

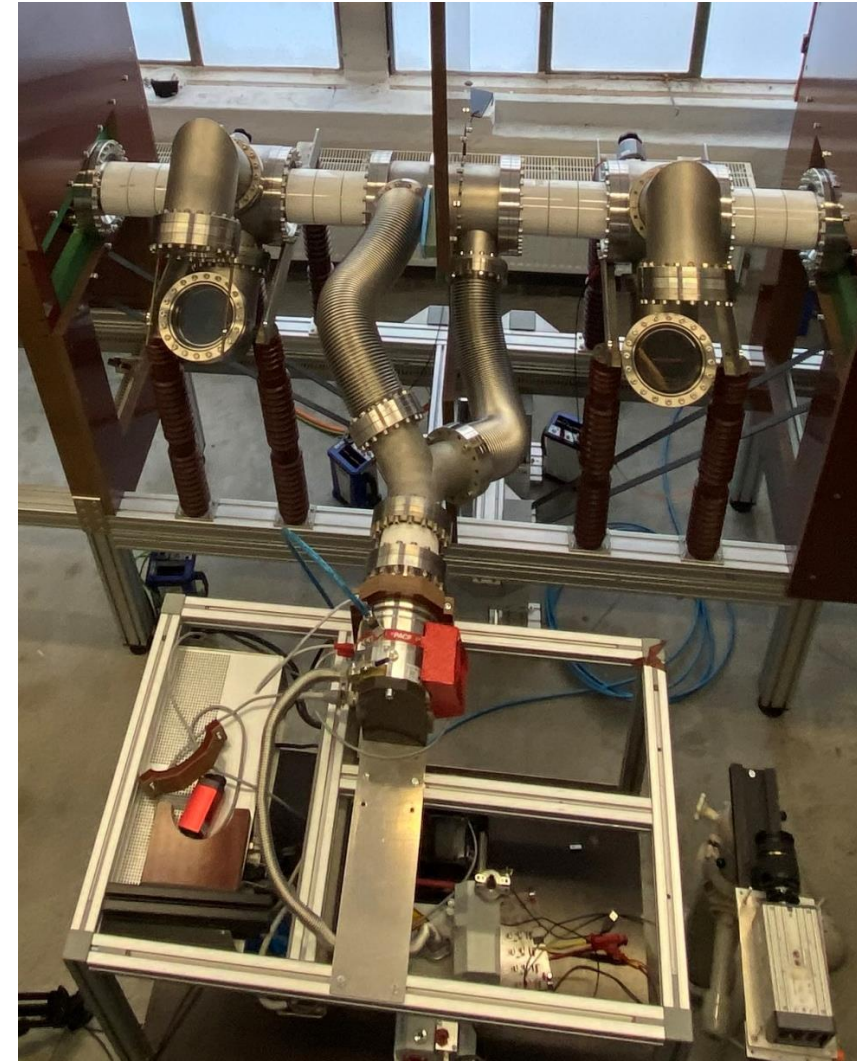


Optical and electrical parameters for classifying arc mode and movement using TMF-contacts

02/06/2025 Timo Meyer, Karen Flügel, David Cziumplik, Marius Hinz and Michael Kurrat

Agenda

1. Introduction
2. Setup
3. Arc dynamics
 1. Arc movement
 2. Arc mode
 3. Contact erosion
4. Conclusion and outlook

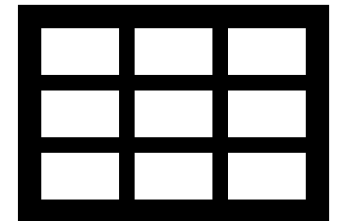
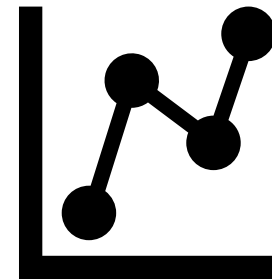
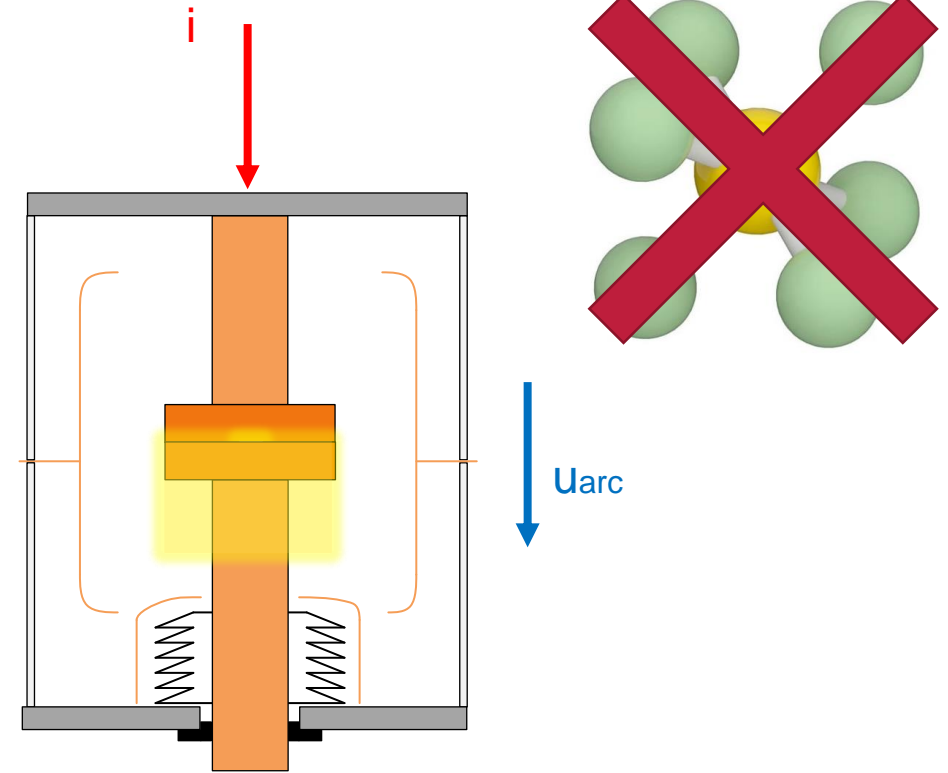
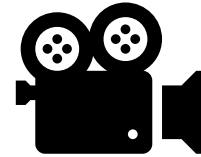


1 Introduction

Introduction

Motivation

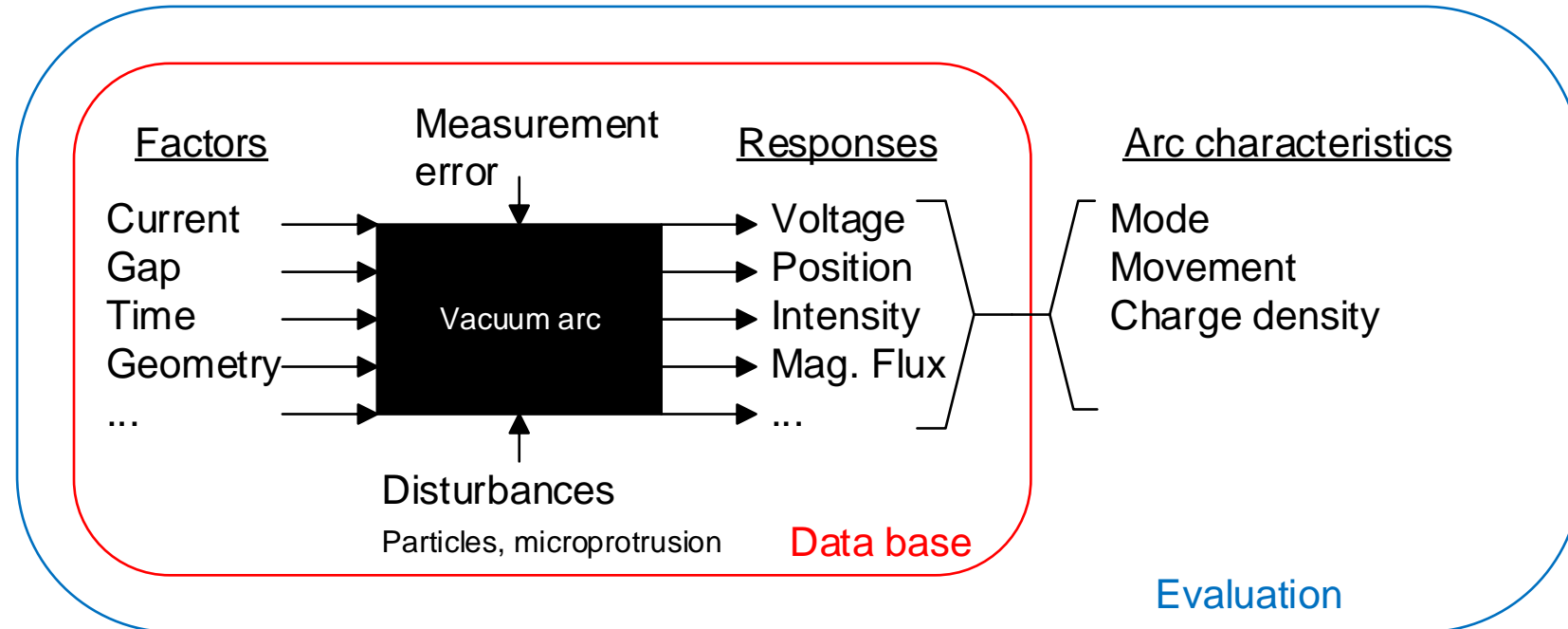
- Vacuum circuit breaker: efficiency for higher requirements
- Limits in contact erosion and dielectric strength
- Knowledge and Control of arc dynamics necessary
- Analysis of electrical and optical data
- Characterisation by influencing factors
- Aim:
 - Statistical vacuum arc models
 - Foundation for a comprehensive database



Introduction

Description of plasma behaviour

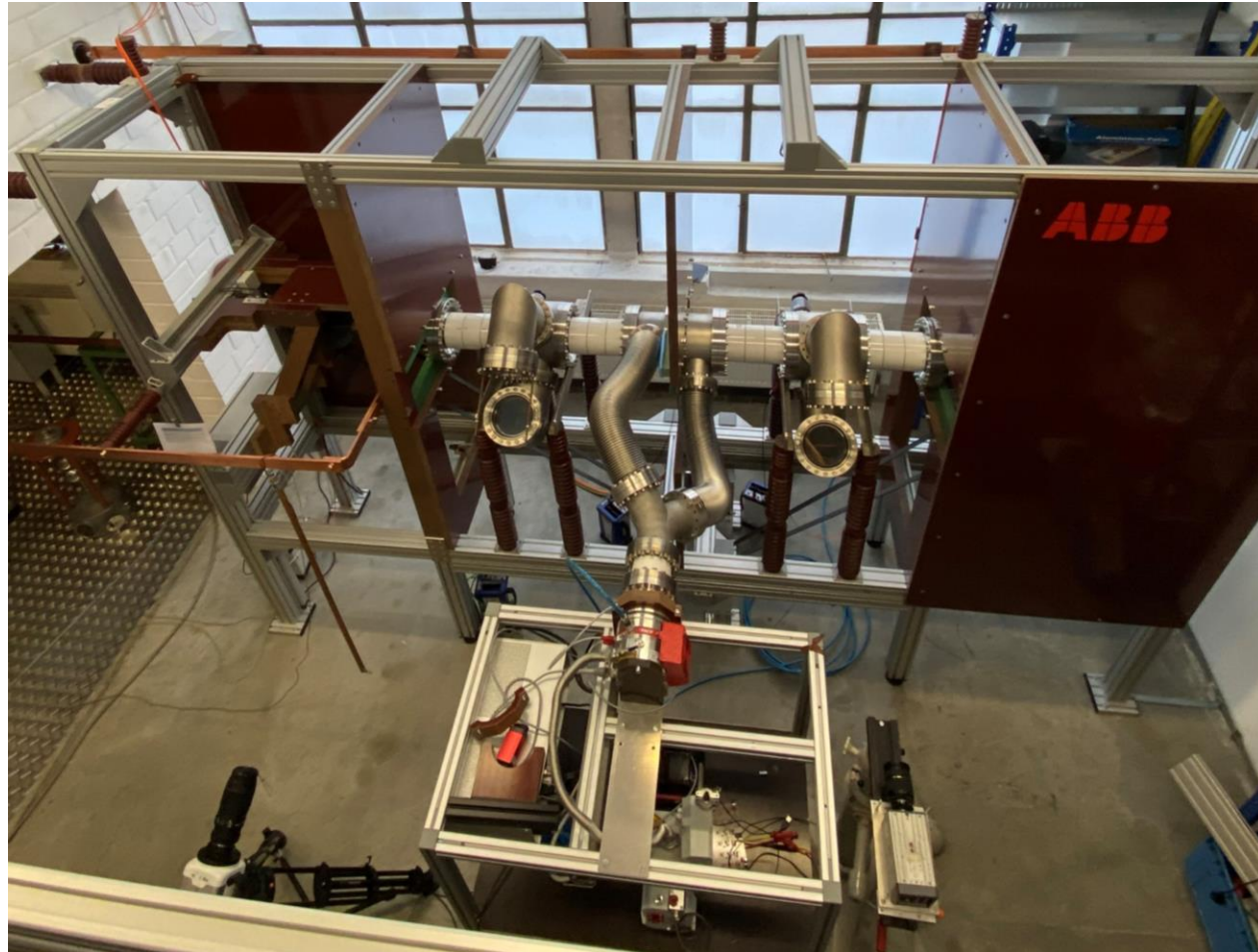
- Many parameter influence the arcing behaviour
- Data analysis is necessary
 - Black box analysis
 - Correlation of responses and characteristic
 - Data base



2 Setup

Lab facilities

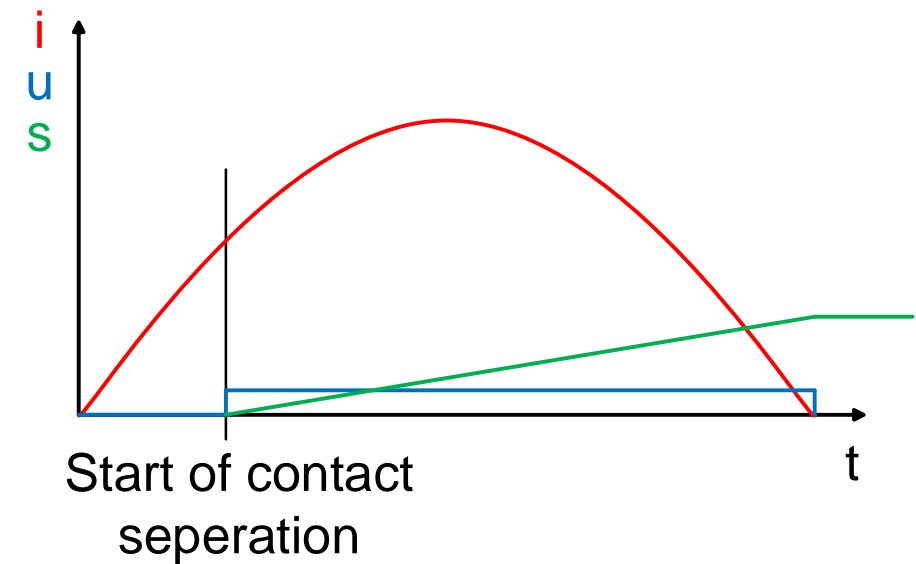
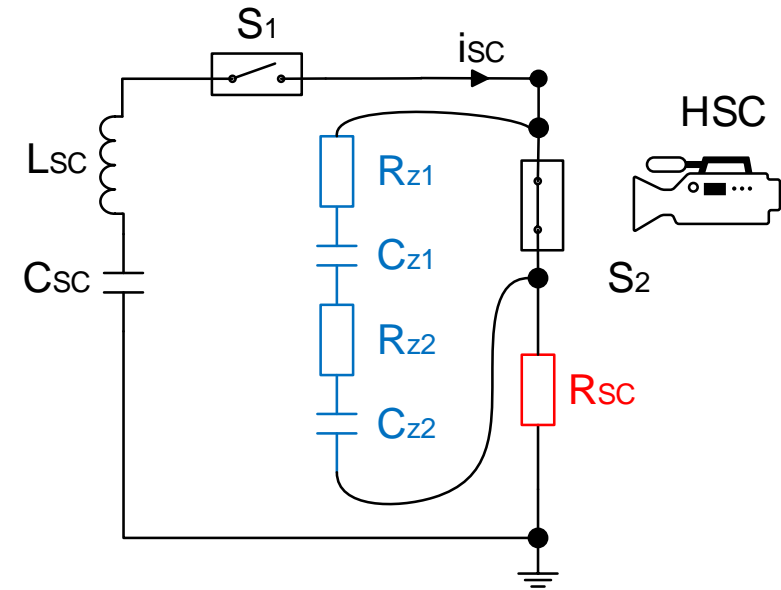
Vacuum interruption for single and double interrupter



Setup

Electrical data measurement

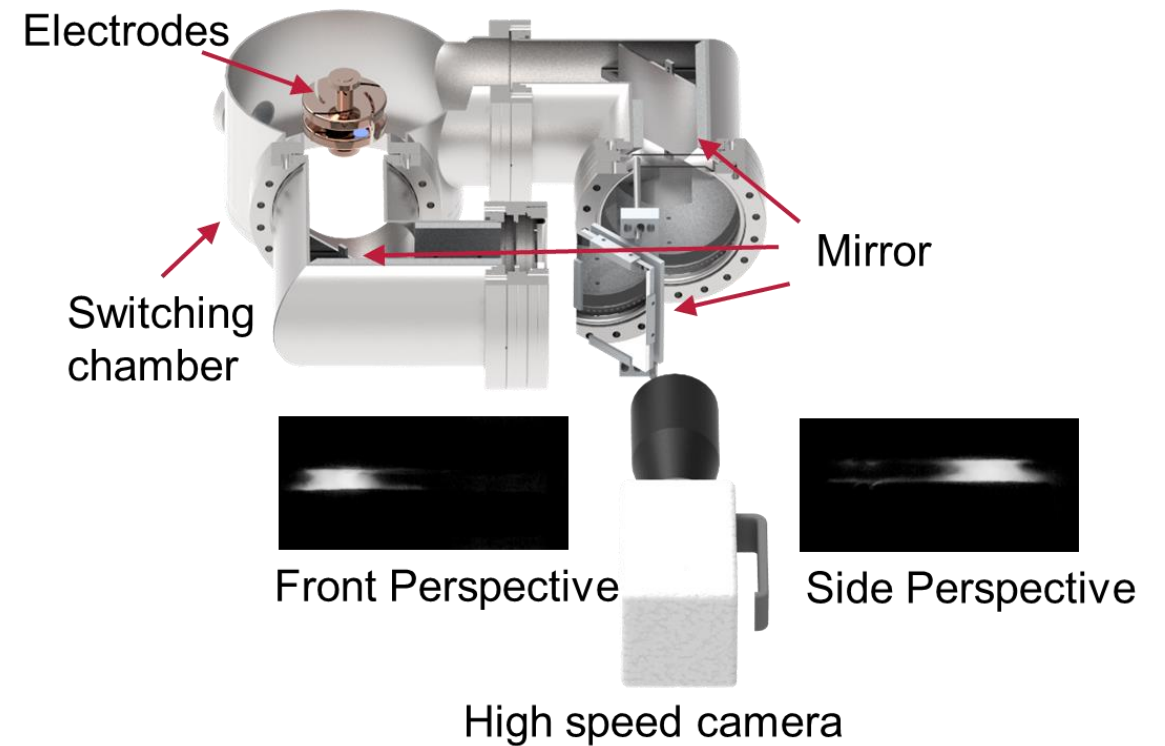
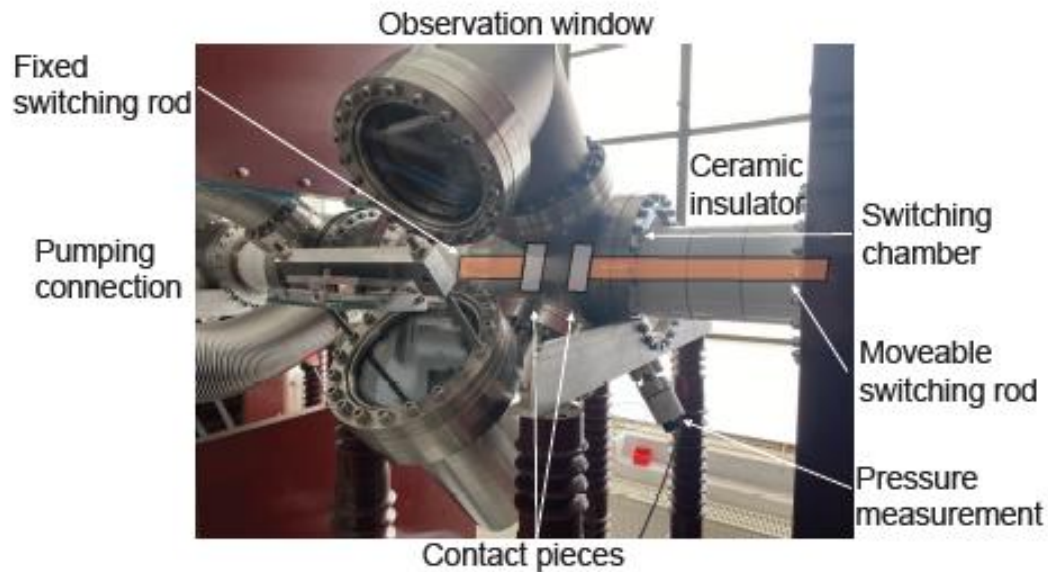
- Current interruption with TMF and AMF-contacts
- Electrical data measurement
 - Shunt for short circuit current
 - Voltage probe for arc voltage
 - Potentiometer for gap



Setup

Optical examination: 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)

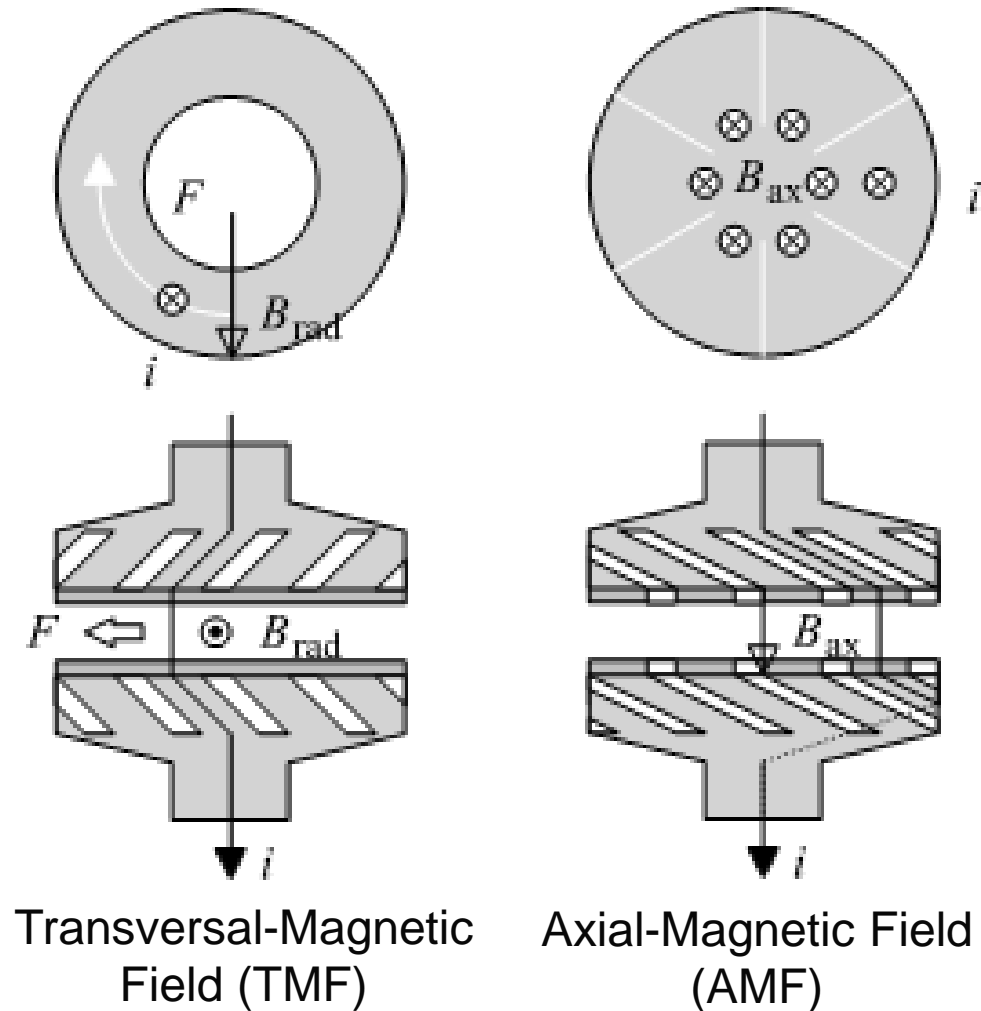


3 Arc dynamics

Arc dynamics

Electrode design

- Butt contacts have high contact erosion
- Reducing contact erosion by contact design
- Two contact designs exist:
 - Axial-Magnetic Field (AMF)
 - Transversal-Magnetic Field (TMF)

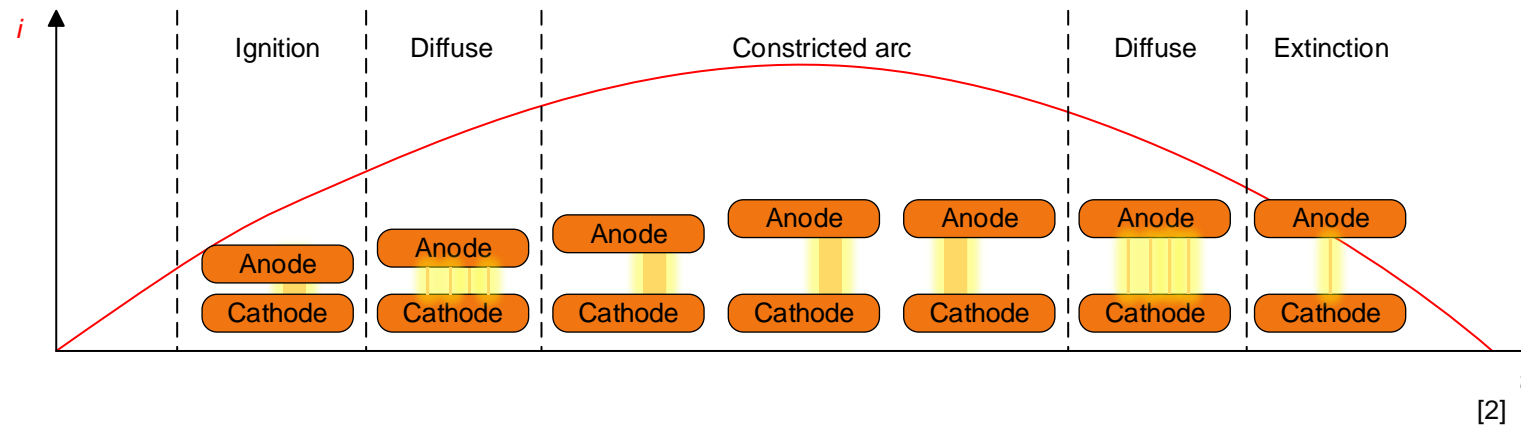
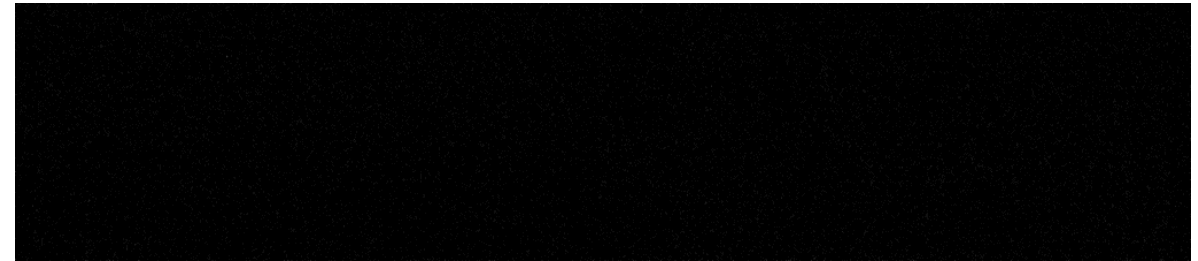


[1]

Arc dynamics

Arc movement with TMF-contacts

- Various arc modes depends on current and gap
- Contact erosion influence by arc mode



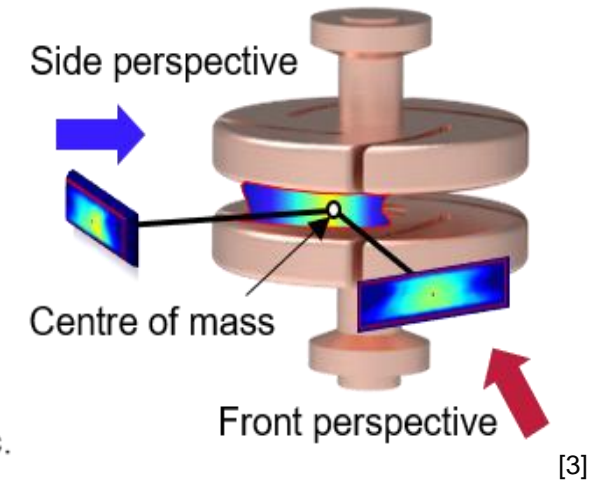
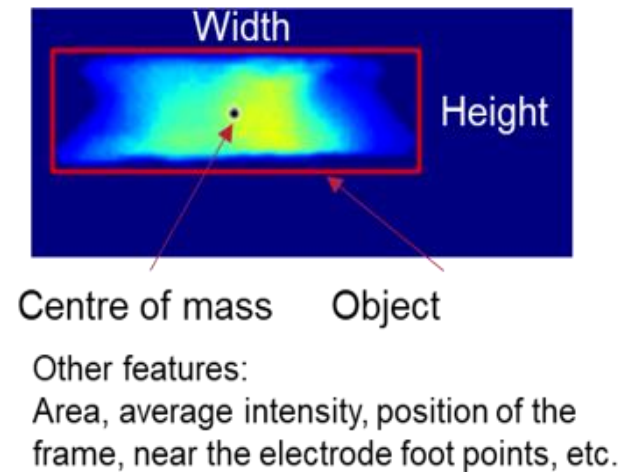
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3.1 Arc movement

Arc dynamics (TMF)

Arc movement

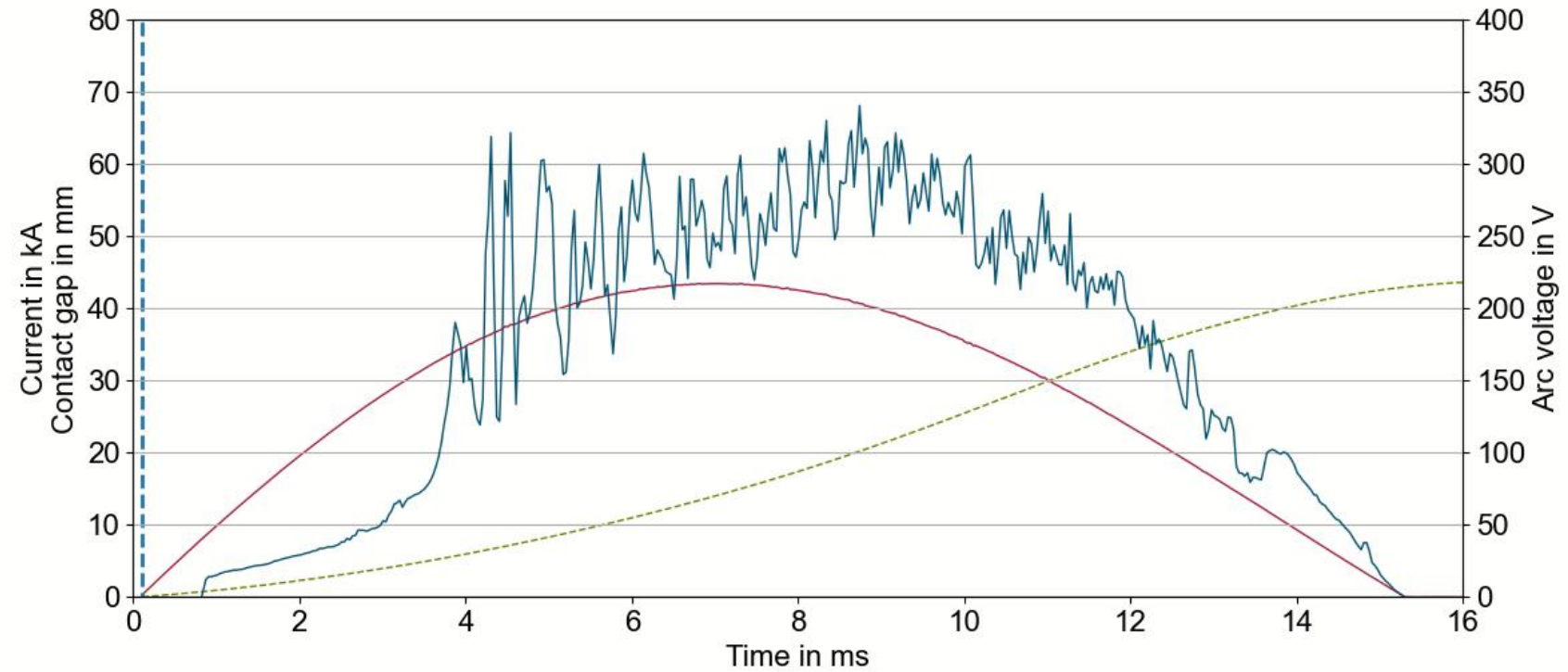
- Arc localisation by two perspective by two perspective
- Determination of arc's centre by optical intensity
- Analyse the movement during the contact separation
 - Number of rotation
 - Arc speed
- Automated evaluation with Python



Arc dynamics (TMF)

Arc movement

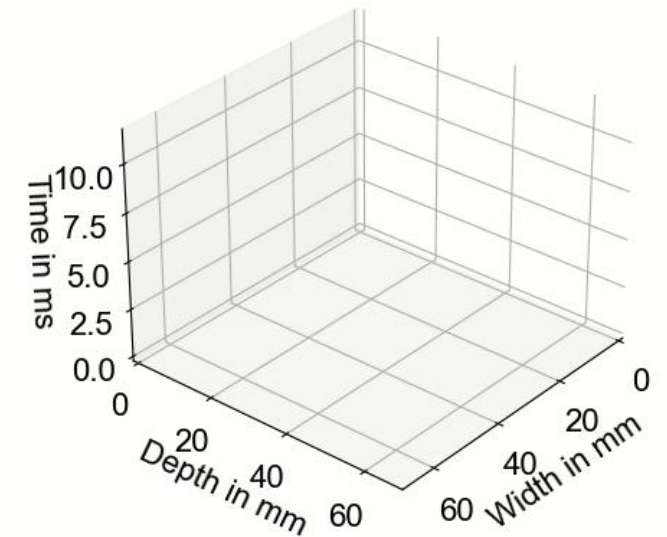
- 31,5 kA rms & 44 mm at 35 Hz
- equipped with CuCr35



Width Perspective



Depth Perspective

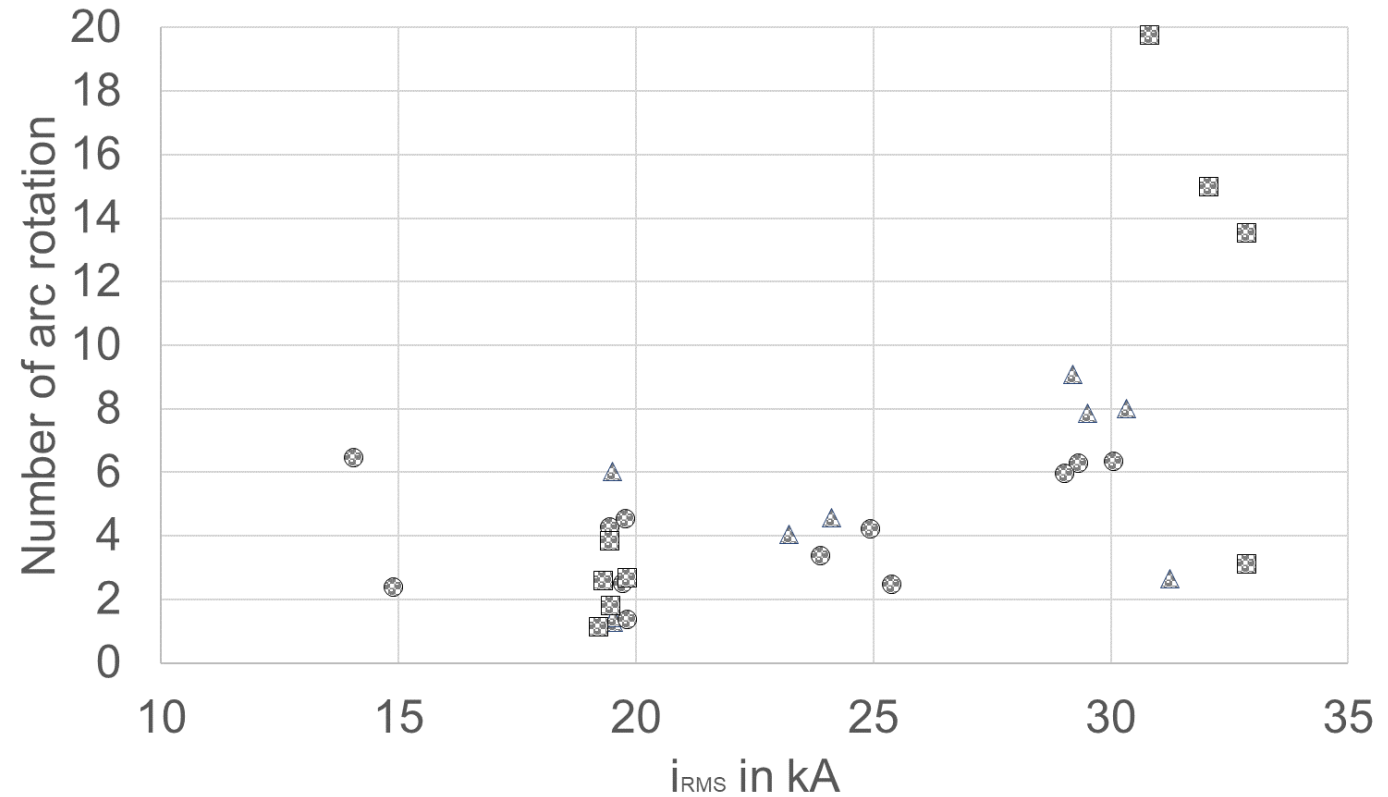
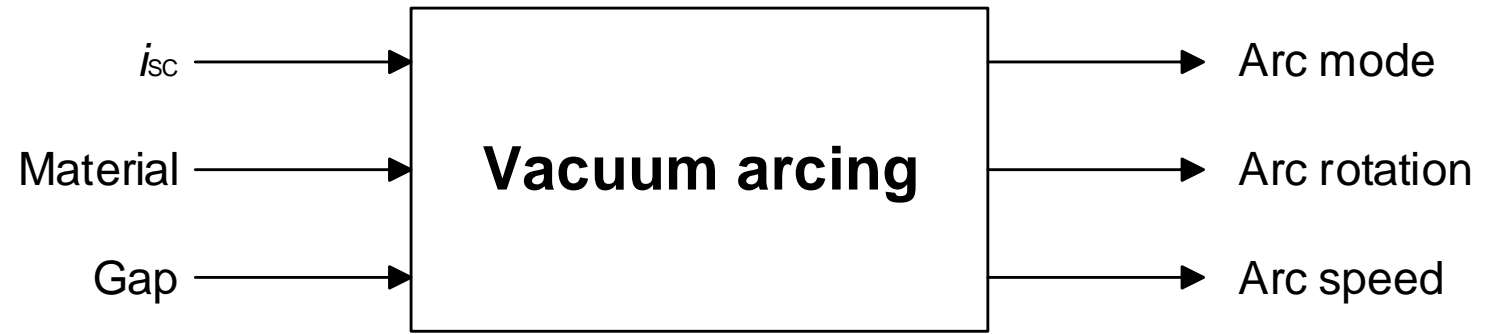


Arc dynamics (TMF)

Arc movement

- Arc rotation and speed influence by different parameters

Factors			Responses	
isc in kA	Gap	Material	No. of arc rotation	V _{arc} in m/s
31.5	20	CuCr25	6.90±2.51	228.00±22.97
31.5	30	CuCr25	6.20±0.19	183.18±1.13
31.5	45	CuCr25	16.09±3.07	240.36±13.33



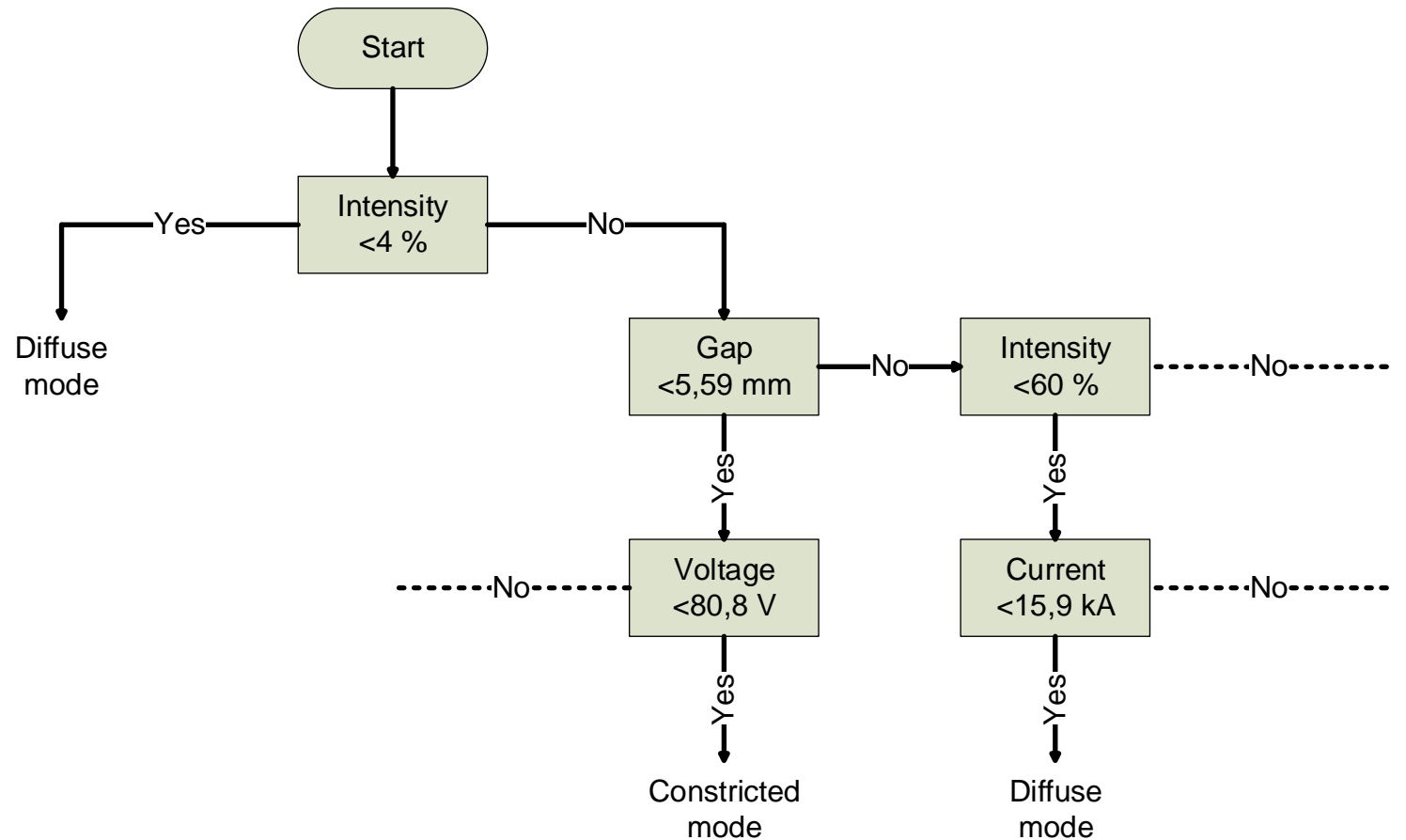
▲ 20 mm ● 30 mm ■ 45 mm

3.2 Arc mode

Arc dynamics (TMF)

Arc mode identification

- Decision tree for arc modes
 - Optical data
 - Electrical data
- Criteria:
 - Short-circuit current
 - Arc voltage
 - Gap
 - Optical intensity
- Automated evaluation by Python

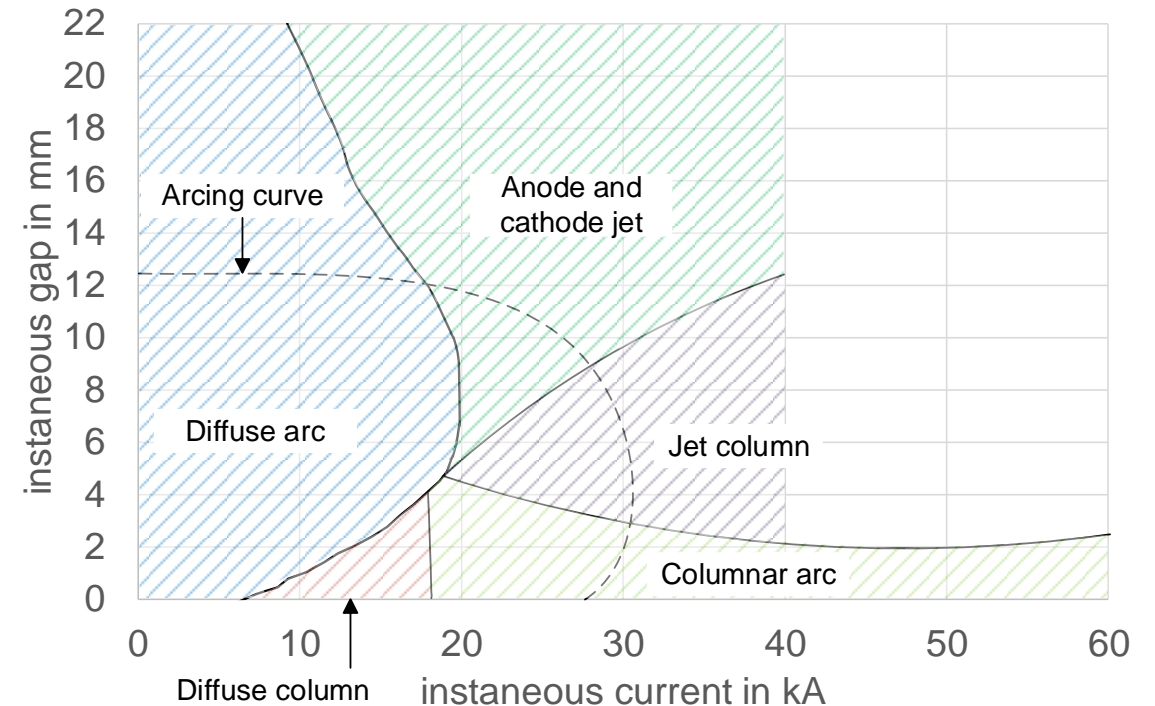


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Arc mode (TMF)

Arc appearance diagram

- The arc appearance diagram used to classify the arc mode by gap and current
- Aim
 - Determination of the required mode (avoidance of strong contact erosion)
 - Additional examination of the trajectories to investigate the higher gaps
 - Reducing of contact erosion by using the correct trajectory

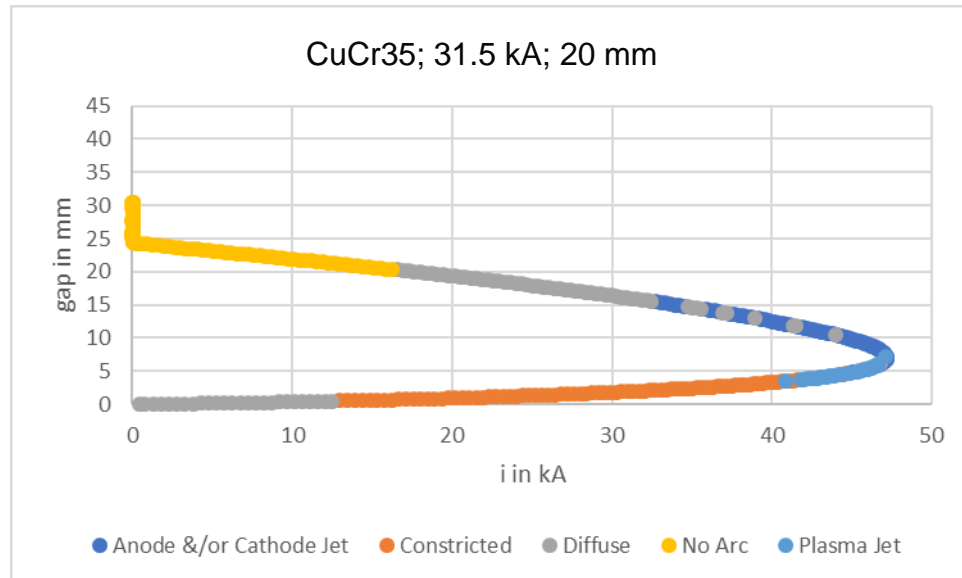


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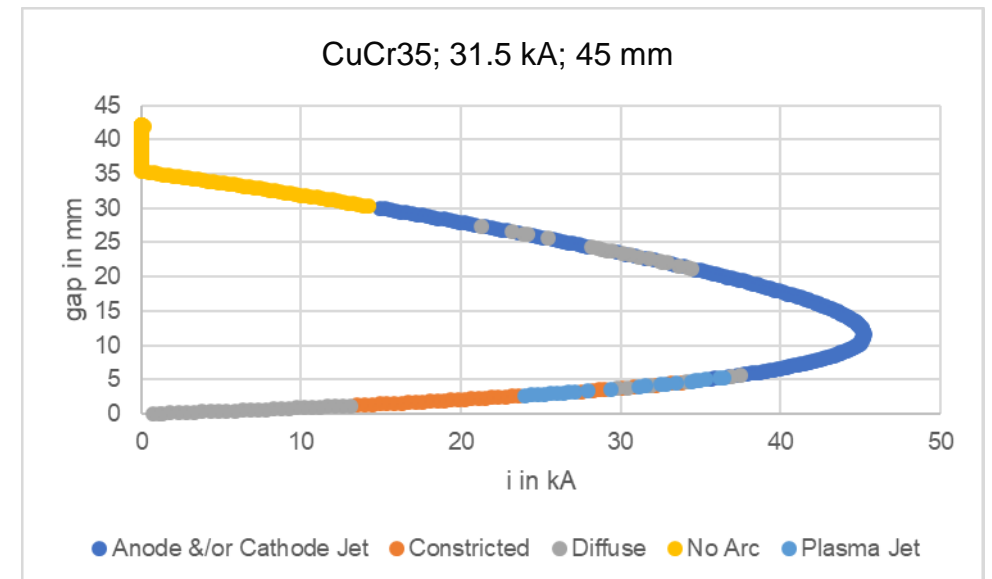
Arc mode (TMF)

Arc appearance diagram by each frame

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



Jet: 50.0 %
Constricted: 23.3 %



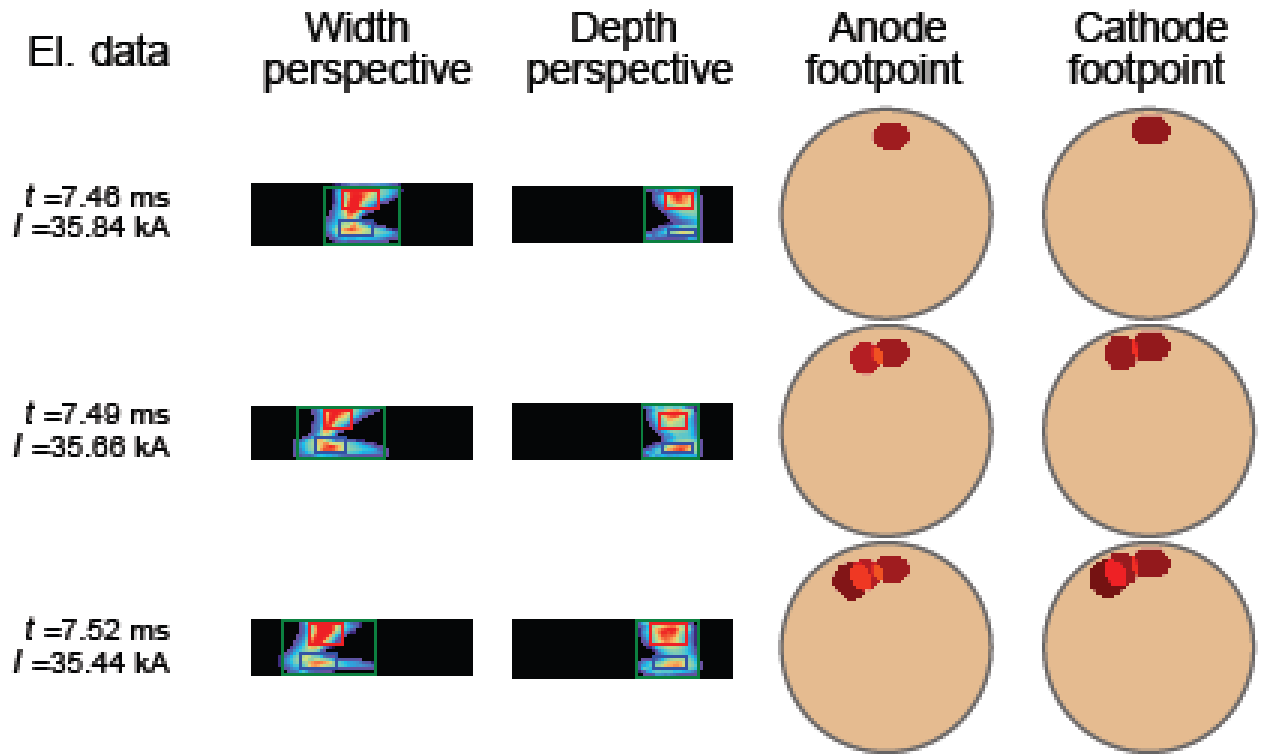
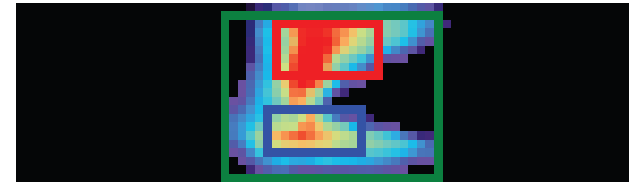
Jet: 64.7 %
Constricted: 12.8 %

3.3 Contact erosion

Arc dynamics (AMF & TMF)

Contact erosion

- For comparison of contact designs
- Charge input as indicator for contact erosion
- Localisation and current enable hot spots of charge input
- The colour scale is determined by transferred charge
- The individual foot points are superimposed

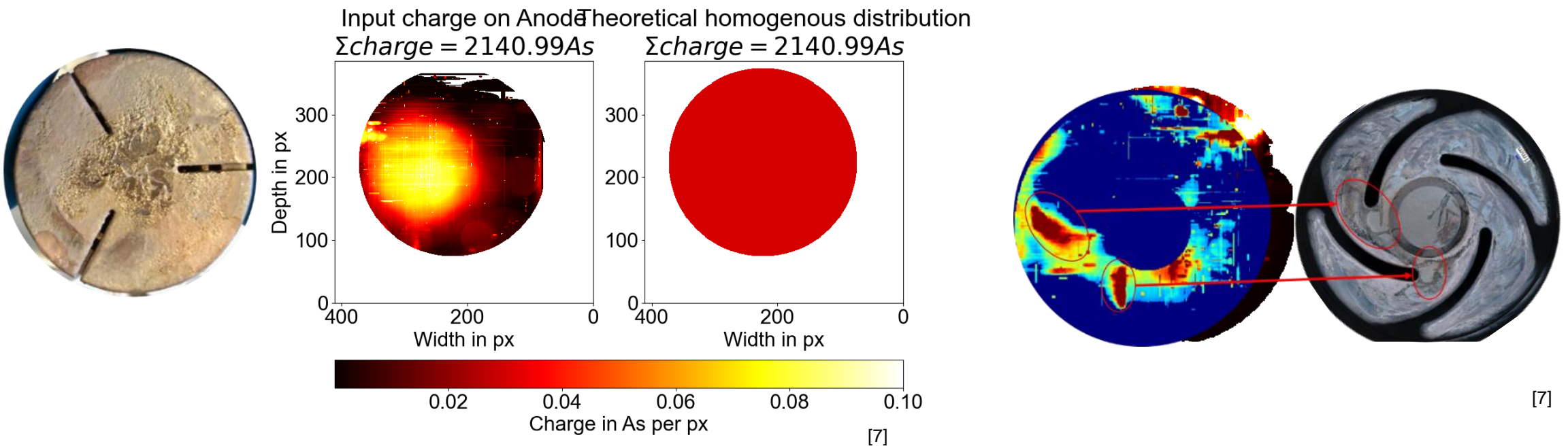


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Arc dynamics (AMF & TMF)

Contact erosion

- AMF
 - Even distribution of diffuse arc
- TMF:
 - Hot spots on the surface detectable



4 Conclusion and outlook

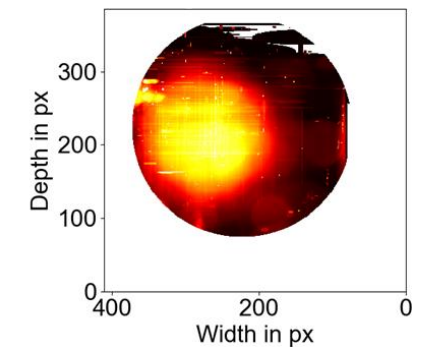
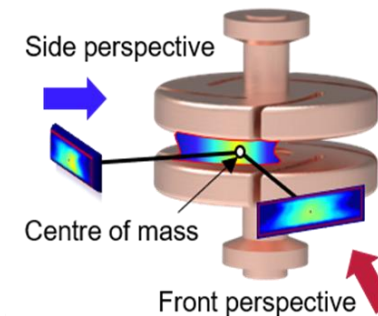
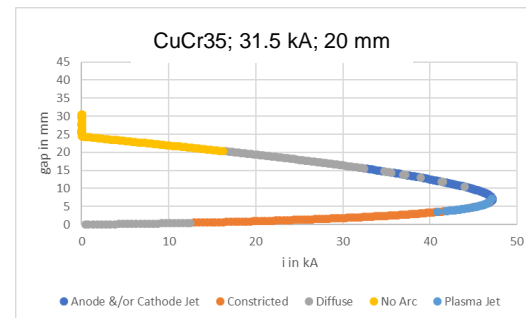
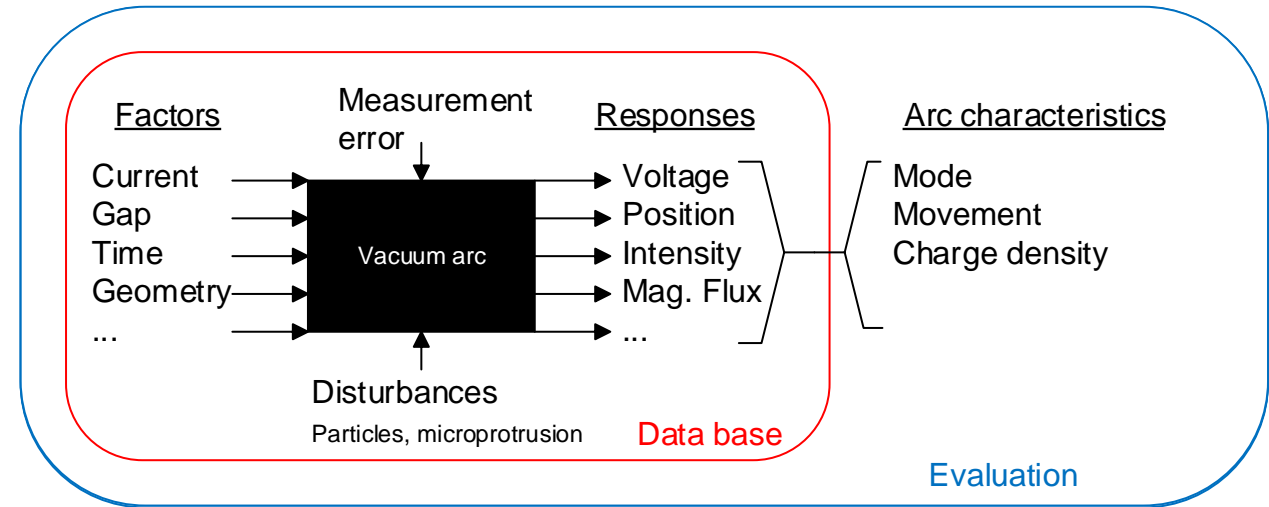
Conclusion and Outlook

Conclusion

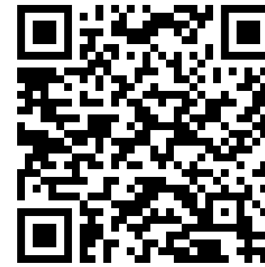
- Black box modelling
 - Description by regression
 - Data base
- Measurements can statistical describe arc characteristics

Outlook

- Other parameters will be checked:
 - Conductivity
 - Arc energy
 - Post-arc current
- Next Updates on ISDEIV 2025



Contact



List of publication



CV



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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 (Selection)

- 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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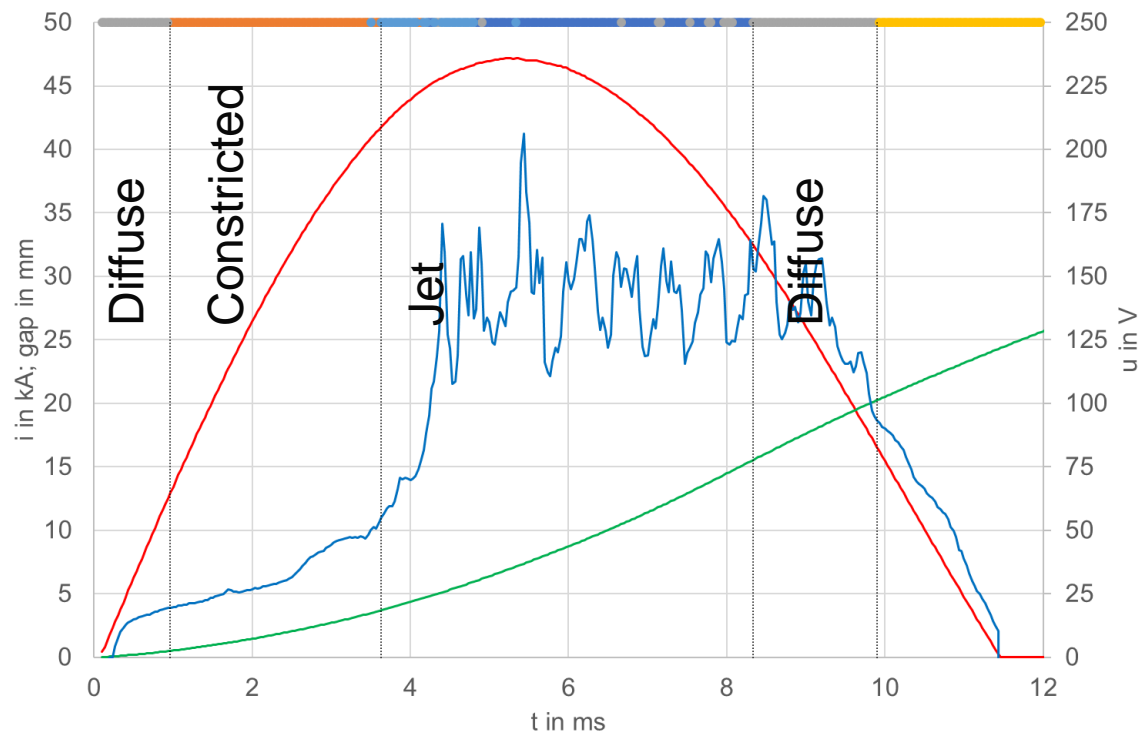
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- [2] Ito, Hiroki: Switching equipment; Cham, Switzerland: Springer, 2019.
- [3] Dorsch C. et. al.: Cross validation of magnetic and optical localization methods for rotating vacuum arcs. 30th International Symposium on Discharges and Electrical Insulation in Vacuum (ISDEIV). Okinawa, Japan, 2023.
- [4] Slade, Paul G.: The Application of Vacuum Interrupters in HVDC Circuit Breakers, *IEEE Trans. Plasma Sci.*, 2022.
- [5] Heberlein, J. V. R.; Gorman, J. G.: The High Current Metal Vapor Arc Column between Separating Electrodes, *IEEE Trans. Plasma Sci.*, 1980.
- [6] Weber, Benjamin: Automated Multivariate Analysis of Vacuum Arcs between TMF-Contacts; Ph. Thesis; Braunschweig, 2024.
- [7] Meyer, Timo; Gentsch, Dietmar; Michael, Kurrat: Vacuum Contacts: Analysing Contact Lifespan for Enhanced Performance in Grids, 28th Conference and Exhibition on Electricity Distribution (CIRED 2025), Geneva, Switzerland, 16 – 19 June, **not published yet**

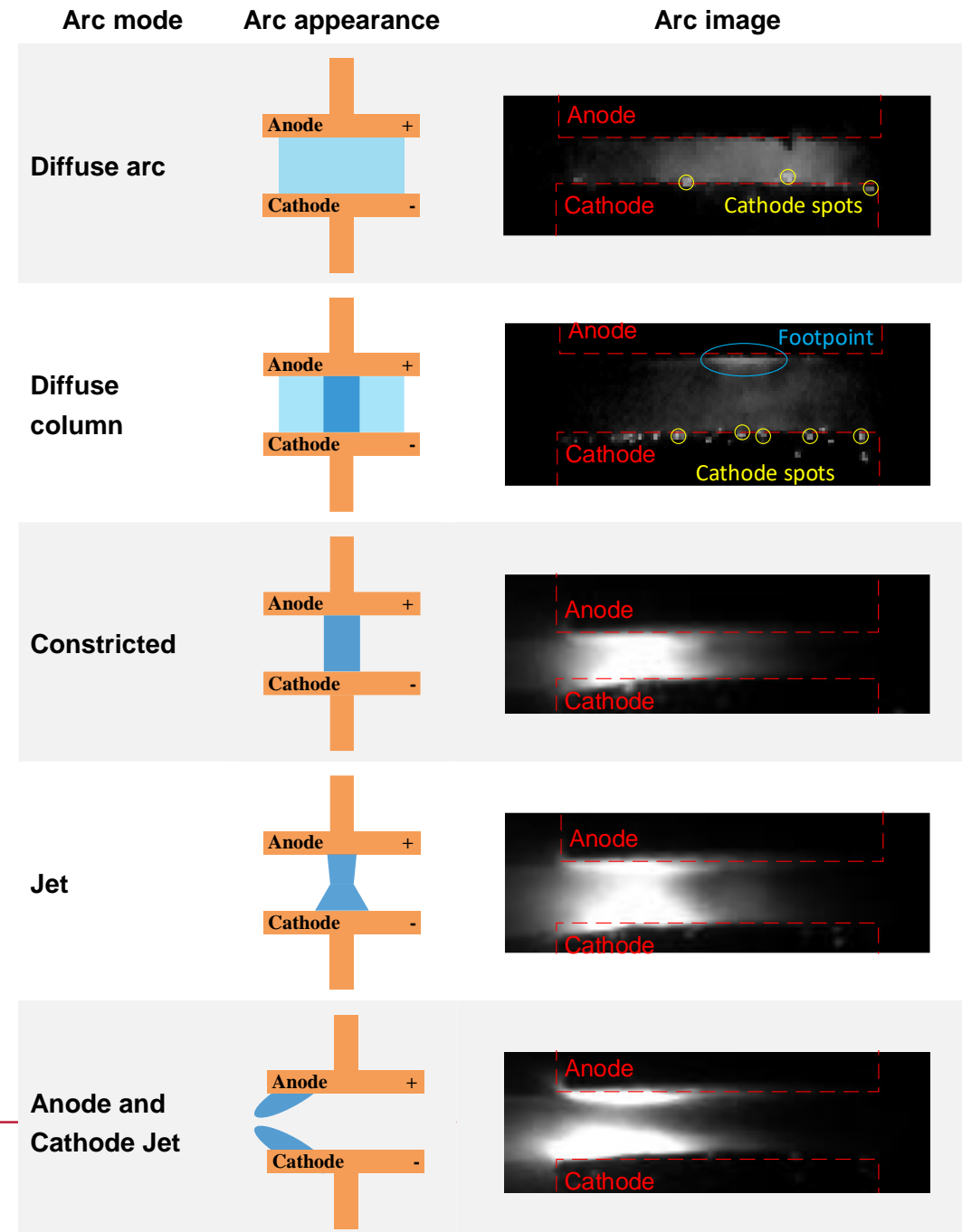
A Appendix

Arc mode

- During the arcing phase different modes are detectable with High-Speed-Camera
- The arc mode influences the contact erosion and the resulting lifespan



parameters for classifying arc mode and movement



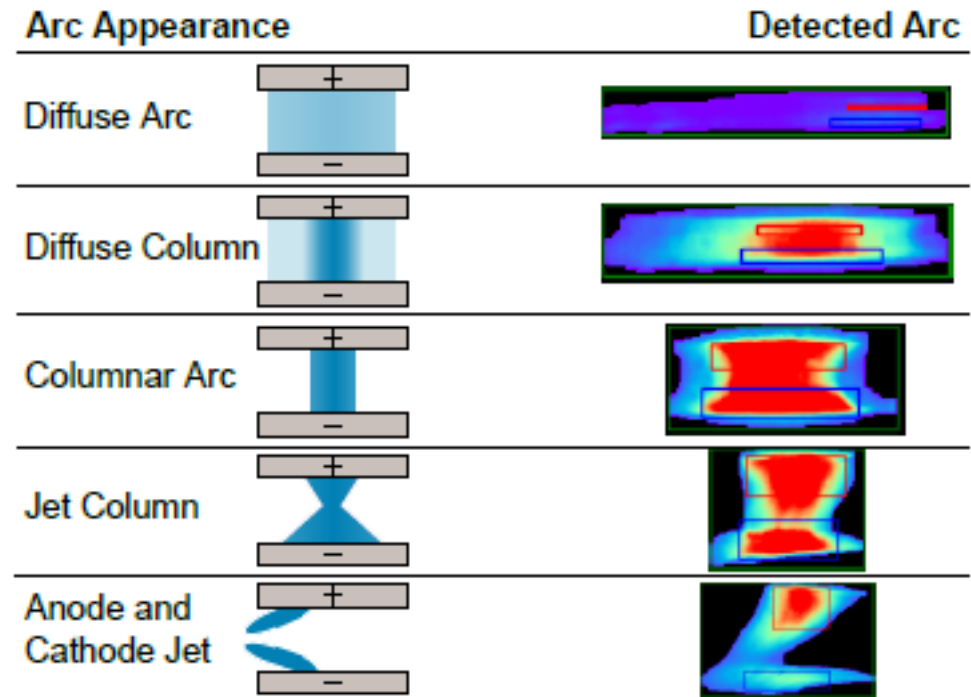


Figure 4.4: Examples of every arc appearance mode with detected footprints on anode (red) and cathode (blue)

Arc mode

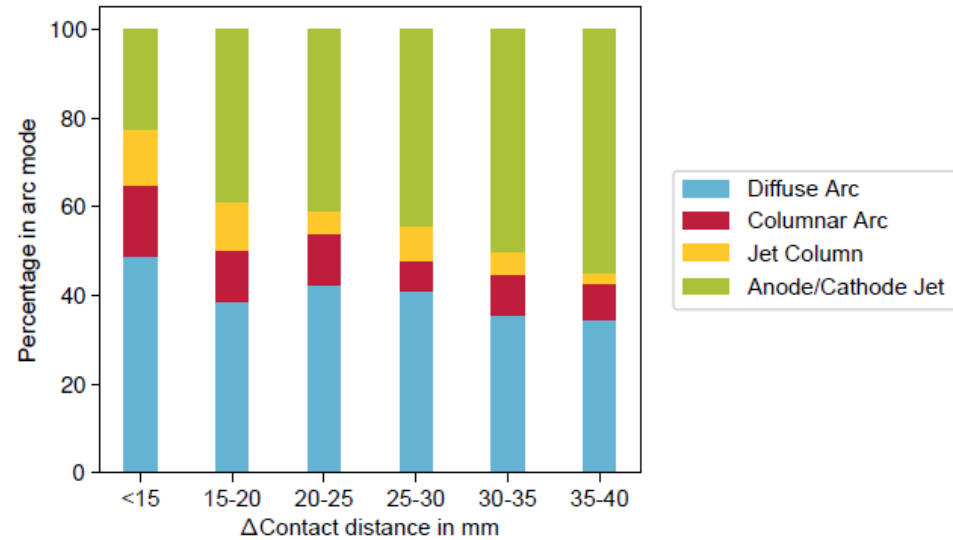


Figure 5.17: Percentages in four main arc modes in dependence of traveled contact distance (in averaged groups) at various currents during active arcing phase

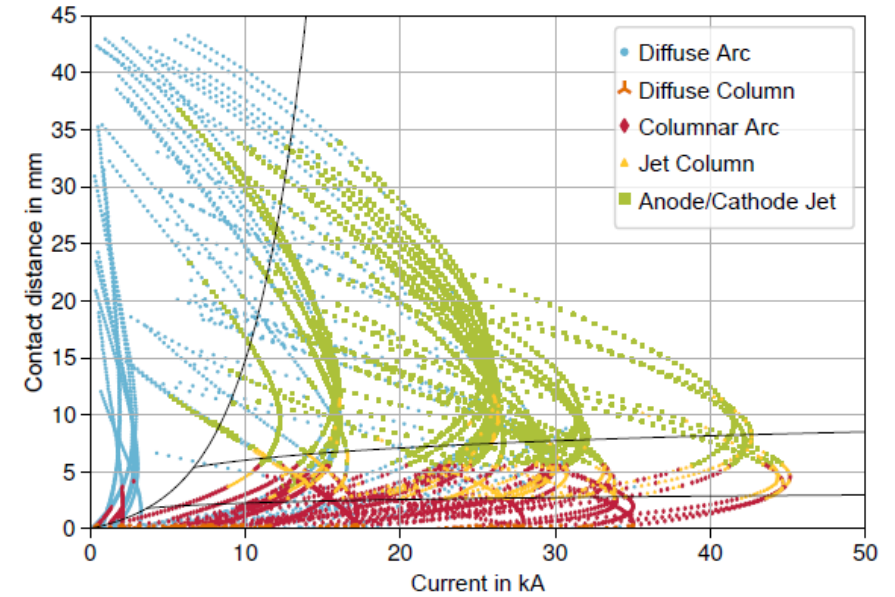


Figure 5.15: Arc existence diagram with detected modes based on machine learning algorithm applied on 52 tests; CuCr25 contact pieces with 68 mm diameter

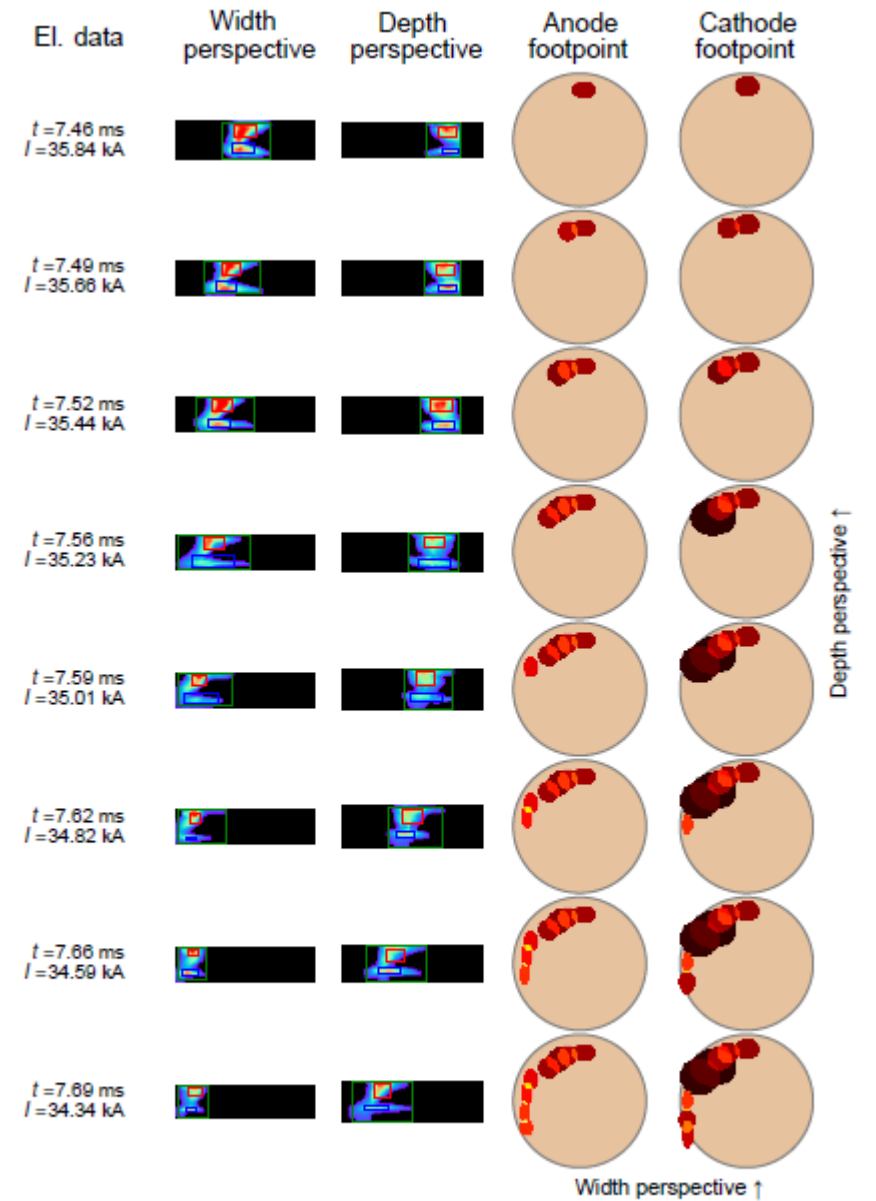


Figure 5.18: Visualization of 8 consecutive high-speed images, the determined footprint movement on contact surface and corresponding current