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Vacuum interrupters equipped with TMF contacts and contact material different from each other; A study under short circuit current conditions and high-speed arc observation during current interruption

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Vacuum Interrupter equipped with TMF contacts

Overview

- **Introduction**
- **Vacuum interrupter principle**
  - Basic tasks and design of vacuum interrupter and simulation
  - Motivation and function description of arc movement
  - Study under short circuit current conditions
  - Contacts and contact material different
  - High-speed arc observation during current interruption

  Technical data and test results
  - Technical details of surface layer
  - Final principle in practice
  - Practice application and final practise
- **Summary**

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Vacuum Interrupter families type series VS. . , VG . ., UFES

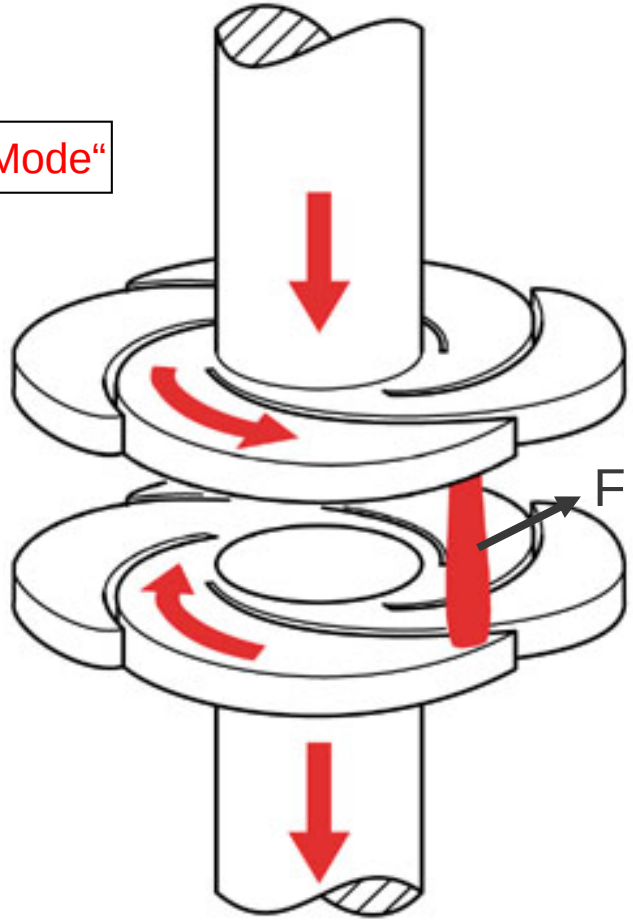
Introduction

Wide range and multipurpose vacuum interrupter family, maintenance free, robust, compact and optimized vacuum interrupter the VG- and VS- series for ratings from 1 - 52 kV and 4 - 85 kA for low and medium voltage switchgear application.

Vacuum Interrupter equipped with TMF contacts

Introduction

„TMF – Mode“



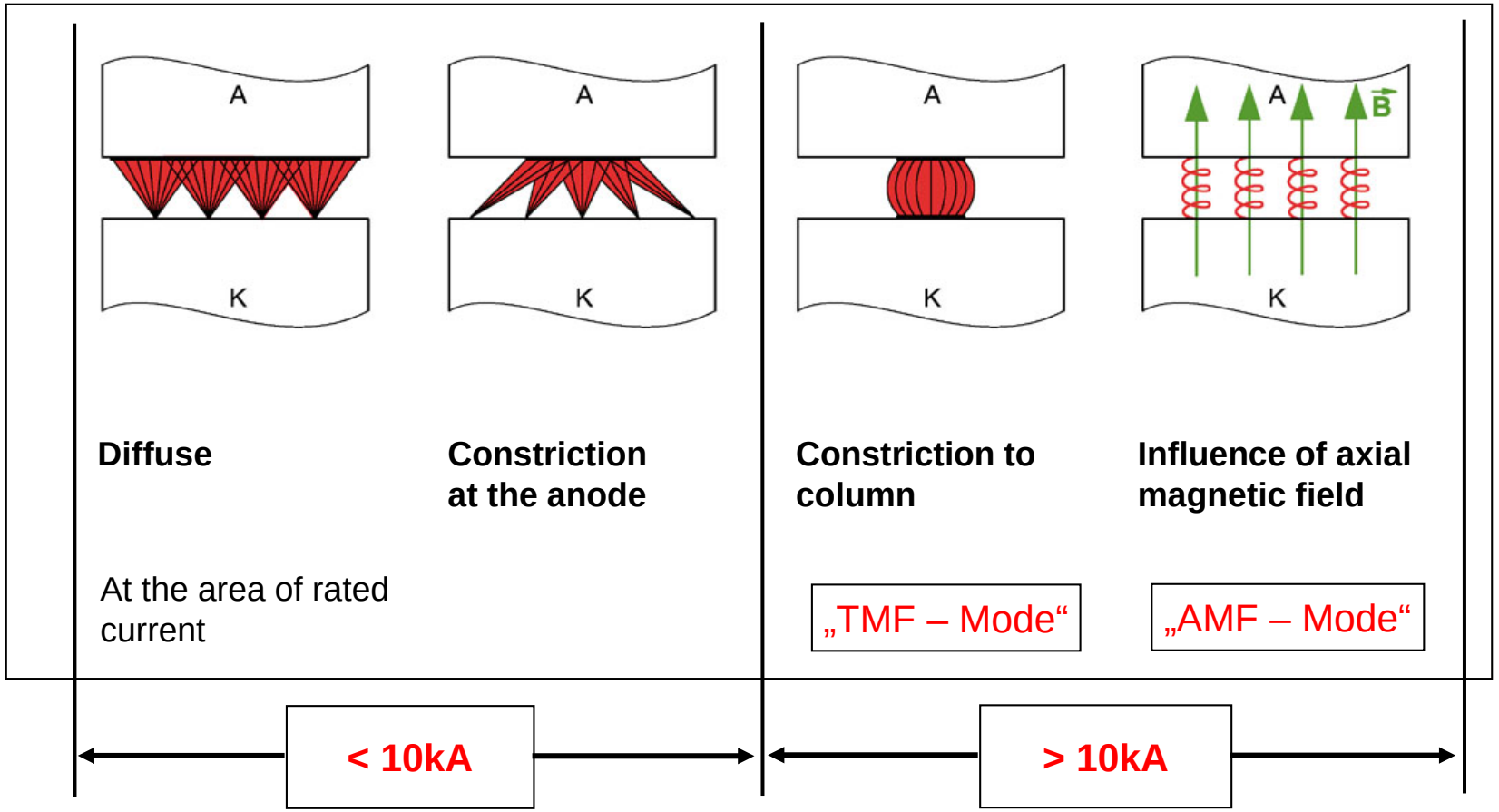
Spiral contact material (based on CuCr)

Function of the TMF contact sytem*:*

- The current path extended.
- Based on the current path there occur a magnetic force.
- Within the system only the “vacuum arc” moves and rotate inside the contact gap.
- Rotating column arc, to reduce the thermal local load at the contact surface.

Vacuum Interrupter equipped with TMF contacts

Introduction



Schematic illustration of the different mode of the vacuum arc

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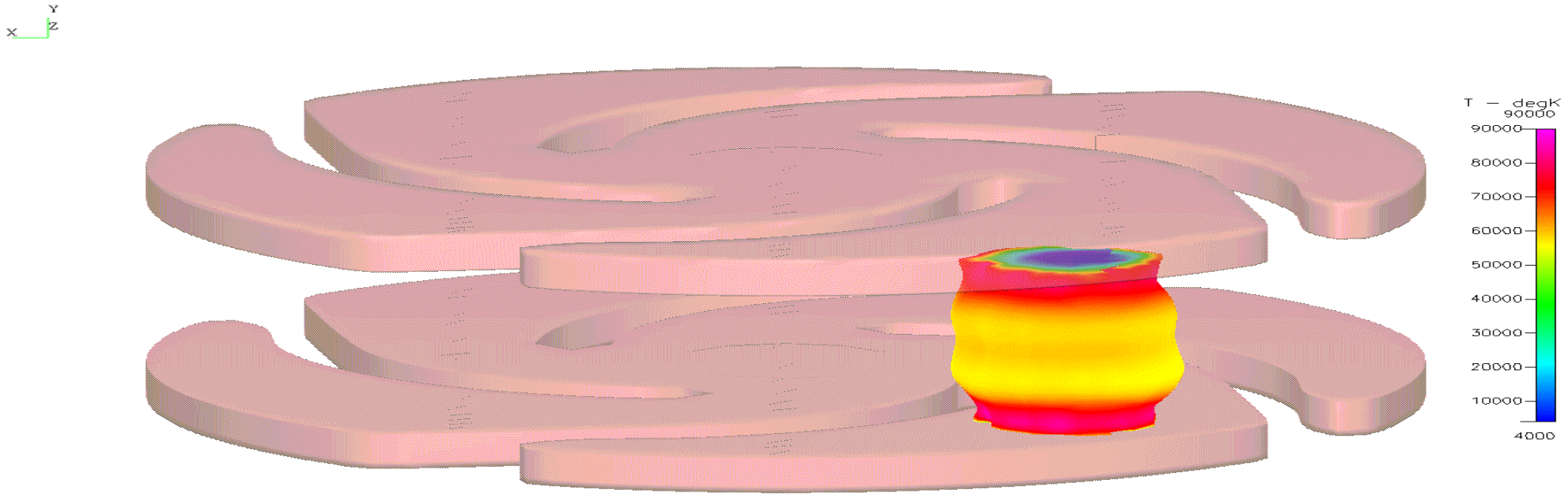
Vacuum Interrupter equipped with TMF contacts

Basic tasks and design of vacuum interrupter and simulation

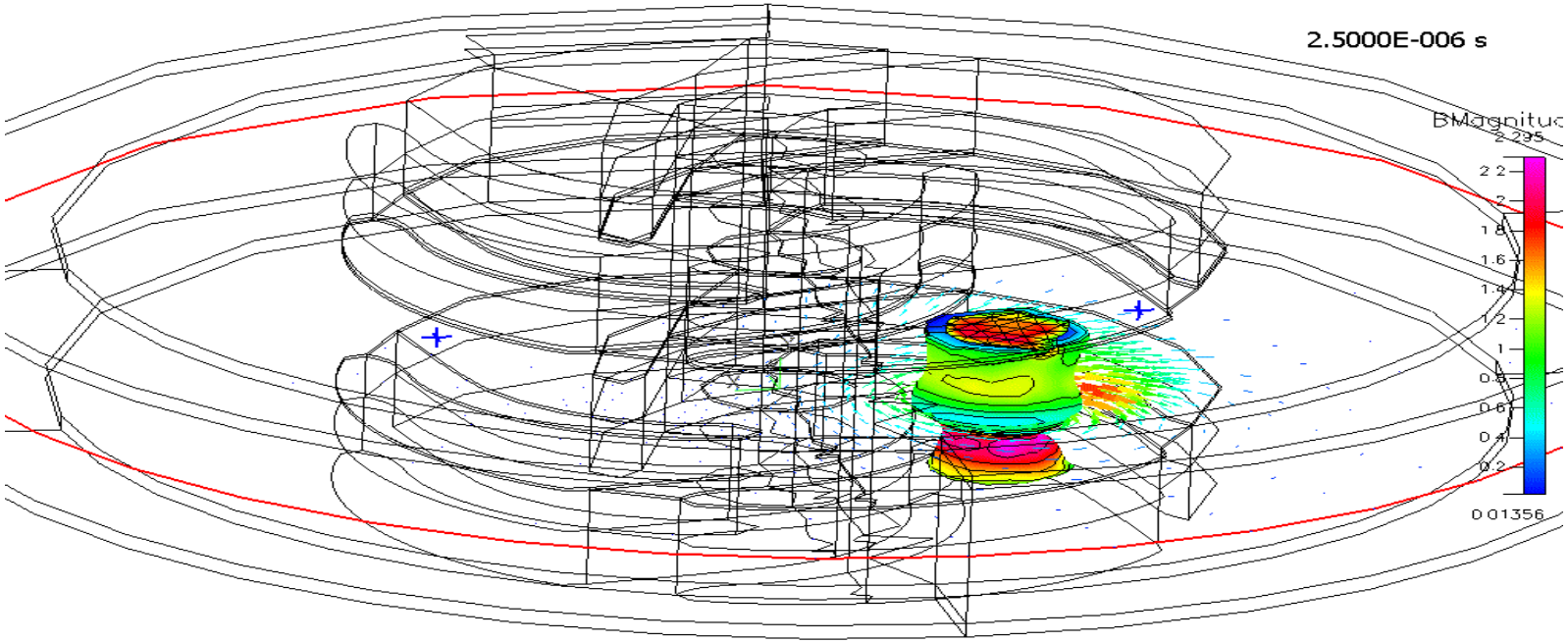


3D – Simulation of TMF arc at 25kA:

- **Stepwise movement of vacuum arc, time step 1ms**
- **Overcome of contact gap, at contact distance 10mm**

Vacuum Interrupter equipped with TMF contacts

Basic tasks and design of vacuum interrupter and simulation



3D – Simulation of TMF arc at 40kA:

- **B – field direction and size, temperature not shown.**
- **Stepwise movement of vacuum arc, time step 1ms**
- **Overcome of contact gap, at contact distance 10mm**

Vacuum Interrupter equipped with TMF contacts

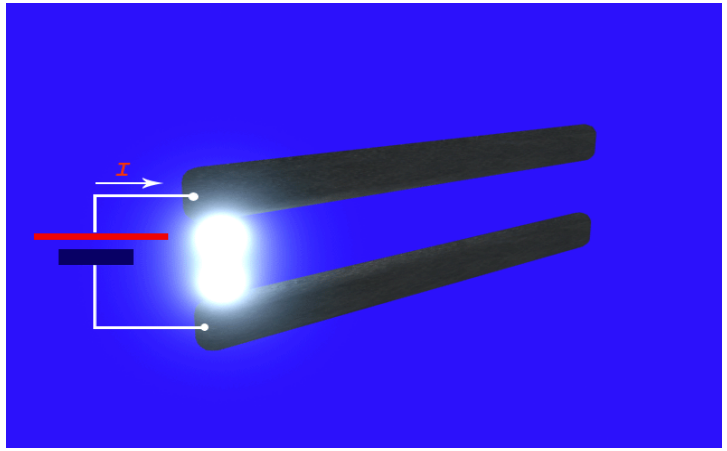
Basic tasks and design of vacuum interrupter and simulation

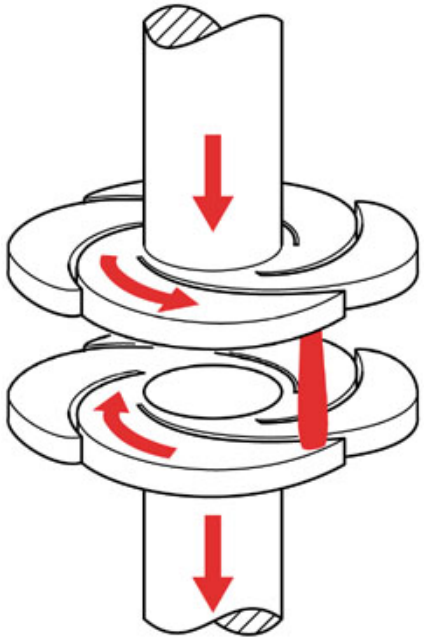
„TMF – Mode“

Radial magnetic field

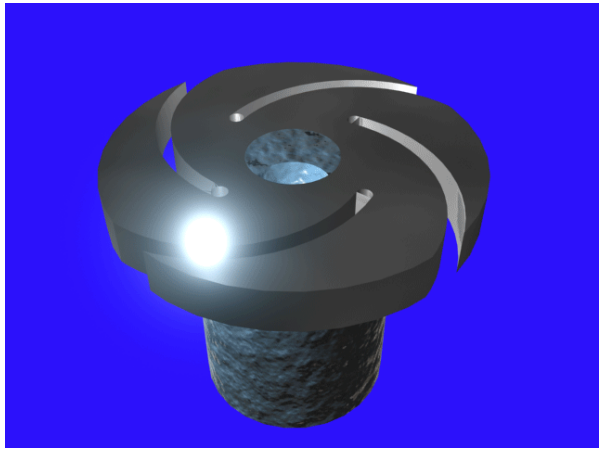
Transverse Magnetic Field (TMF) contact arrangement

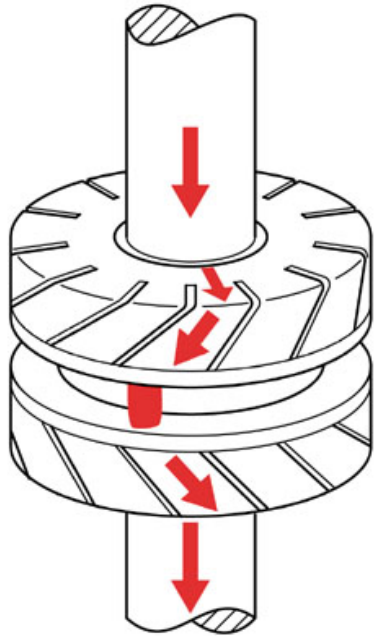
Basic principle
of constricted arc movement





Spiral contact





Cup contact

Vacuum Interrupter equipped with TMF contacts

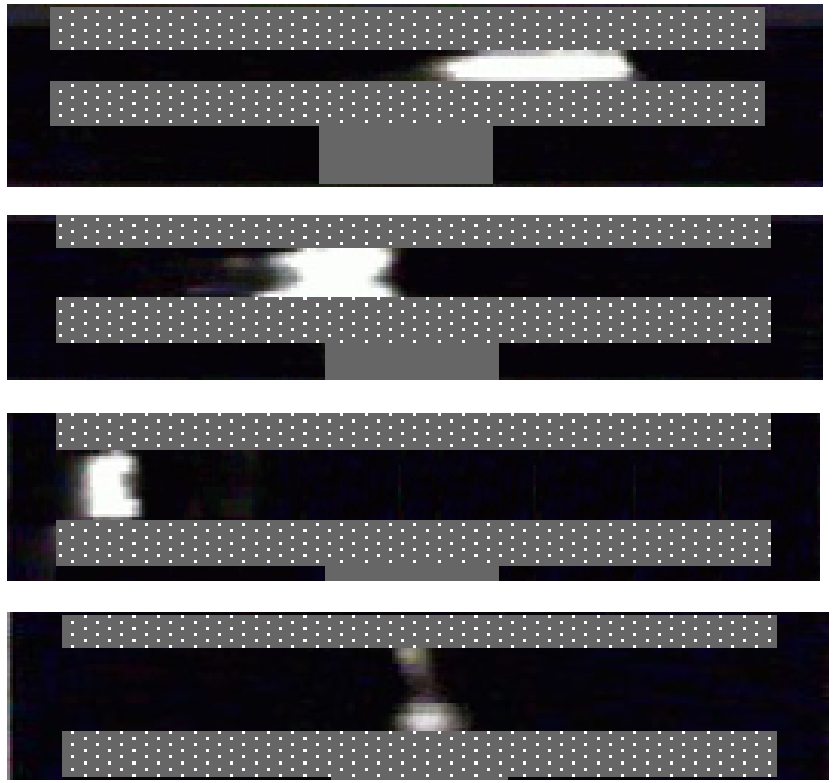
Basic tasks and design of vacuum interrupter and simulation

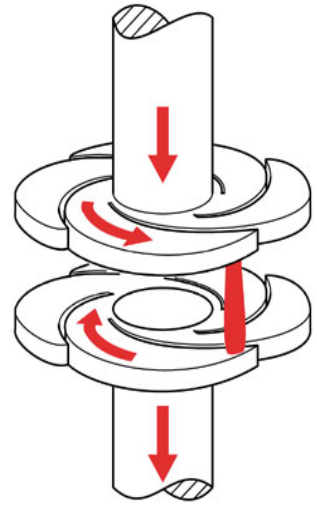
Radial magnetic field Transverse Magnetic Field (TMF) contact arrangement

„TMF – Mode“

- Typical appearance of a constricted vacuum arc

- 1. Arc, small contact distance
  (2 ms after contact separation)
- 2. Arc, higher contact gap
  (6 ms)
- 3. Arc, full open gap
  (8 ms)
- 4. Arc after (12 ms)



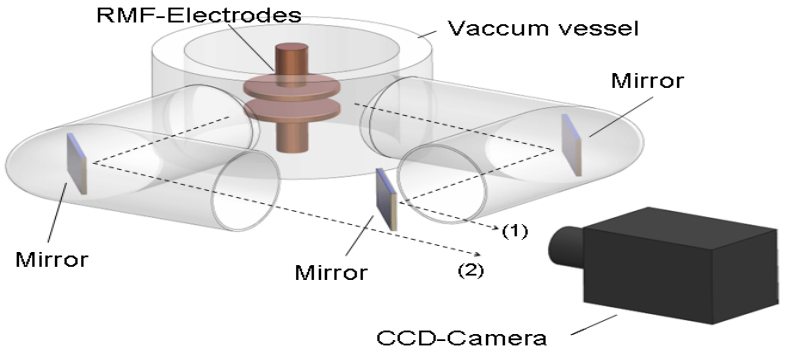


Vacuum Interrupter equipped with TMF contact

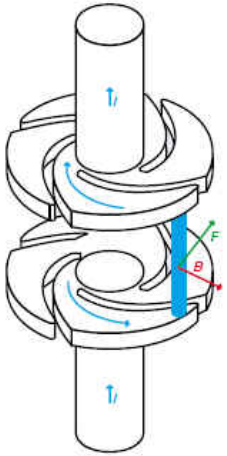
Motivation and function description of arc movement

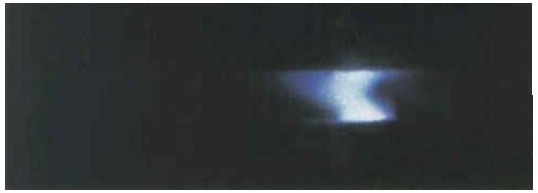
Video sequence of a short-circuit interruption

(under TMF condition)

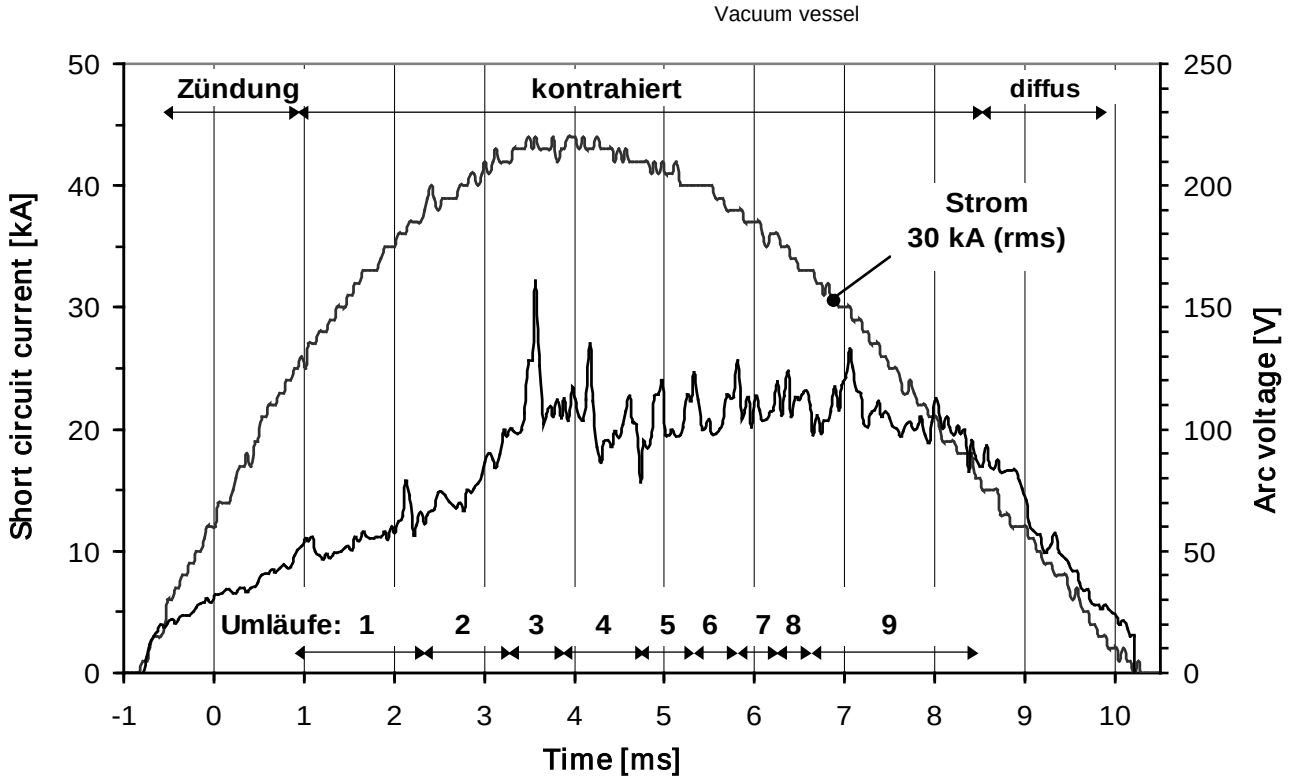


- **Short circuit current: 30 … 40kA**
- **Contact diameter: 68 mm**
- **Contact gap (open position): 10 mm**





Rotating column arc, to reduce the thermal local load at the contact surface



Vacuum Interrupter equipped with TMF contacts

Motivation and function description of arc movement

Video sequence of a short-circuit interruption

(under TMF condition)

- **Short circuit current: 30 … 40 kA**
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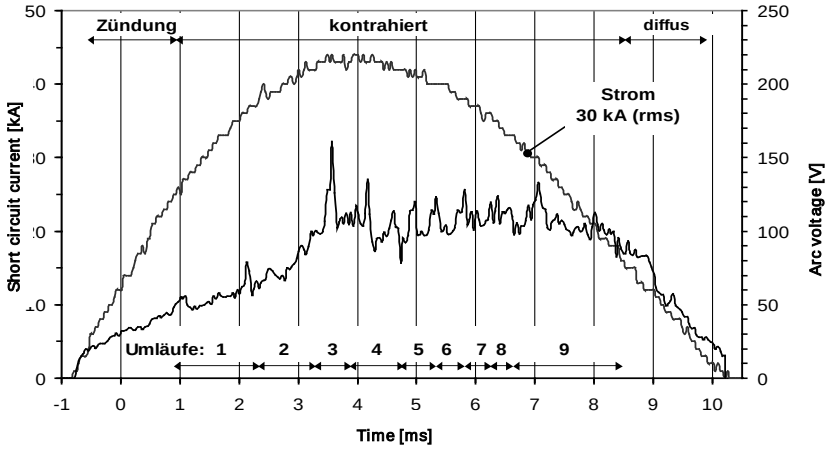

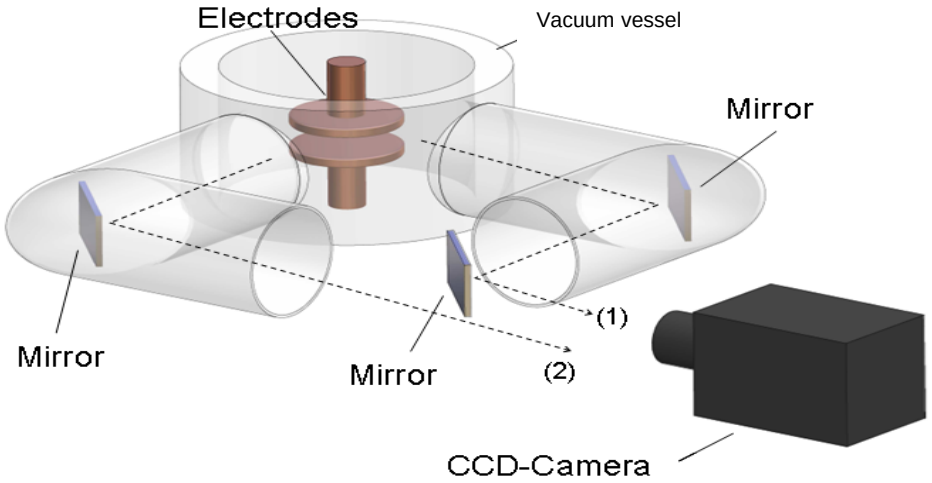

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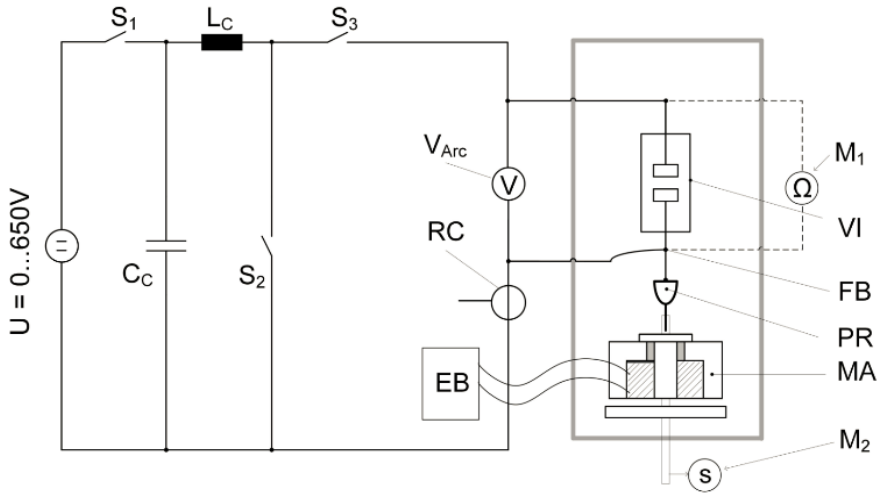
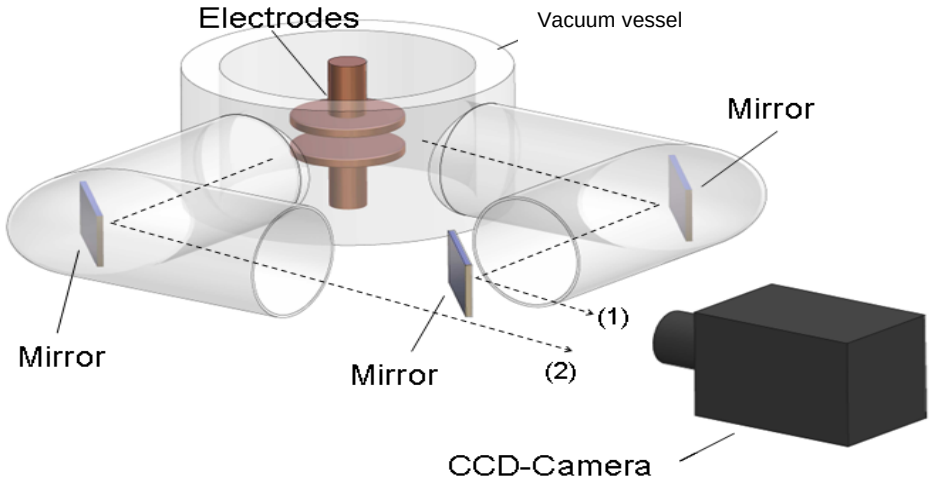
Vacuum Interrupter equipped with TMF contacts

Study under short circuit current conditions

Circuit diagram of the synthetic test circuit with the high current source at the test set-up vacuum vessel:





- At the high current source the DC power supply is max. U: 650 V.
- The vacuum interrupter (VI) vessel is driven downward by the magnetic actuator (MA) and the control unit (EB).
- The insulation push rod (PR); the current flow is established by providing a flexible band (FB) to the movable side of the VI vessel.
- After each operation the resistance of the current path is measured by the M1 device and the resistance after the operation measured by the M2 device.

Schematic of optical setup: electrode pair at arc vessel, optical paths (1) and (2) are recorded side by side in one frame:

- Base to investigate the arc path and by time the velocity of arc.

Vacuum Interrupter equipped with TMF contacts

Study under short circuit current conditions

Each contact pair is tested to a defined sequence with 9 short circuit current steps:

- Resistance measured over the current path at the **start of each step sequence at short circuit current**:

  - 3 operation at 5 kA rms
  - + 3 operation at 8 kA rms
  - + 3 operation at 10 kA rms

  ------ transition from diffuse to constricted arc ------

  - + 5 operation at 15 kA rms
  - + 5 operation at 20 kA rms
  - + 5 operation at 25 kA rms
  - + 5 operation at 30 kA rms
  - + 5 operation at 35 kA rms
  - + 5 operation at 40 kA rms

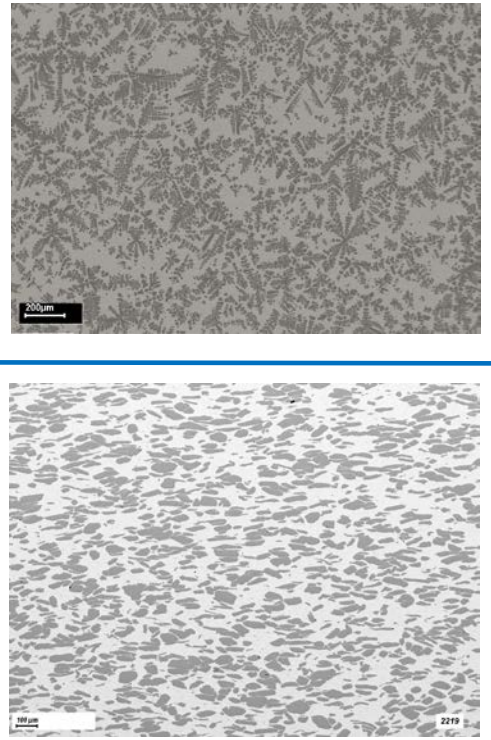
→ In total 39 short circuit interruption operation.

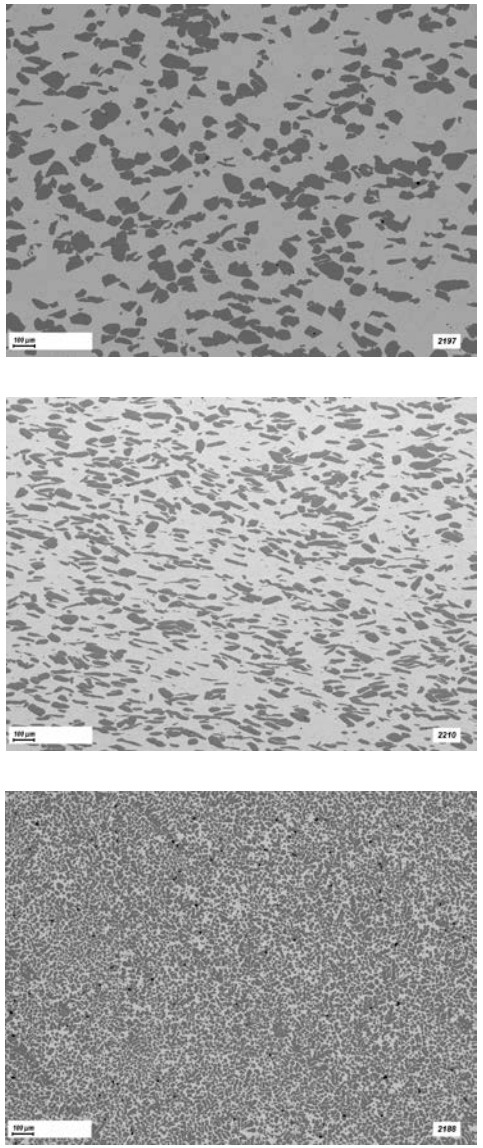
Vacuum Interrupter equipped with TMF contacts

Contacts and contact material different

Investigated material pair to their arc velocity:

Material [wt.%]	Added elements
CuCr 25 (Solid state sintered)	- Standard material (**STS**) -
CuCr 25 (Molten material)	- Standard material **(MM)** -
CuCr 25+ (Solid state sintered)	- plus material **(STS+)** -
CuCr 35+ (Solid state sintered)	- plus material **(STS+)** -
CuCr 50 (Molten material)	- Standard material **(MM)** -





CuCr 25

CuCr 50

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High-speed arc observation during current interruption

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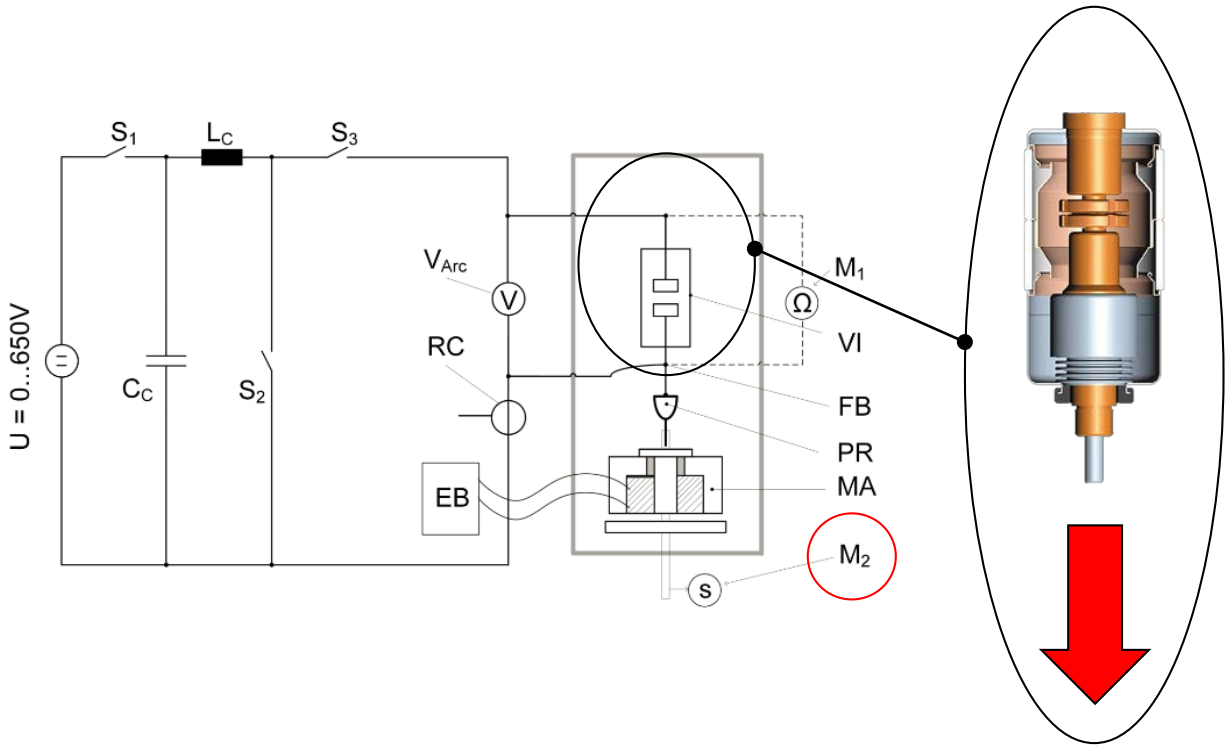
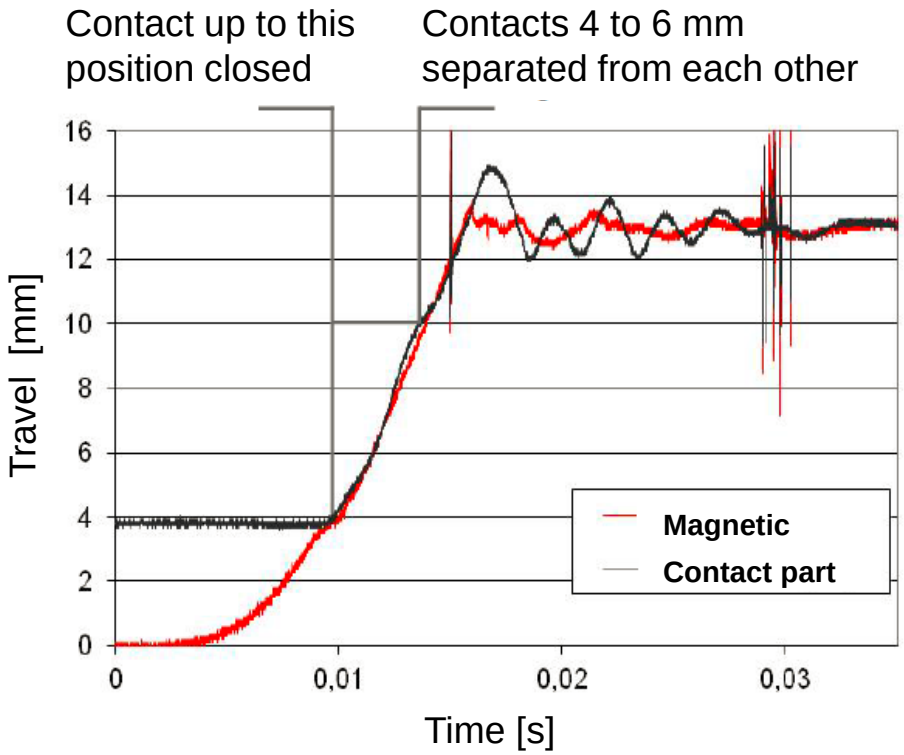


Travel-curve of the mechanical interruption:
Contact part movement of the test switch at vacuum interrupter



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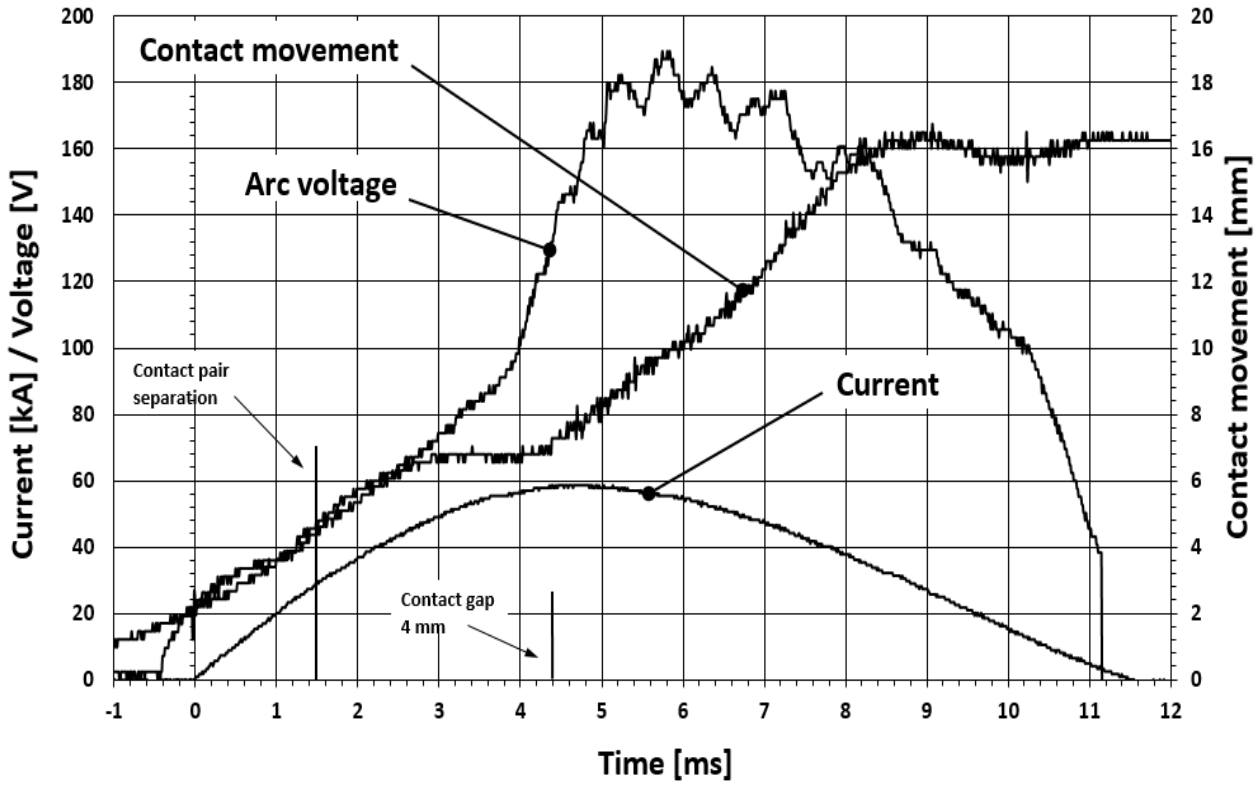
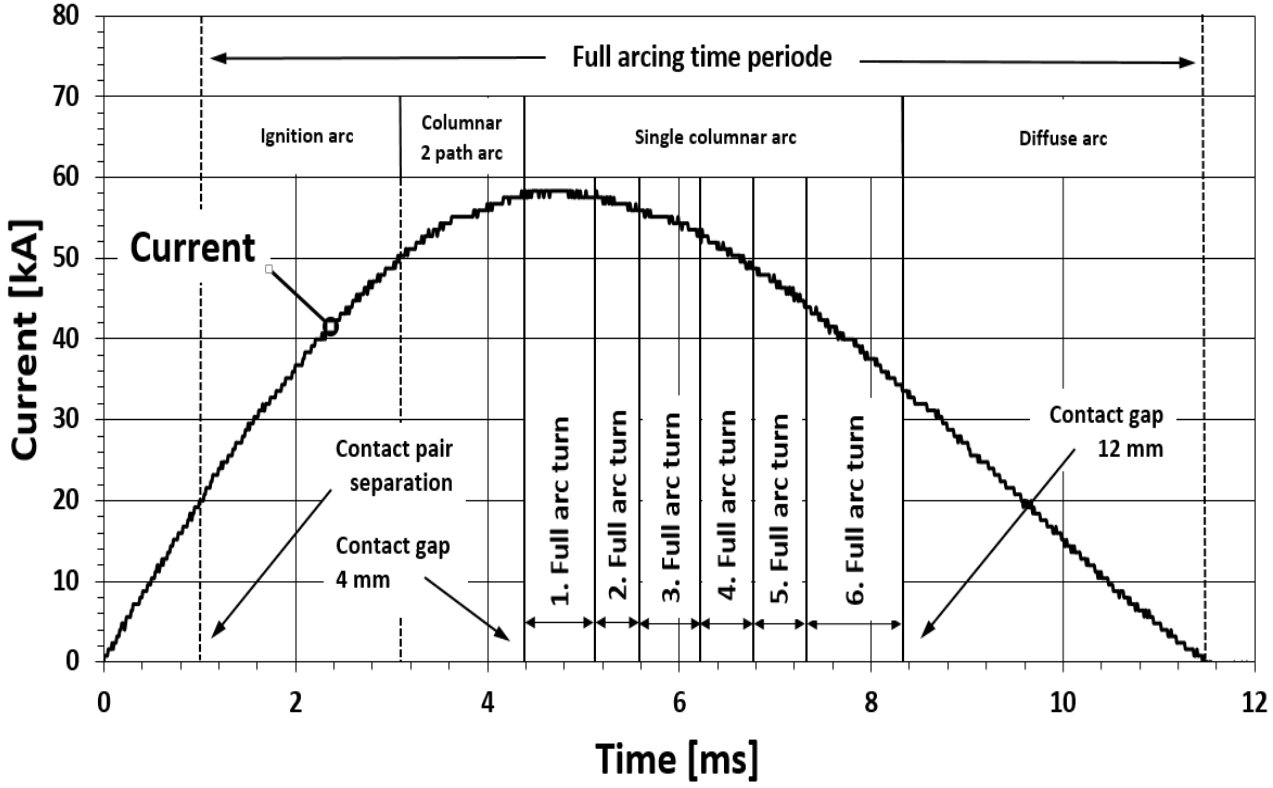
High-speed arc observation during current interruption



- Single interruption operation figured at 40 kA rms obtained during interruption with the occurrence of arc voltage and the mechanical travel curve measured by M2.

Vacuum Interrupter equipped with TMF contacts

High-speed arc observation during current interruption



- Single interruption operation at 40 kA rms occurrence of one single columnar arc at 4 mm contact gap - starting from the point of arc turning round one to the number six, up to the diffuse arc mode.

Vacuum Interrupter equipped with TMF contacts

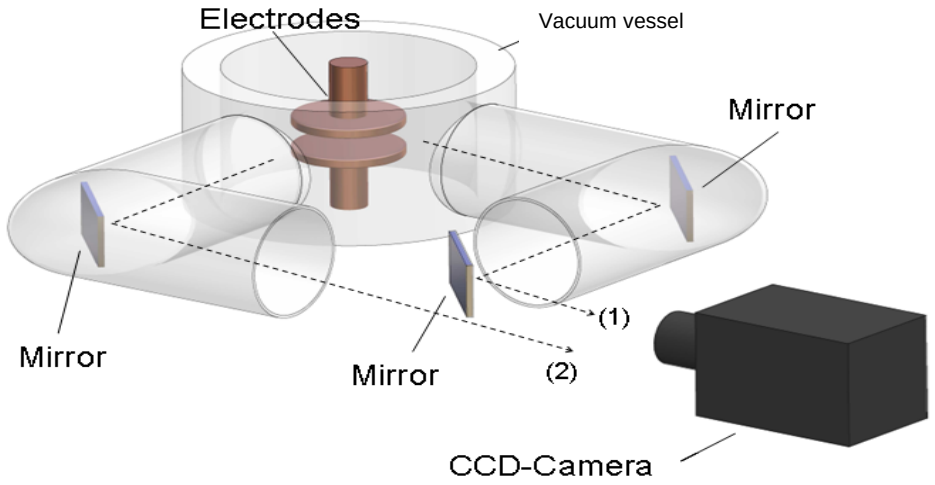
High-speed arc observation during current interruption

Full video sequence:

One loop video sequence:

Schematic of optical setup: electrode pair at arc vessel, optical paths (1) and (2) are recorded side by side in one frame:

- Base to investigate the arc path and by time the velocity of arc.
- CCD – Camera with 120 frames / ms.



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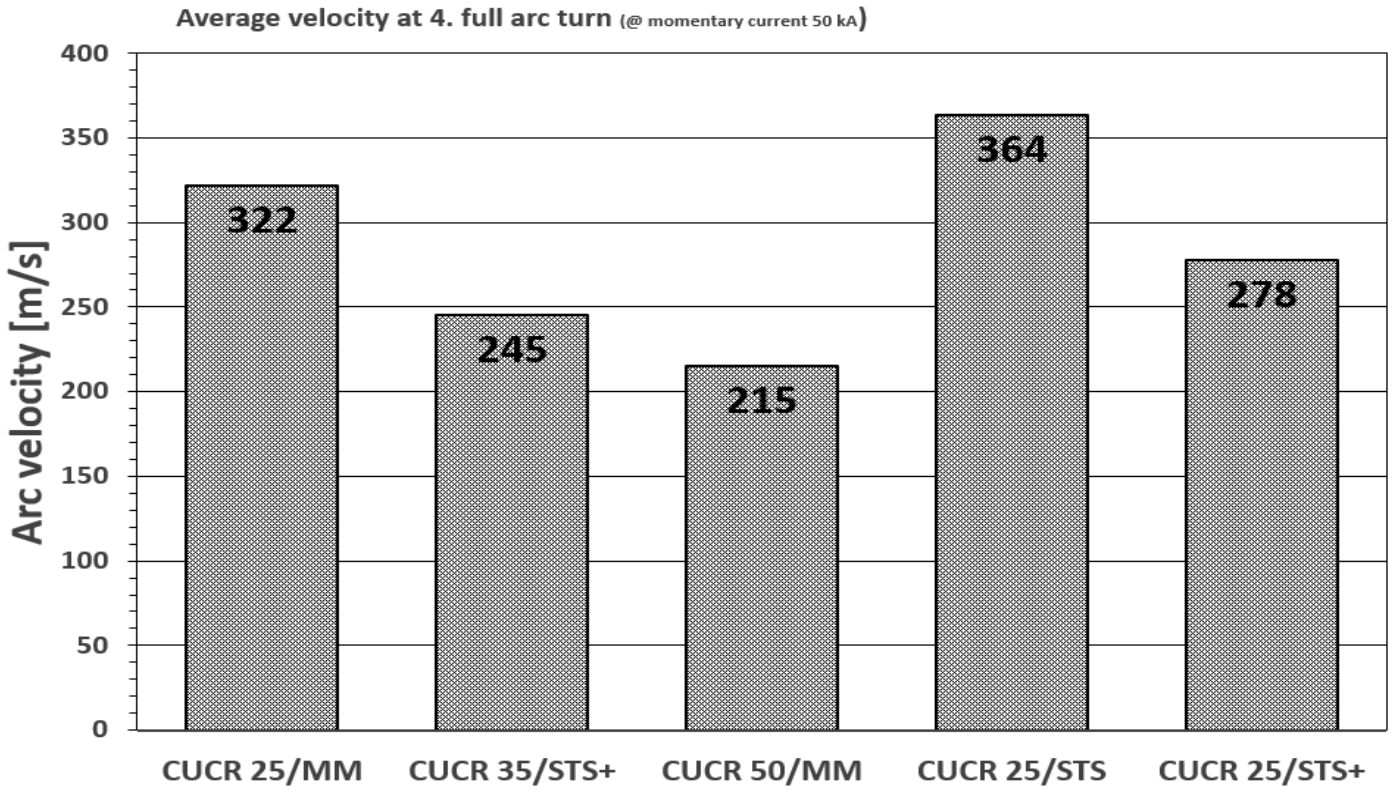
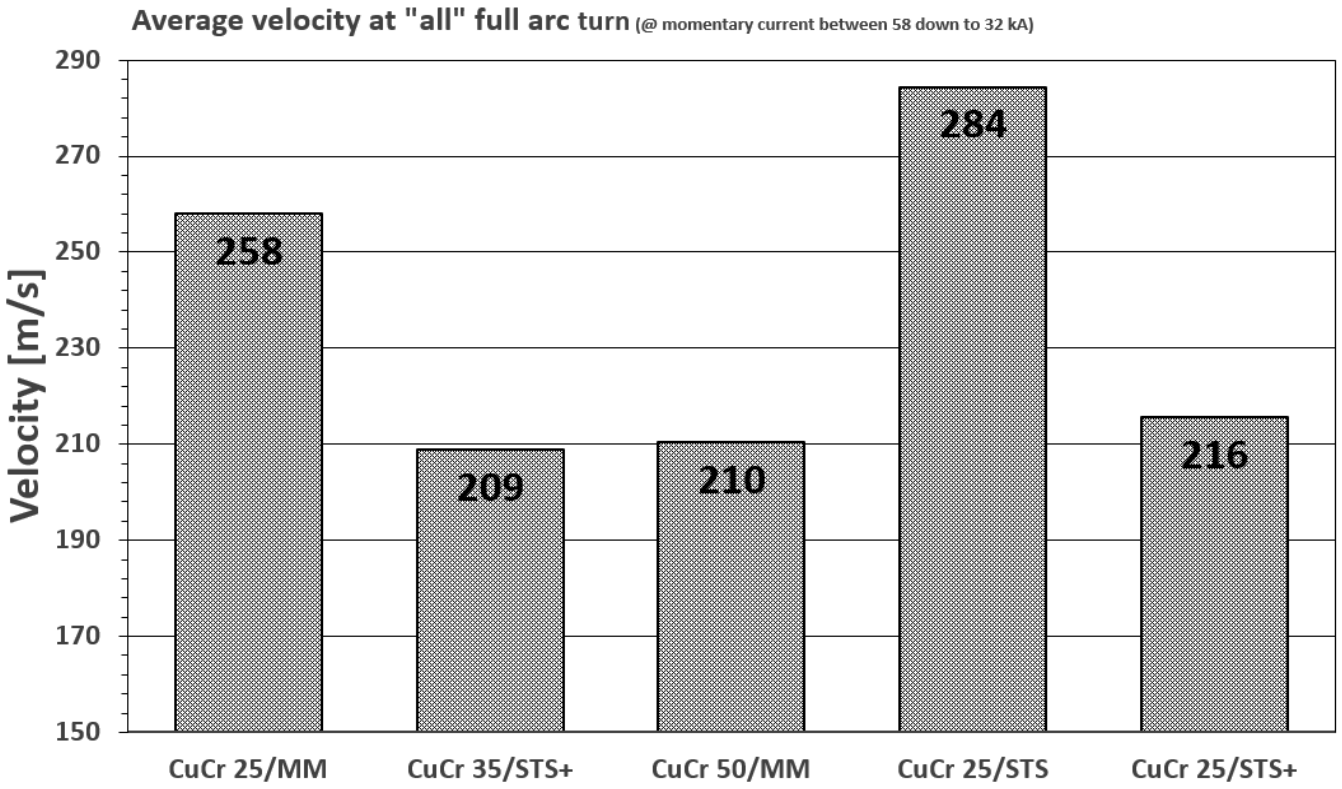
High-speed arc observation during current interruption



- Examined from 3 full videos, average columnar arc velocity at 8 mm contact gap (at 4th full arc turn) with for selected contact material.
- Proportion of chromium content increase, reduces the arc moving velocity at TMF spiral arm contact.
- The method for how the material is produced is limited: Compare molten “left hand side” to sintered “right hand side”.

Vacuum Interrupter equipped with TMF contacts

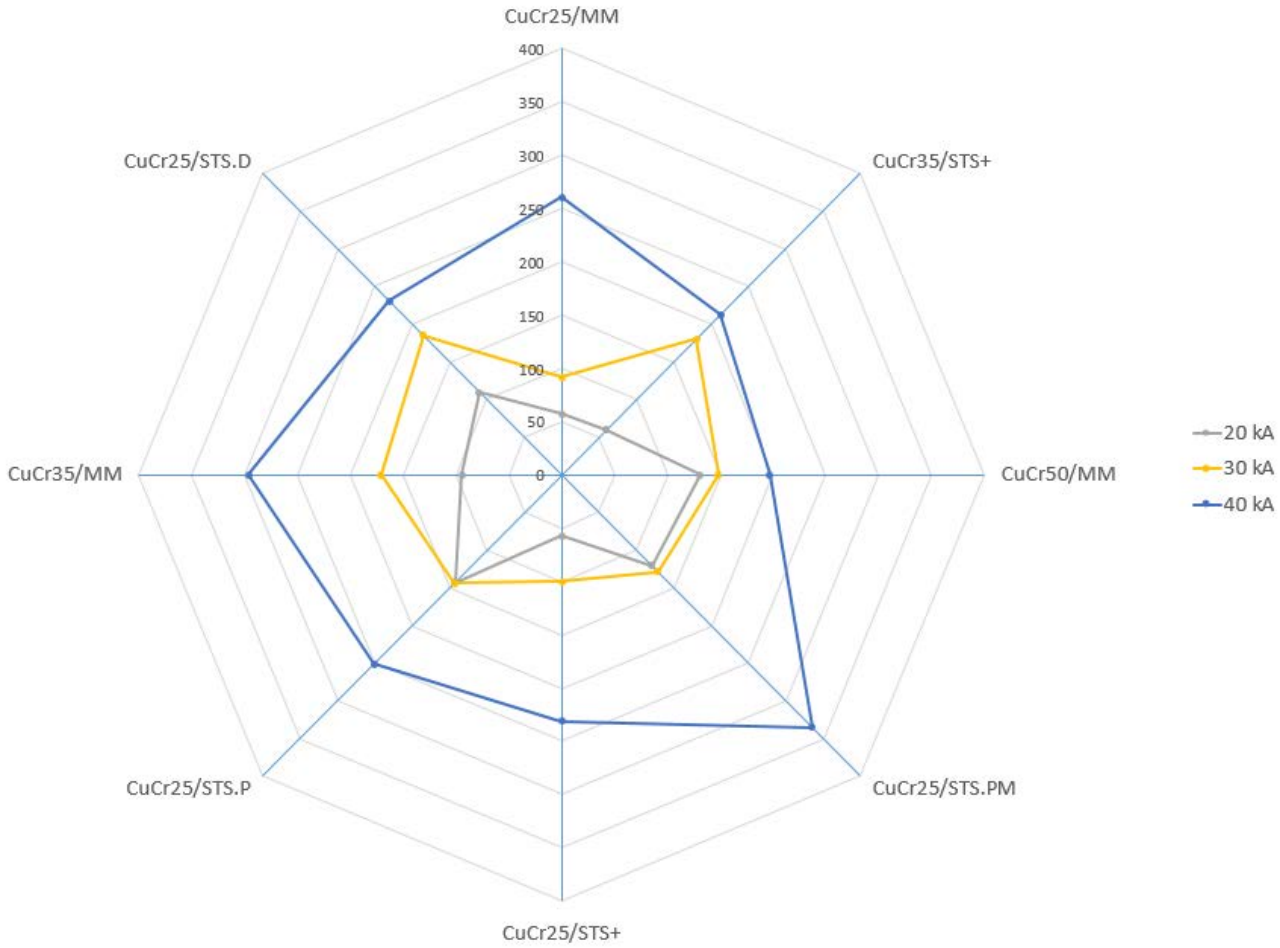
High-speed arc observation during current interruption



- Examined from 3 full videos average columnar arc velocity starting from 4 to 12 mm contact gap (at 1th to 6th full arc turn) for selected contact material.
- Proportion of chromium content increase, reduces the arc moving velocity at TMF spiral arm contact.

Vacuum Interrupter equipped with TMF contacts

High-speed arc observation during current interruption



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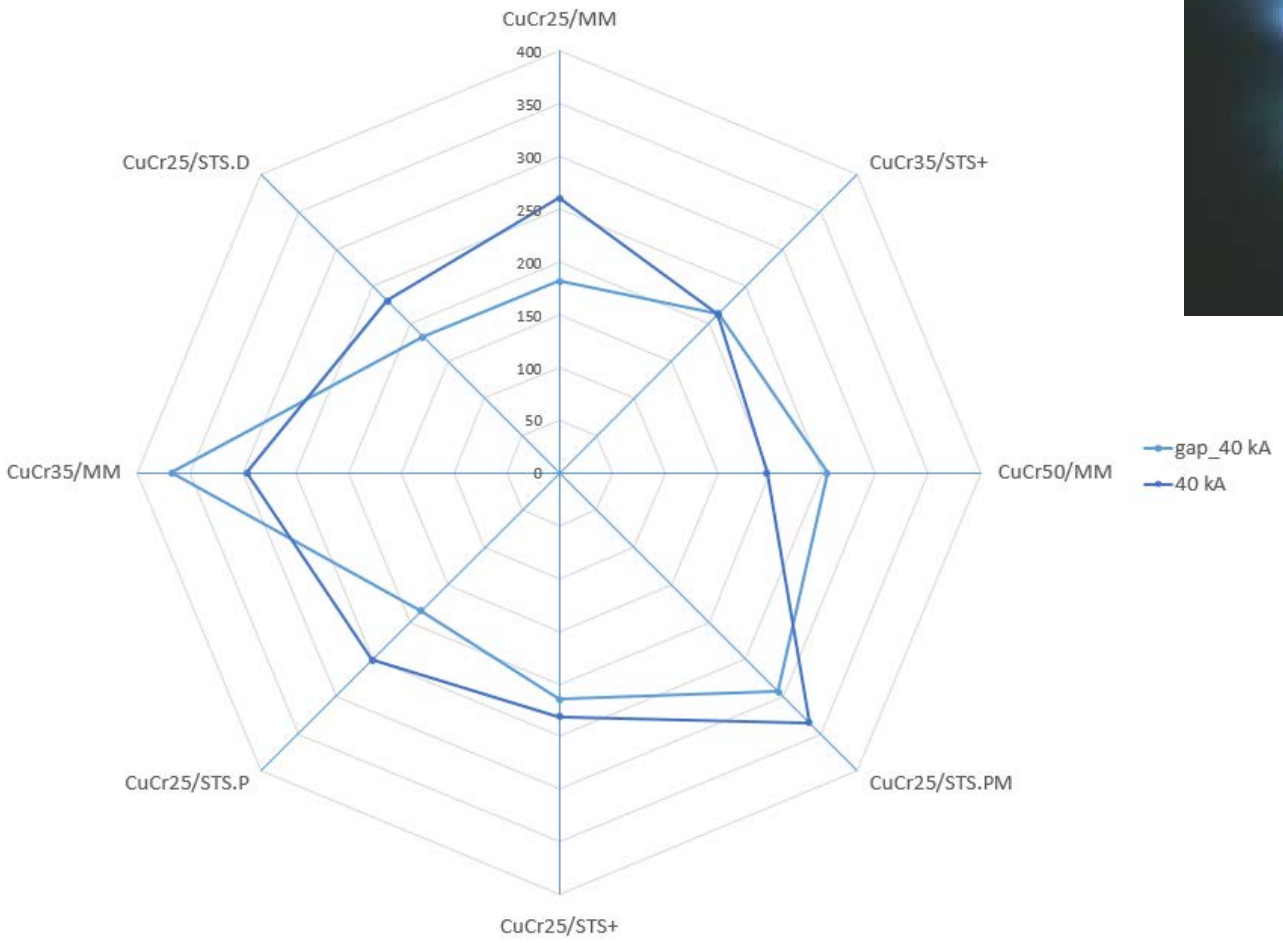

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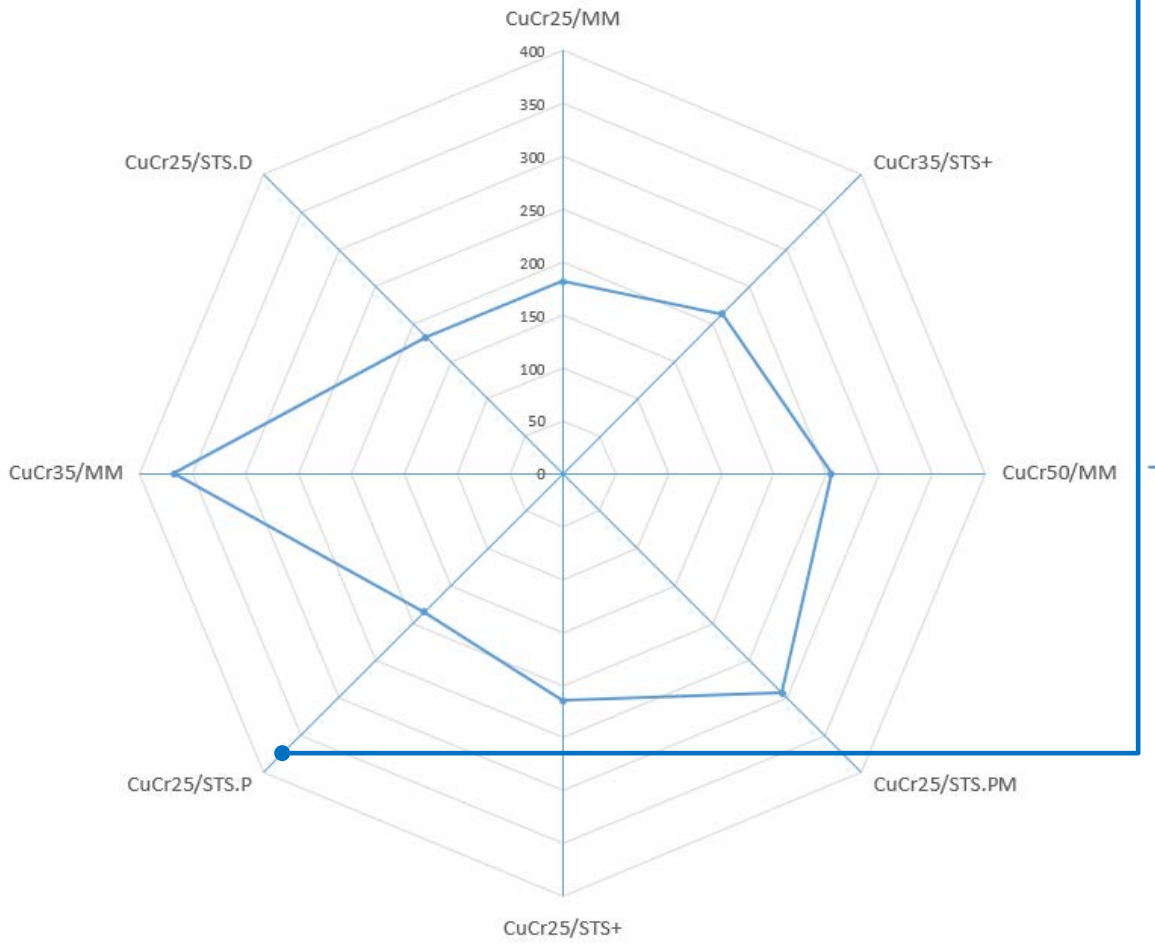
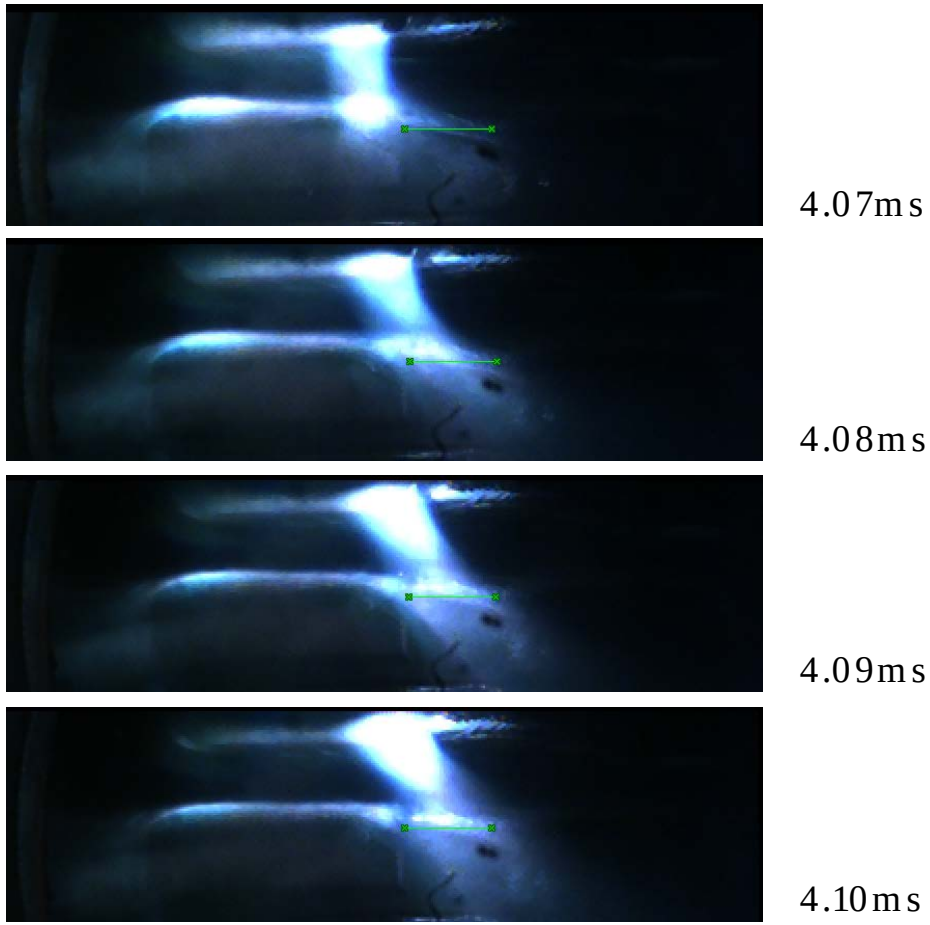
High-speed arc observation during current interruption



CuCr 25 STS / 40kA/ 10mm contact gap / @ momentary current 50kA



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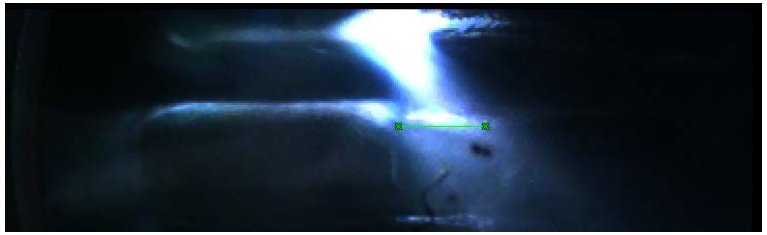
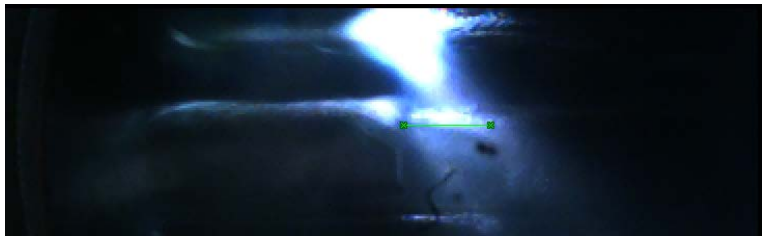
High-speed arc observation during current interruption



4.10ms

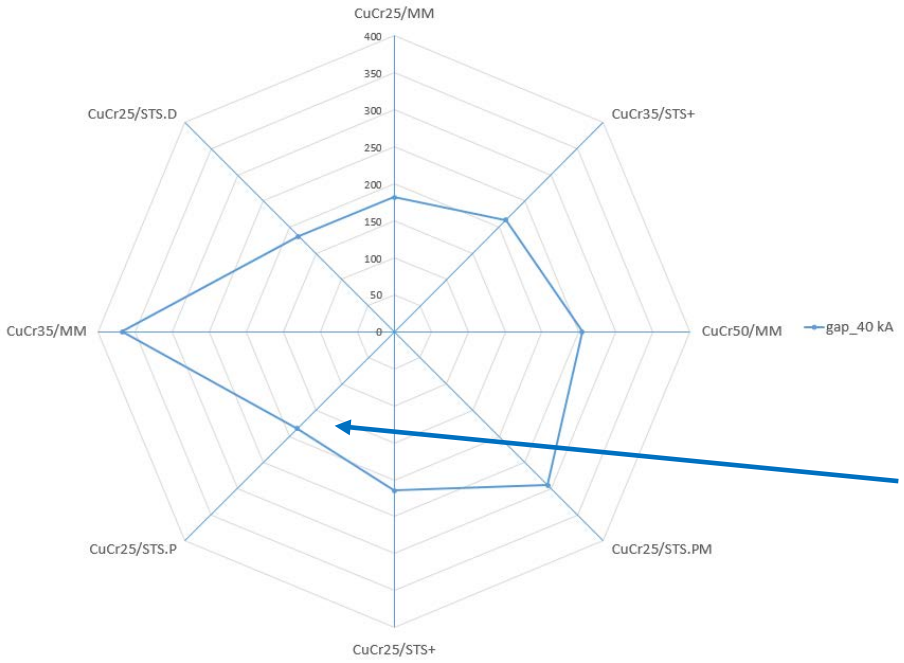


4.11ms

4.12ms

4.13ms

4.14ms



→ 185 m/s

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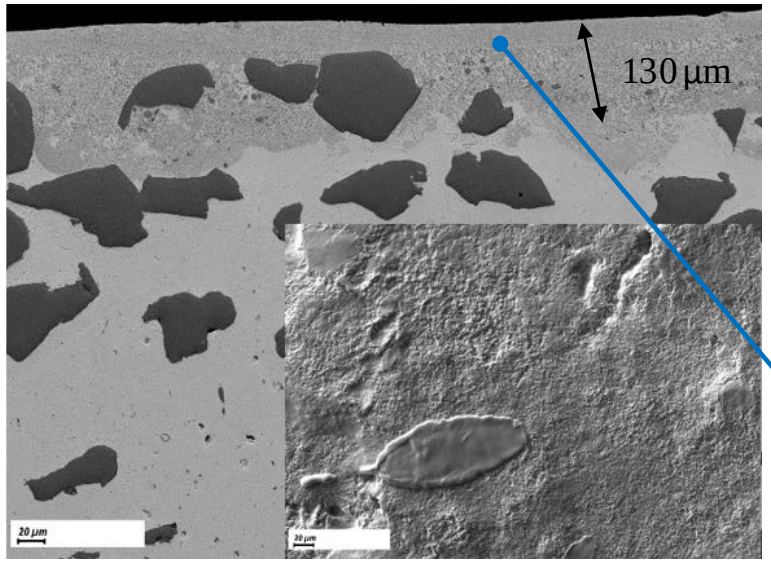
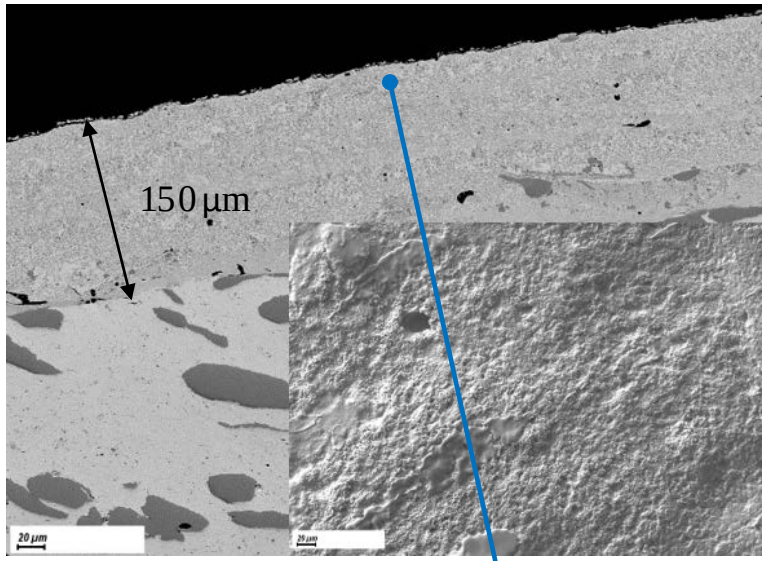
Technical data and test results, Final principle in practice

Technical details of surface layer:





- **Cross section of the STS material CuCr 25 . On the left hand side the standard material is shown and on the right hand side, the – plus – version. The surface is smooth and without cracks after making and breaking operations.**
- **The molten layer at surface has the ratio Cu/Cr: STS 25 [73/27] and STS 25+ [70/30]**

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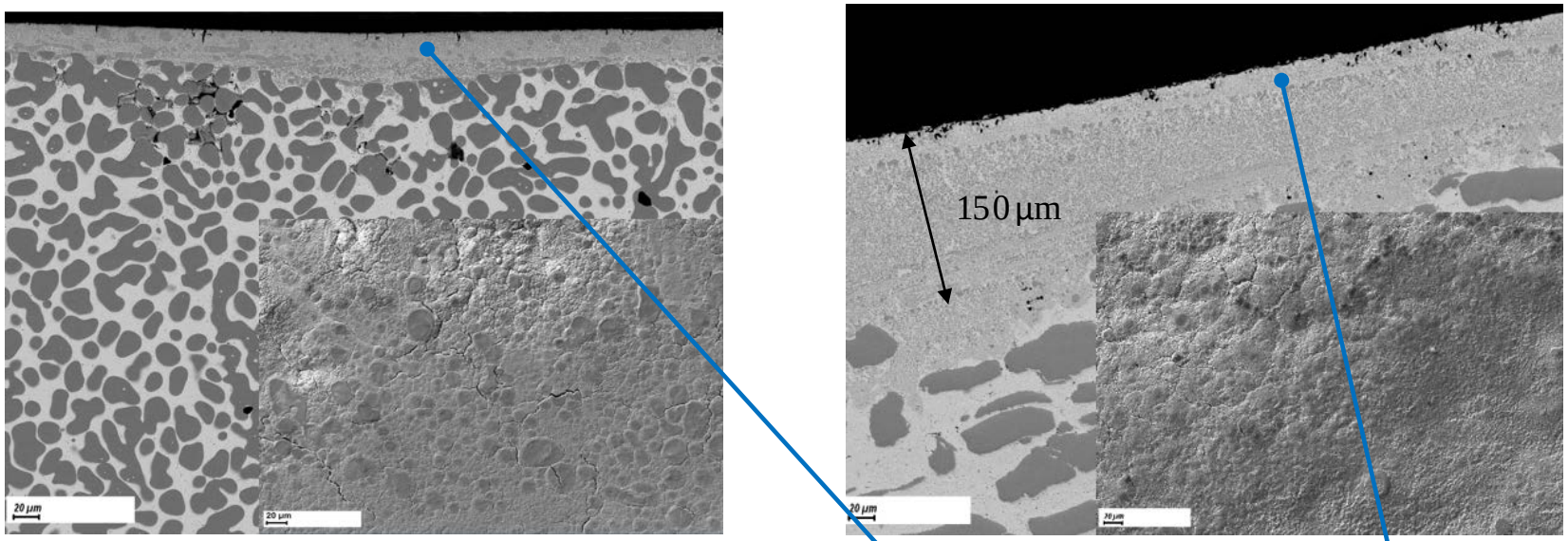
Technical data and test results, Final principle in practice

Technical details of surface layer:



- **Cross section of the MM CuCr 50. On the left hand side the molten material is shown and on the right hand side the –plus – version CuCr 35. The surface is smooth and without cracks after making and breaking operations for CuCr35+.**
- **The molten layer at surface has the ratio Cu/Cr: MM 50 [46/54] and STS 35+ [61/39].**

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Practice application and final practise

- To achieve correlation between the applied short circuit current interruption the resulting columnar arc movement velocity and the applied contact material:
  - A sequence of currents starting from 5 kA up to 40 kA rms were applied, while keeping all other parameters…
  - Vacuum vessel and vacuum condition, contact travel, and video settings constant.
- The contact materials were found to have an influence on the arc motion and velocity throughout the current quarter of the applied half cycle especially on the arc movement velocity.
- Fife different contact material types were tested based on copper and chromium compound materials at short circuit current of up to 40 kA rms:
  - The arc movement velocity around the 56 kA current peak with 322 m/s decreased from contact material with 25 wt.-%
  - With proportion of 50 wt.-% chromium content to 215 m/s at 8 mm contact gap of fourth (4.) arc turns.
  - The proportion of chromium content in between the velocity developed close to linear.
- The contact material production technology and the solid state sintered or molten material has a minor influence on arc movement velocity.

Vacuum Interrupter equipped with TMF contacts

Practice application and final practise

•Fife different contact material types were tested based on copper and chromium compound materials at short circuit current of up to 40 kA rms:

The arc movement: (… around the 56 kA current peak)

•Contact material with 25 wt.-% velocity with 322 m/s, 30 – 32 m/Ω mm²
•Contact material with 35 wt.-% velocity with 245 m/s.
•Contact material with 50 wt.-% velocity with 215 m/s, 20 – 25 m/Ω mm².

•More chromium rate reduces the content of the copper quantity and therefore the thermal and electrical conductivity for e.g. typically 25 wt.% to 50 wt.% chromium drops down to about 2/ 3.

•The CuCr 35 nearly has close to the same short circuit current interruption ability as CuCr 25.

Vacuum Interrupter equipped with TMF contacts

Overview

- **Introduction**
- **Vacuum interrupter principle**
  - Basic tasks and design of vacuum interrupter and simulation
  - Motivation and function description of arc movement
  - Study under short circuit current conditions
  - Contacts and contact material different
  - **High-speed arc observation during current interruption**
- **Technical data and test results**
  - Technical details of surface layer
  - Final principle in practice
  - Practice application and final practise
- **Summary**

Vacuum Interrupter equipped with TMF contacts

Summary

- The contact materials were found to have an influence on the arc motion throughout the current quarter of the applied half cycle especially on the arc movement velocity → Currents up to 40 kA rms were applied, while keeping all other parameters.
- Fife different contact material types were tested based on copper and chromium compound materials at short circuit current of up to 40 kA rms:
  - Arc speed values are illustrated, has an average value for CuCr 25 wt.-% - MM / STS of 322 / 364 m/s
  - In case of CuCr 50 wt.-% - MM a velocity of 215 m/s can be measured.
- Summarising the short-circuit interruption ability results it can be stated that the VIs equipped with the standard CuCr 25 … 35 wt.-% provide an excellent performance and it seems that there is an optimum for the different necessities concerning to the contact material.
- The contact material production technology and the solid state sintered or molten material has a minor influence on arc movement velocity.