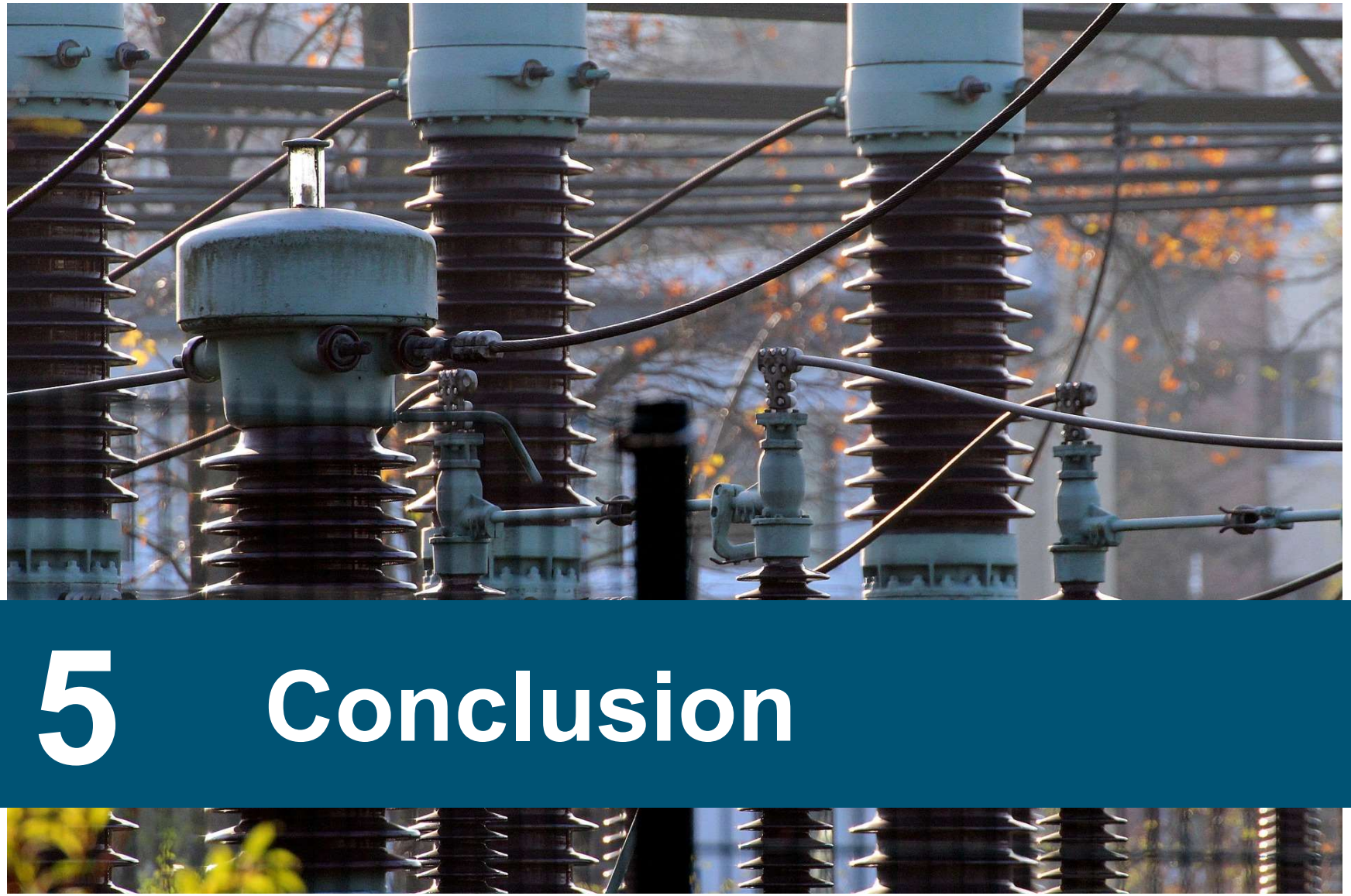
Duration of jetmode increases by gap

- 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



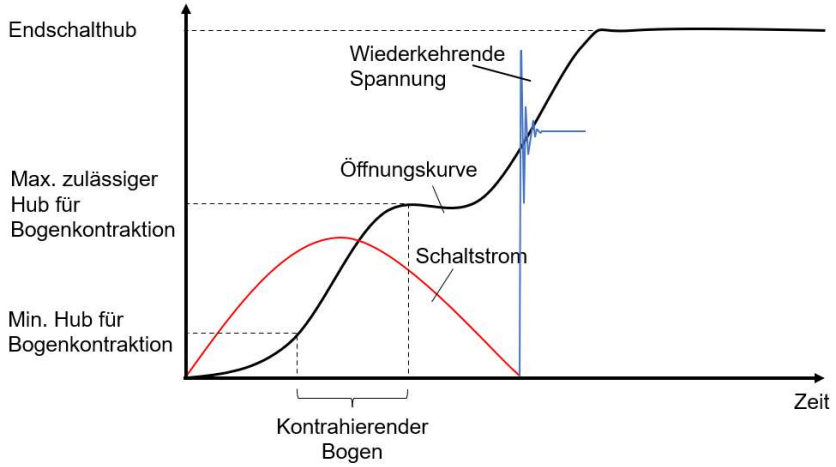


5 Conclusion

Conclusion

- Results:
  - Tested with CuCr25 and CuCr35+ up to 31.5 kA
  - The increased contact gap has no negative effect on the arc rotation or arc speed
  - TMF-contact is feasible for long gap applications
  - The advantages of low losses and inexpensive manufacturing of TMF-designs still apply
  - The arc voltage of longer gaps have an increased oscillation
  - Higher gaps results to longer duration of jet mode
  - Important for the number of arc rotation is the arc mode

- Outlook:
  - Comparison with AMF
  - Arc mode verification by arc voltage
  - Opening of two gaps for higher gaps
  - TRV and post-arc investigation
  - Step curves



Contact

List of publication

CV

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Arbeitsgruppe:	Energy technology
Team:	High voltage, vacuum and plasma technology (HVP)

RESEARCH

- Analysis of plasma behaviour after current zero crossing
- Experimental investigations of breaking process in a vacuum double interrupter
- Influence of long contact gaps above 20 mm in a vacuum interrupter

PUBLICATION

- Meyer, T., Gentsch, D., Kurrat, M.: **Analysis of the plasma behaviour after current zero phase based on the post-arc current of a vacuum interrupter**, 30th International Symposium on Discharge and Electrical Insulation in Vacuum (ISDEIV), Okinawa, Japan, 25. Juni - 30. Mai 2023
- Meyer, T., Kühn, B., Gentsch, D., Kurrat, M.: **Lightning impulse conditioning of a combined field grading and shielding arrangement for vacuum double break**, 29th International Symposium on Discharge and Electrical Insulation in Vacuum (ISDEIV), Padova, Italien, 26. September - 1. Oktober 2021
- Meyer, T., Weber, B., Gentsch, D., Kurrat, M.: **Design of experiments for characterization of a high voltage circuit generating a transient recovery voltage**, VDE High Voltage Technology, Berlin, 9.-11. November 2020.

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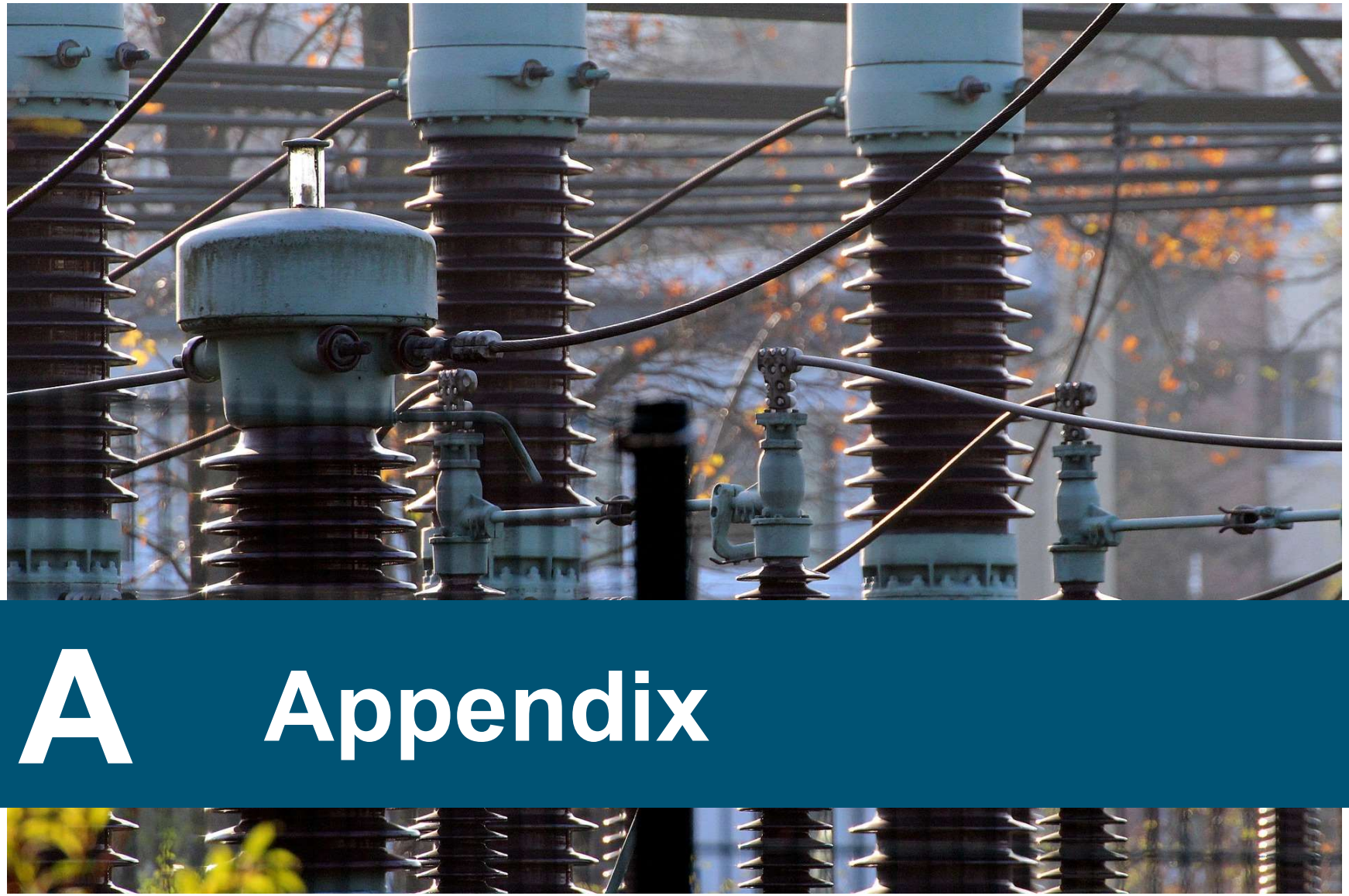
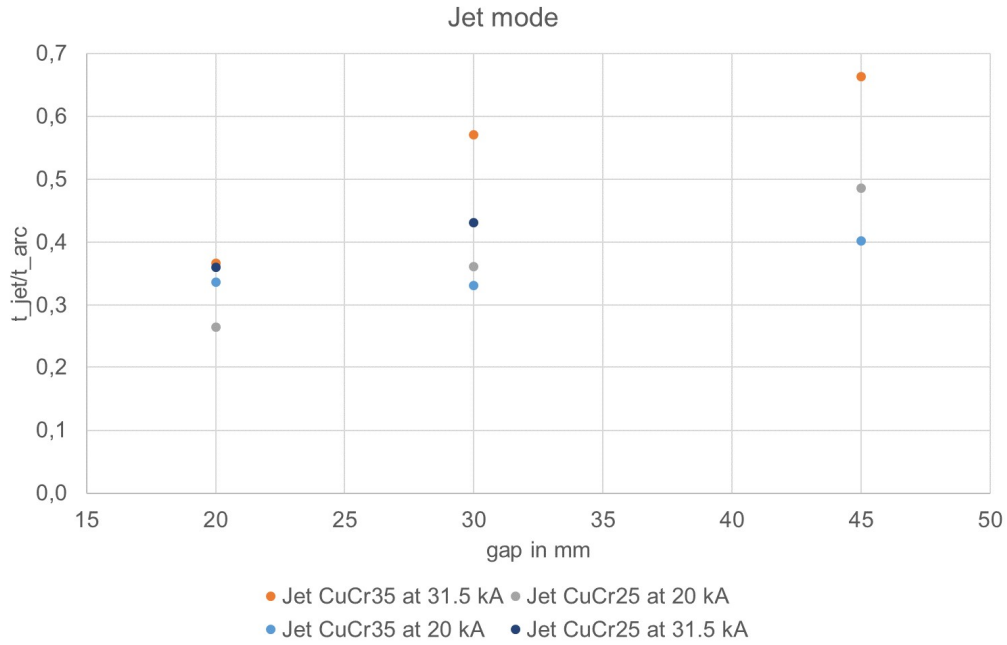


A Appendix

Jetmode

- Jetmode in relation to the arcing time



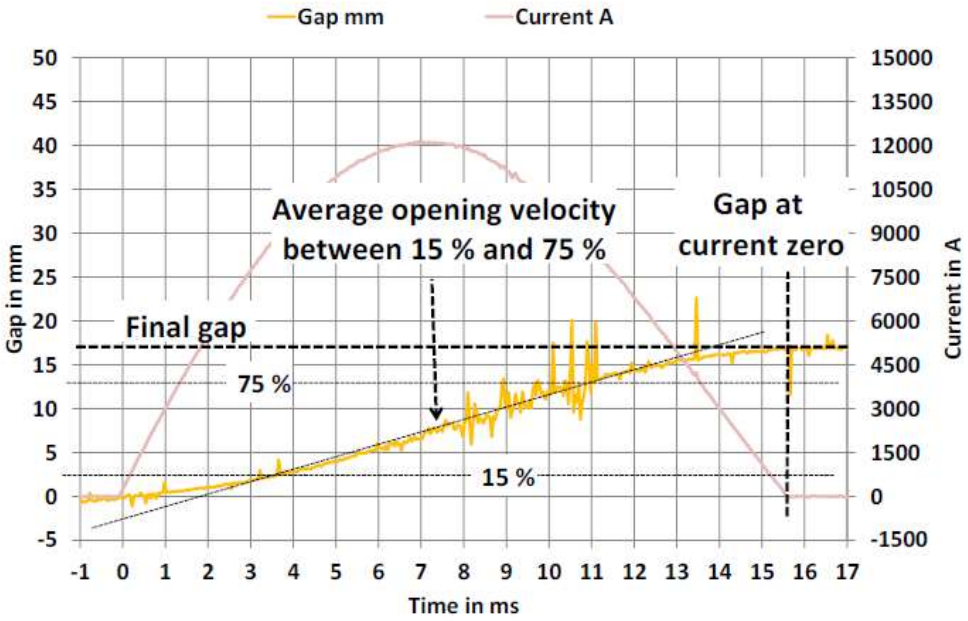
Contact erosion

- CuCr25
- More molten surface due to the higher Cu part and their lower melting temperature

- CuCr35

Determination v_gap

- 75%/15% Method [Diss Kühn]



- Maximum Speed [Diss Weber]

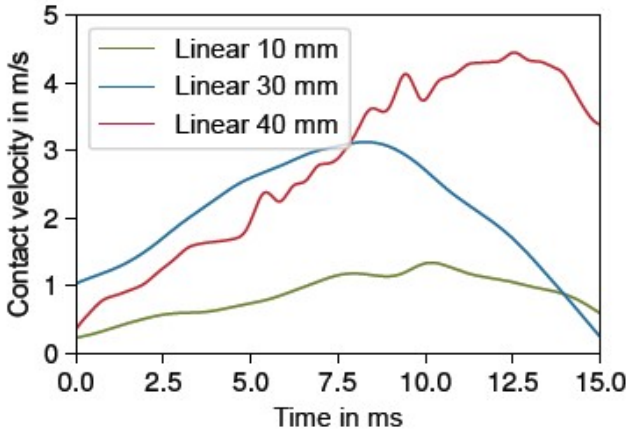
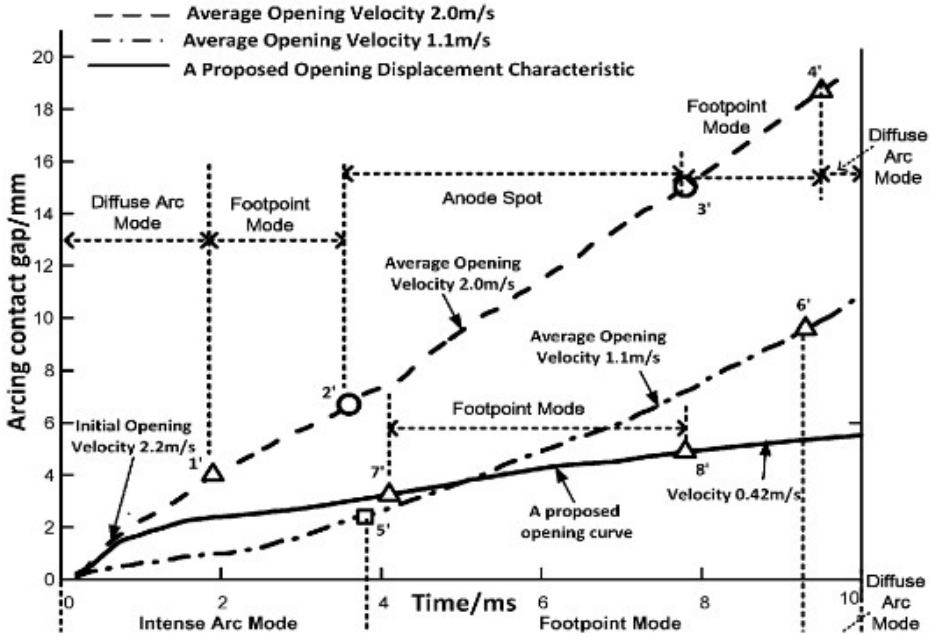
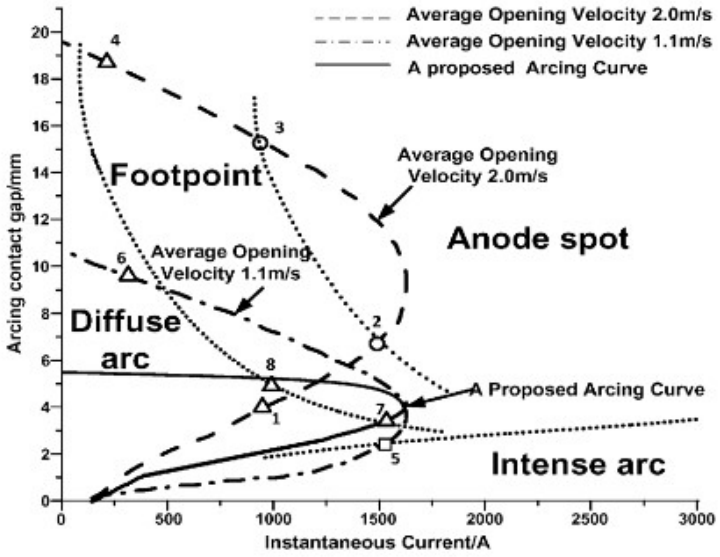


Figure 3.6: Corresponding velocity for selection of opening curves (cf. figure 3.5)

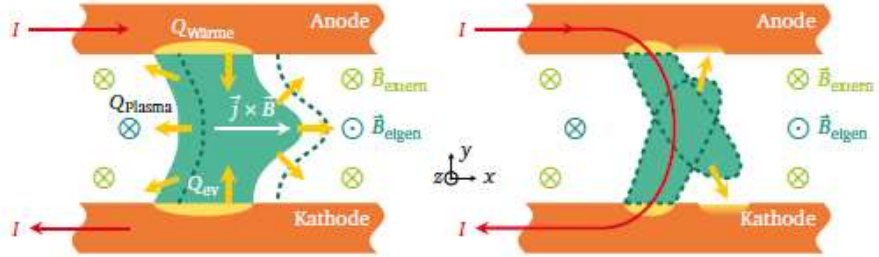
Nutzung des Diagramms zur Steuerung der Öffnungskurve





An Opening Displacement Curve Characteristic Determined by High-Current Anode Phenomena of a Vacuum Interrupter; Liqiong Sun, Li Yu, Zhiyuan Liu, Member, IEEE, Jianhua Wang, and Yingsan Geng; 2013

- Bogen wird durch starke Anodenspots aufgeheizt und eine stärke Kontakterosion entsteht [1;2]
- These: Jet sorgt für größere Geschwindigkeit des Bogens, weil die Oberfläche stärker aufgeheizt wird und es somit zu stärkeren Lorentz-Kräften kommt und der Bogen schneller rotiert.



[1] Anode Modes in Vacuum Arcs: Update; H. Craig Miller; 2017
[2] Vacuum Arcs; H. Craig Miller; 2023

Bogenerscheinungsdiagramm TMF

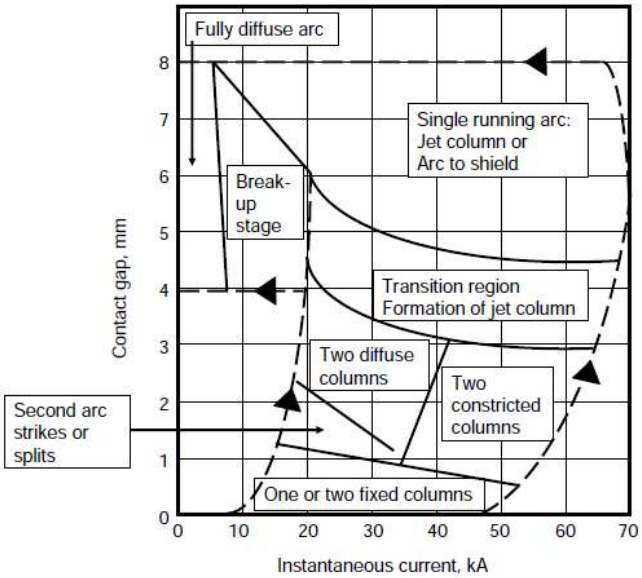


FIGURE 3.25 Columnar arc appearance diagram between spiral TMF, spiral contacts for an opening speed 1.6 m s^{-1}, opening delays of 0.48–2.3 ms into the current half-cycle and final contact gaps of 4–8 mm [83].

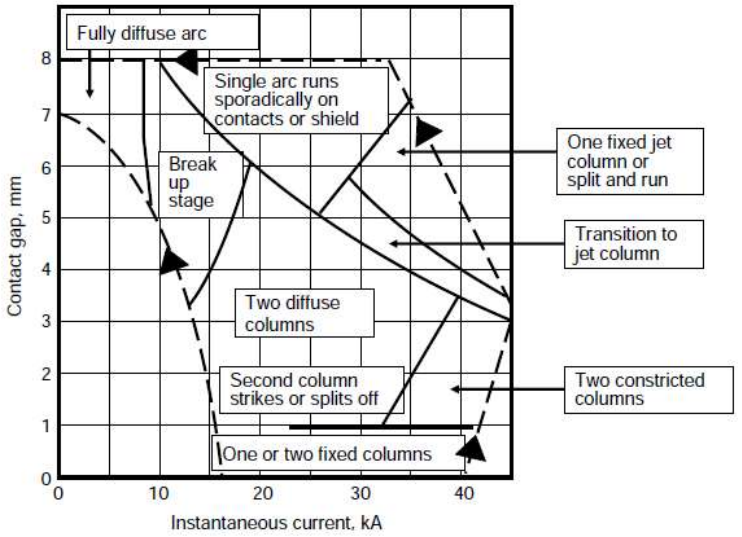


FIGURE 3.26 Columnar arc appearance diagram between spiral TMF, spiral contacts for an opening speed 2.0 m s^{-1}, opening delays of 2.4–4.4 ms into the current half-cycle and final contact gaps of 7–8 mm [83].

[1] The vacuum interrupter; Paul G. Slade; 2021
[2] Separation of spiral contacts and motion of vacuum arcs at high currents; M.B. Schulman; 1993

Auszüge aus Dissertation Weber

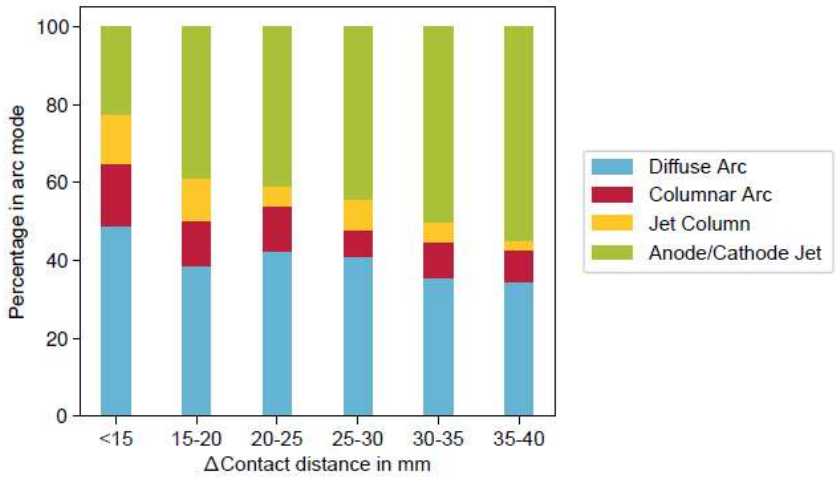


Figure 5.17: Percentages in four main arc modes in dependence of traveled contact distance (in averaged groups) at various currents during active arcing phase

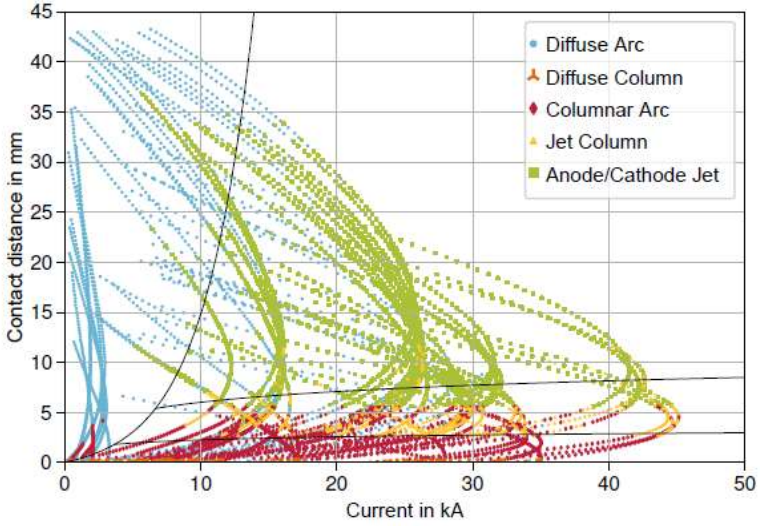


Figure 5.15: Arc existence diagram with detected modes based on machine learning algorithm applied on 52 tests; CuCr25 contact pieces with 68 mm diameter

Auszüge aus Dissertation Weber

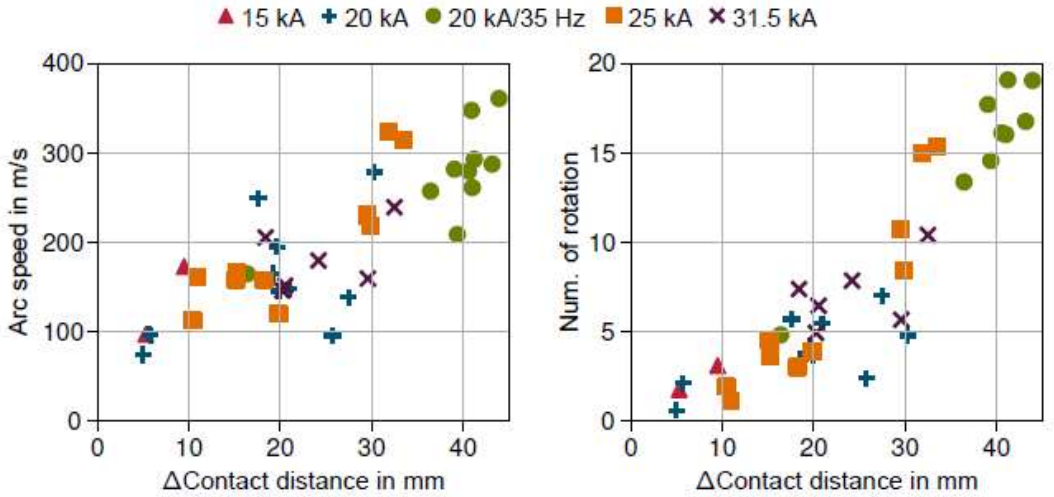
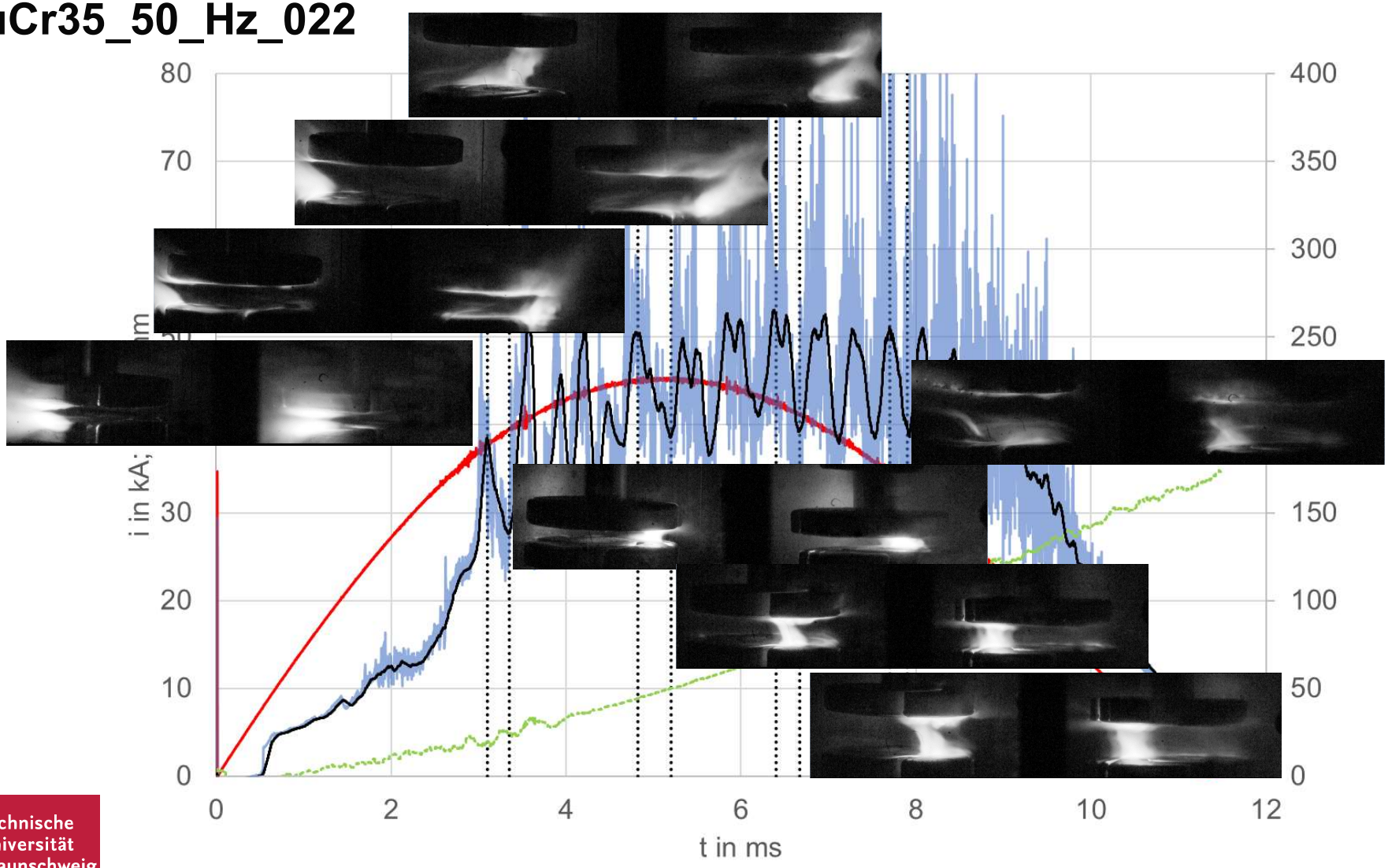


Figure 5.14: Arc speed (left) and number of rotation (right) in dependence of traveled contact distance during active arcing phase

CuCr35_50_Hz_022



Spannungsverlauf

- Hochpunkt Beobachtung:
  - Bogen zerteilt sich
  - Im Hochpunkt kleinerer Leitwert als Tiefpunkt

- Tiefpunkt Beobachtung:
  - Bogen formiert sich zu einer Jetsäule