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“Metal Vapour Impact on Ceramic Surfaces of Vacuum Interrupter” After Current Interruption Operations Dielectric Performance and Surface Resistance Measurement: Final principle in practice

Physikzentrum Bad Honnef

5th ITG International Vacuum Electronics Workshop 8.-9. Sep. - 2016

elenia Institut für Hochspannungstechnik und Elektrische Energieanlagen

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Overview

- **Introduction**
- **Vacuum interrupter principle**
  - Basic tasks and design of vacuum interrupter
  - Motivation and function description
  - Dielectric performance new and after load interruption
- **Technical data and test results**
  - Technical details of surface layer
  - Final principle in practice and simulation
  - Practice application and final practise
- **Summary**

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Vacuum interrupter families type series VS. . , VG . ., UFES
Introduction

- For medium voltage, Contactor and switch – disconnector application incl. Ultra-Fast-Earthing-Switch (UFES)

<u>Ratings</u>:

- Rated voltage range 1.2 up to 40.5 kV
- Up to short circuit current 63kA @ 1.2 and 85kA @ 1.2kV

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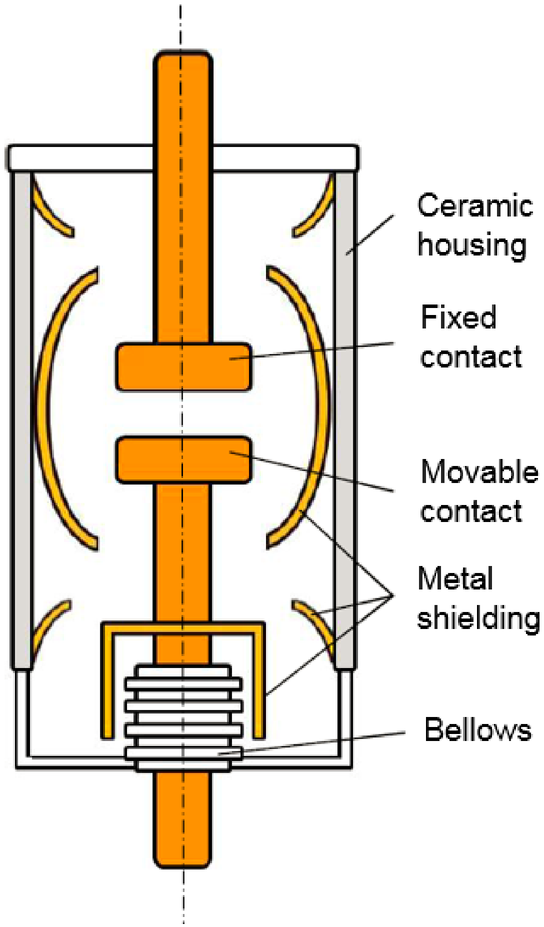
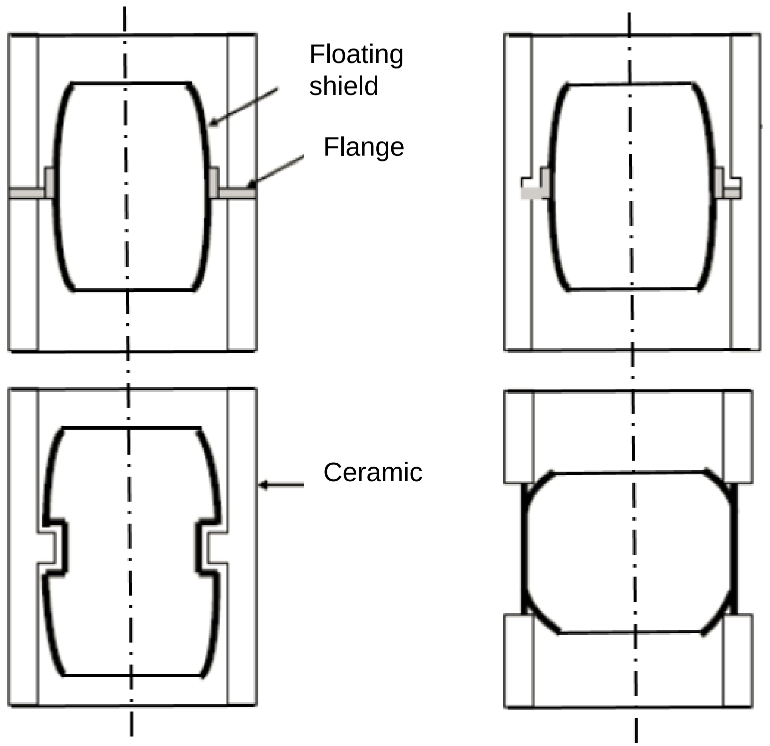
Vacuum interrupter basic principle
Introduction



Schematic sketch of a vacuum interrupter assembly, main shield on floating potential



Different versions of shielding on floating potential
(Slade, 2008)

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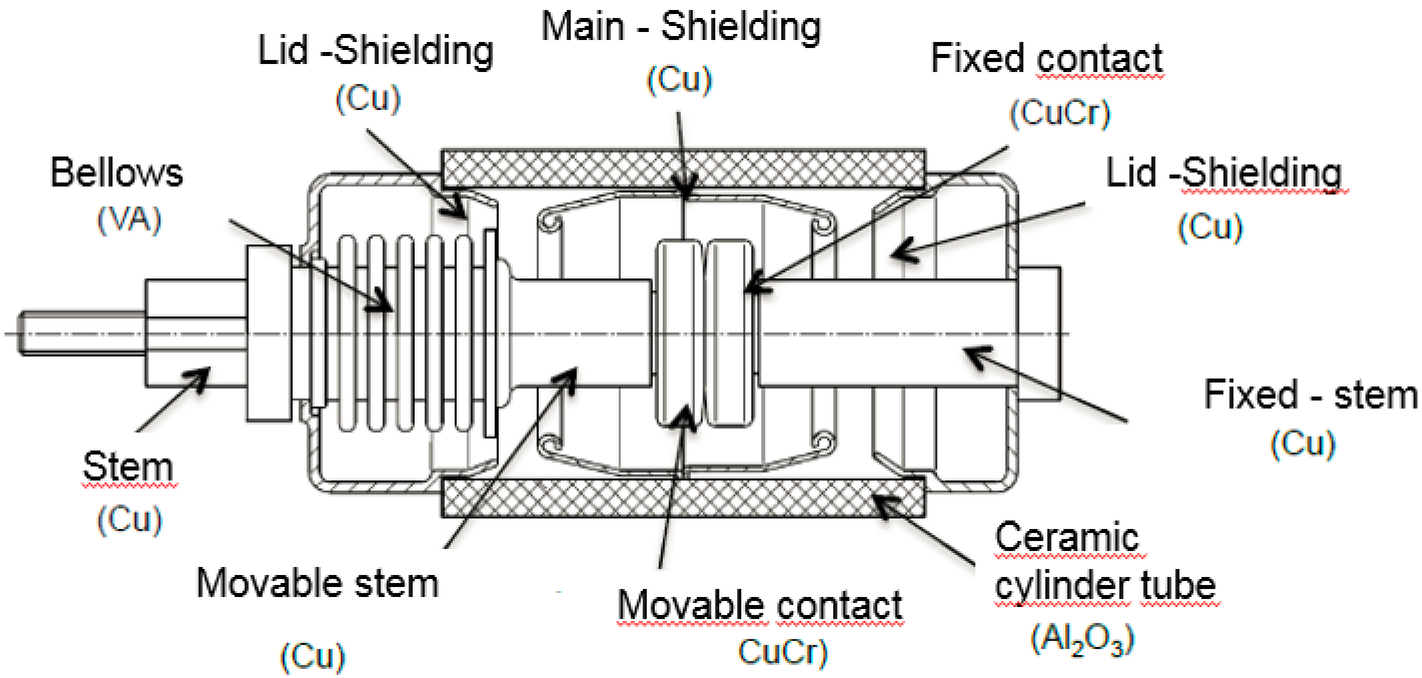
Vacuum interrupter principle
Basic tasks and design of vacuum interrupter

Specifications of the used vacuum interrupter type:
→ 12/24kV @ up to 20kAeff.

Technical item	Rating
Rated voltage	$12kV_{eff.}$ / $24kV_{eff.}$
Rated current	Up to $630A_{eff.}$ (1250A)
Rated short-circuit interruption current	Up to $20kA_{eff.}$
Rated lightning impulse withstand voltage	125kV (peak) 1.2/50µs
Rated power frequency withstand voltage	50kVeff.

Vacuum interrupter principle
Basic tasks and design of vacuum interrupter



Vacuum interrupter with the main shielding on floating potential; Cu = copper, CuCr = copper-chromium, VA = stainless steel, Al_2O_3 = aluminium oxide ceramic

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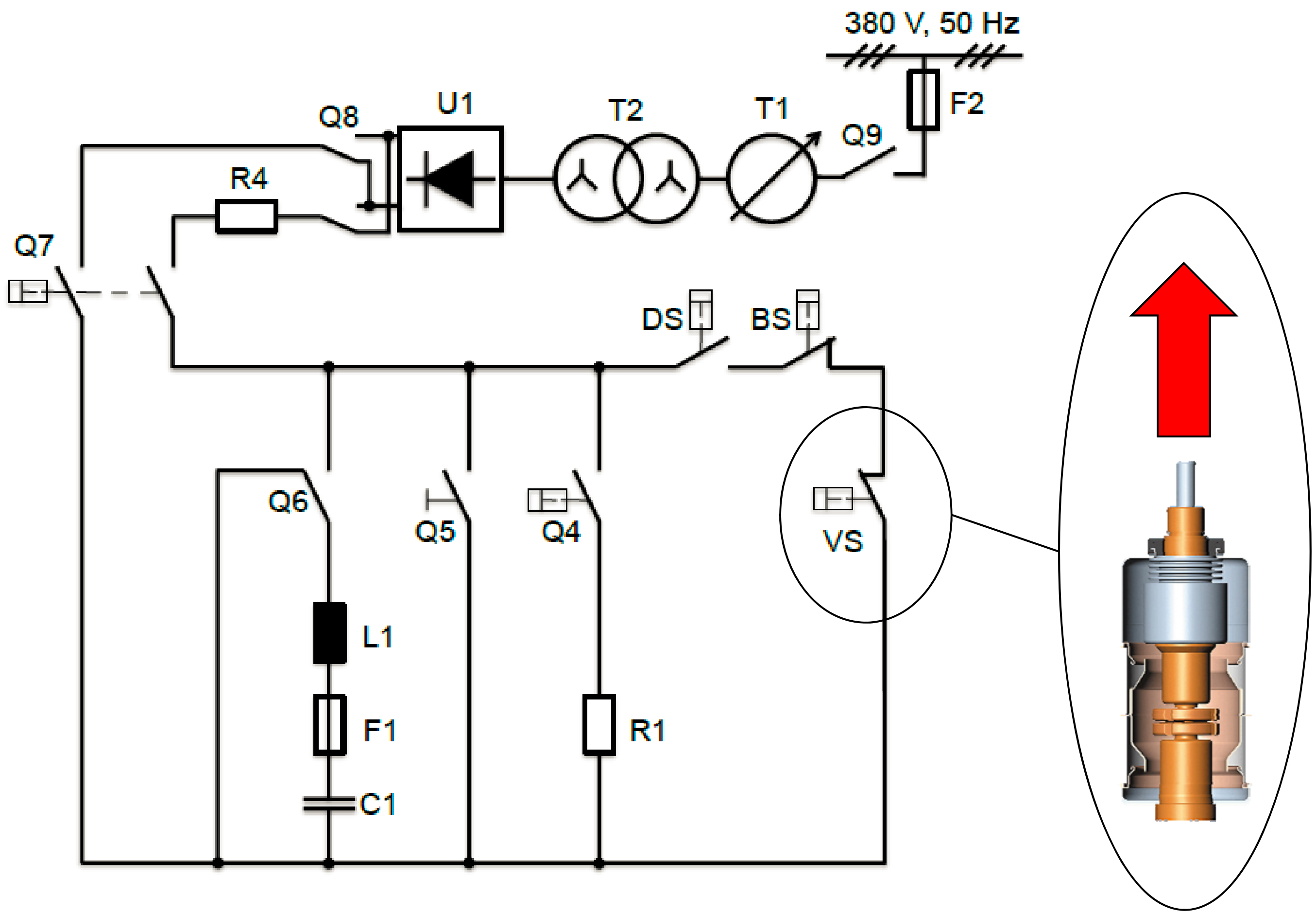
Vacuum interrupter principle
Motivation and function description

- Motivation of the study is to investigate the influence of short circuit current interruption on the lightning impulse withstand voltage of vacuum interrupters.
- It is investigated, causing metal vapor impact at the inner ceramic surface in the vacuum interrupter chamber and which factors significant influence on reducing the lightning impulse withstand voltage.
- By previous investigations, it was confirmed that the conductivity significantly “coated” with metal vapor alumina ceramic surfaces increases.
- It has also been shown that the dielectric strength after short circuit current interruption operations can decrease at the shielding side.
- So far this studies mainly not linked between the shielding and the contact area.

Vacuum interrupter principle
Motivation and function description



High-current circuit of the synthetic test-set up used for interruption investigation under short circuit condition up to 20kAeff.

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Vacuum interrupter principle
Function description and motivation

Test sequence to investigate:

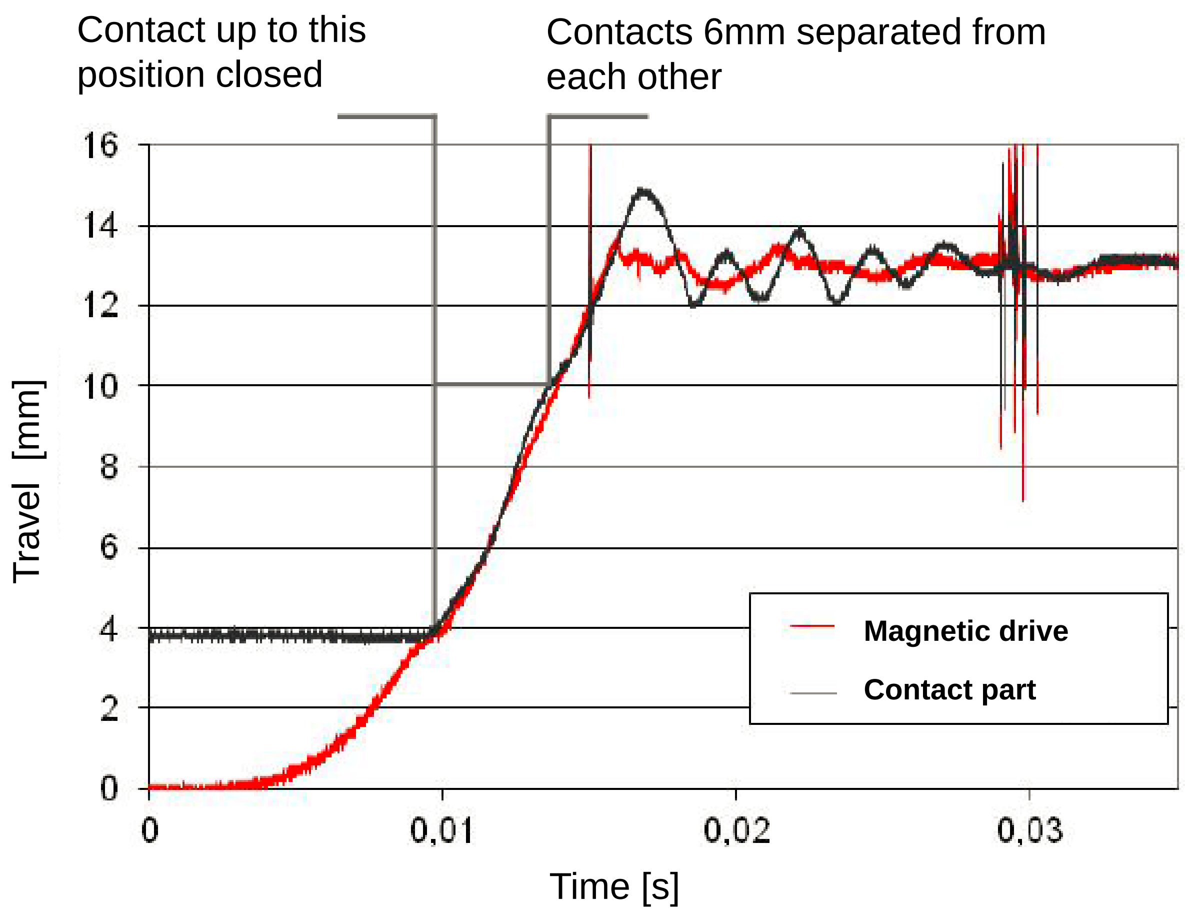
→Dielectric strength and metal vapor impact after arcing.

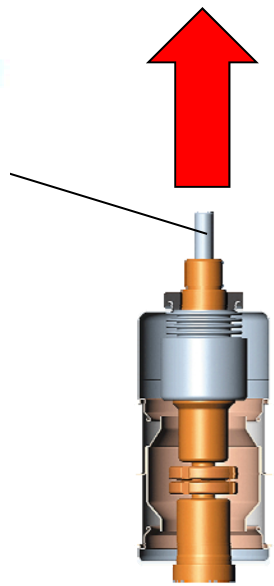
- Investigation will be done by short circuit current interruption operation applying:
  - Each five operation @ 5 – 10 – 15 – 20kA$_{eff.}$.
  - Here to investigate the dielectric performance.

- Investigation will be done by short circuit current interruption operation applying:
  - Each four operation @ 20kA$_{eff.}$.
  - Here to investigate the dielectric performance.

- Investigation will be done by short circuit current interruption operation applying:
  - Each polarity positive and negative 10 – 20 – 30 operation @ 15kA$_{eff.}$.
  - Here to investigate the metal impact, the thickness of the coating.

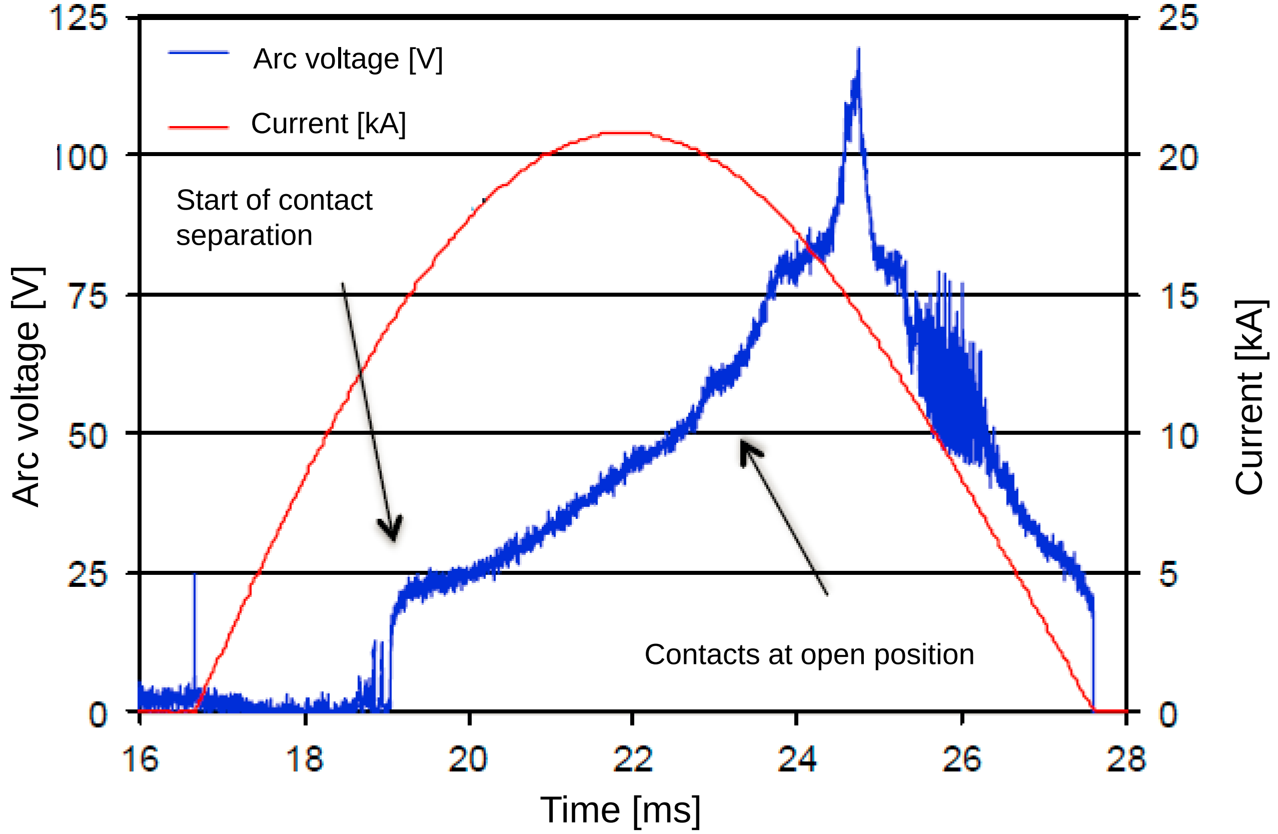
Vacuum interrupter principle
Function description and motivation





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

Vacuum interrupter principle
Function description and motivation



Developing of current and arc voltage during a short circuit interruption under load of $15kA_{eff.}$

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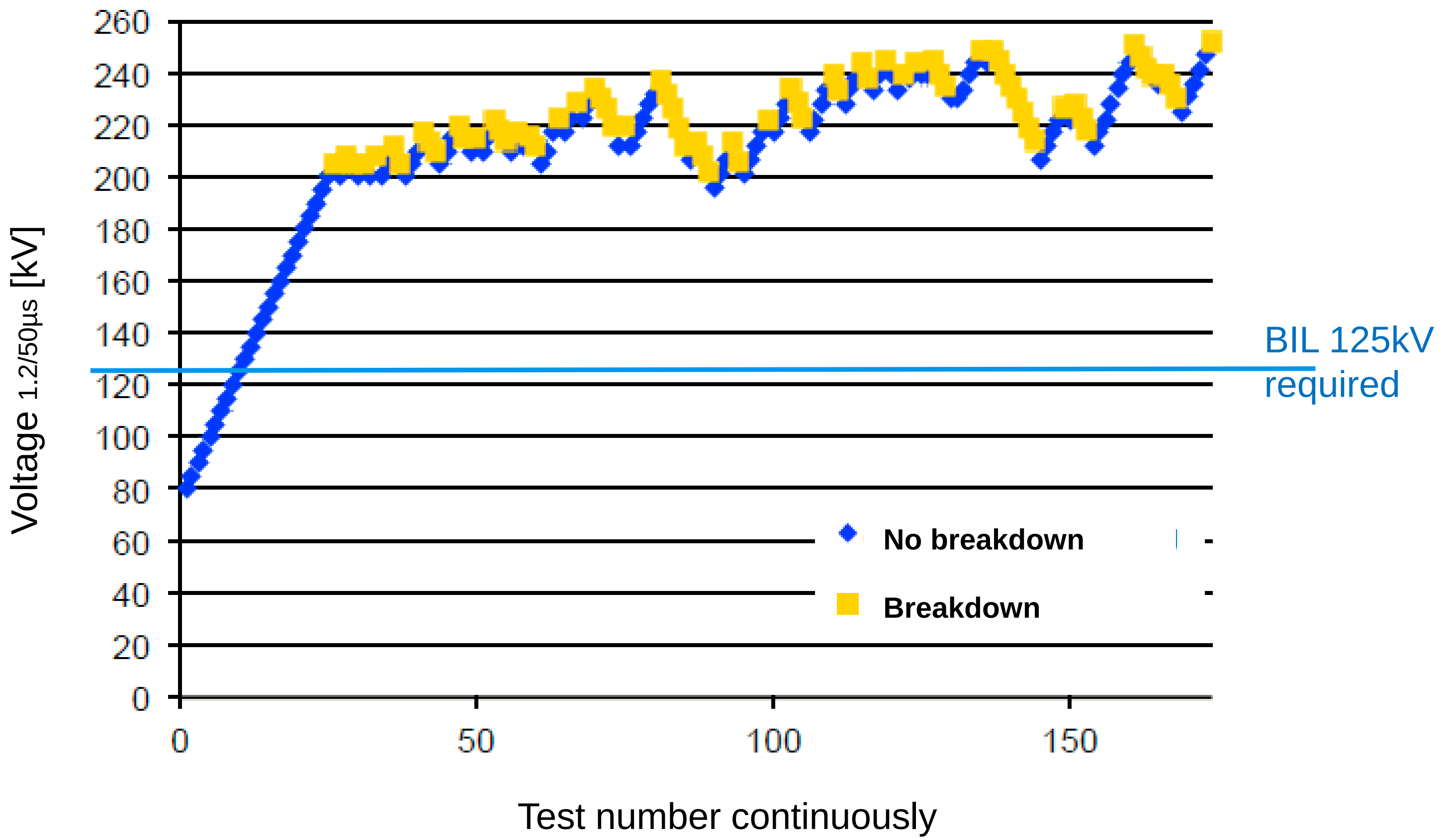
Vacuum interrupter principle
Dielectric performance new and after load interruption



Basic impuls level (BIL: 1.2/50µs) test of vacuum interrupter in the **new condition and AC conditioning**, Up-and-down method

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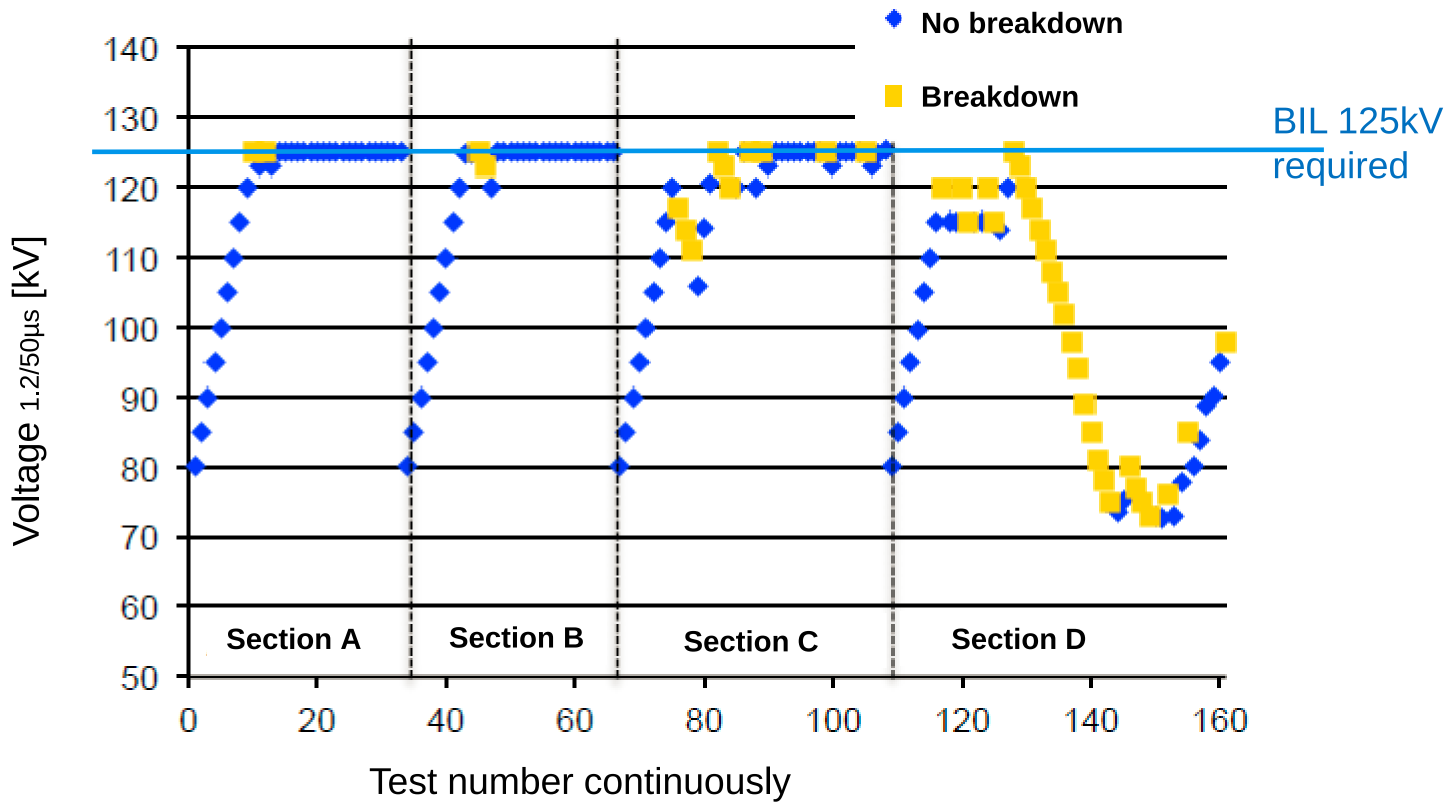
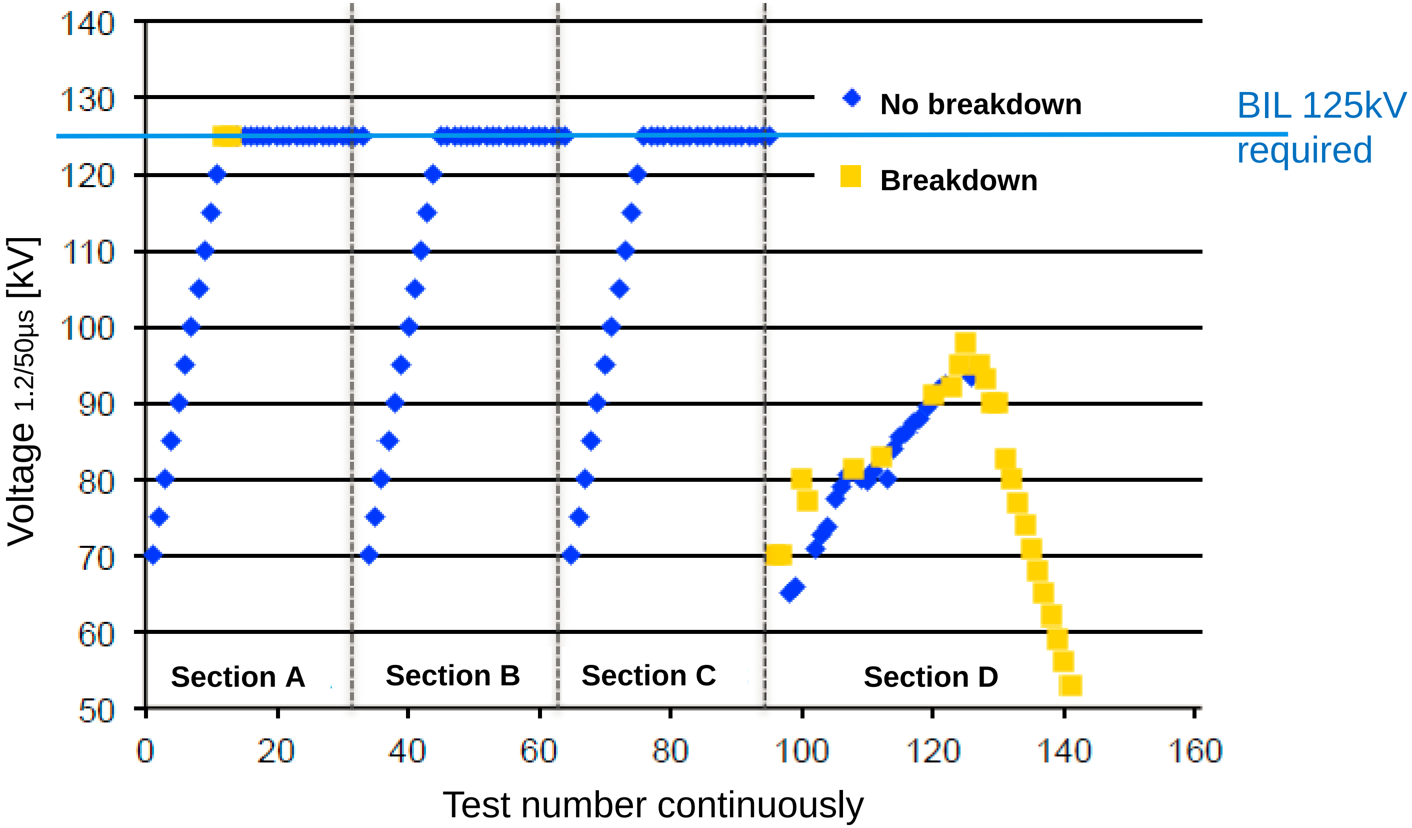
Vacuum interrupter principle
Function description and motivation



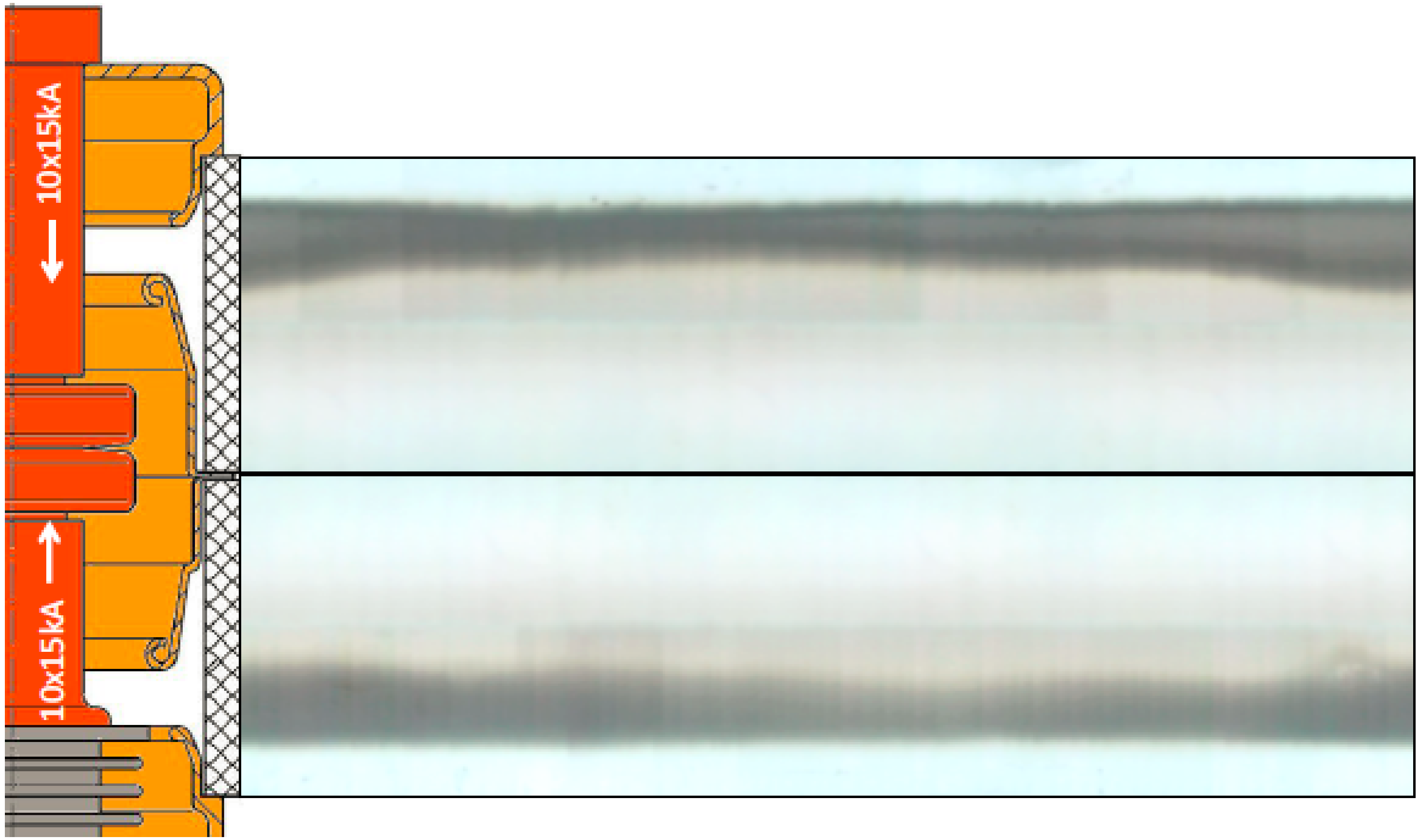
Basic impuls level (BIL: 1.2/50µs) testing: Four interruption operation under load of 20 kAeff, investigation done for each section **after single 20kA interruption**

Vacuum interrupter principle
Dielectric performance new and after load interruption



Basic impuls level (BIL: 1.2/50µs) testing after: **Five interruption operation** under load of **5kAeff (Section A)**, five under load of **10kAeff (Section B)**, five under load of **15kAeff (section C)** and five under load of **20kAeff (Section D)**

Vacuum interrupter principle
Dielectric performance new and after load interruption



Vapor deposition profile of a vacuum interrupter after 20 interruption operations under load @ **15kA$_{eff.}$** with alternating current polarity, shown in a 360 ° developed view

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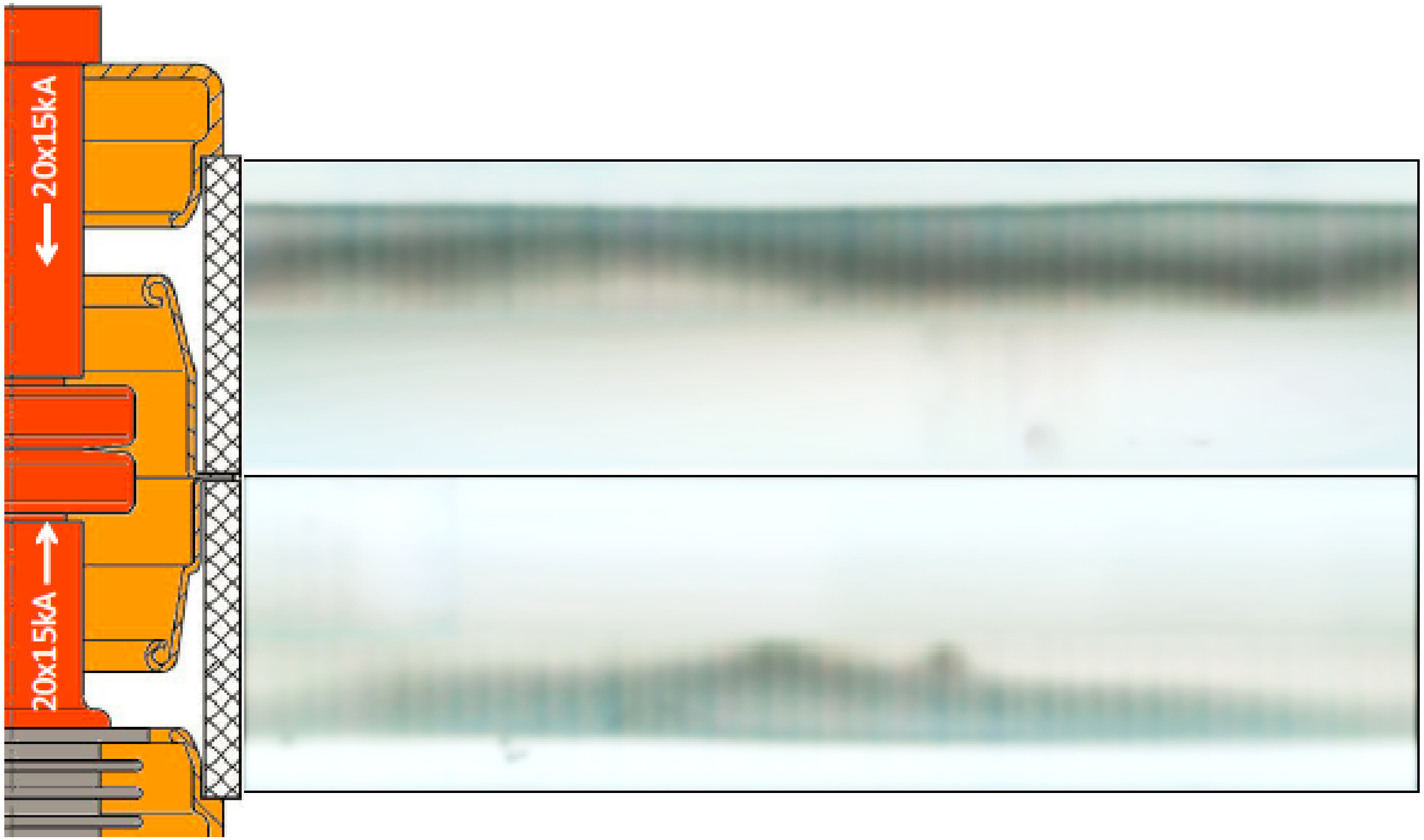
Vacuum interrupter principle

Dielectric performance new and after load interruption



Vapor deposition profile of a vacuum interrupter after 40 interruption operations under load @ **15kA$_{eff.}$** with alternating current polarity, shown in a 360 ° developed view

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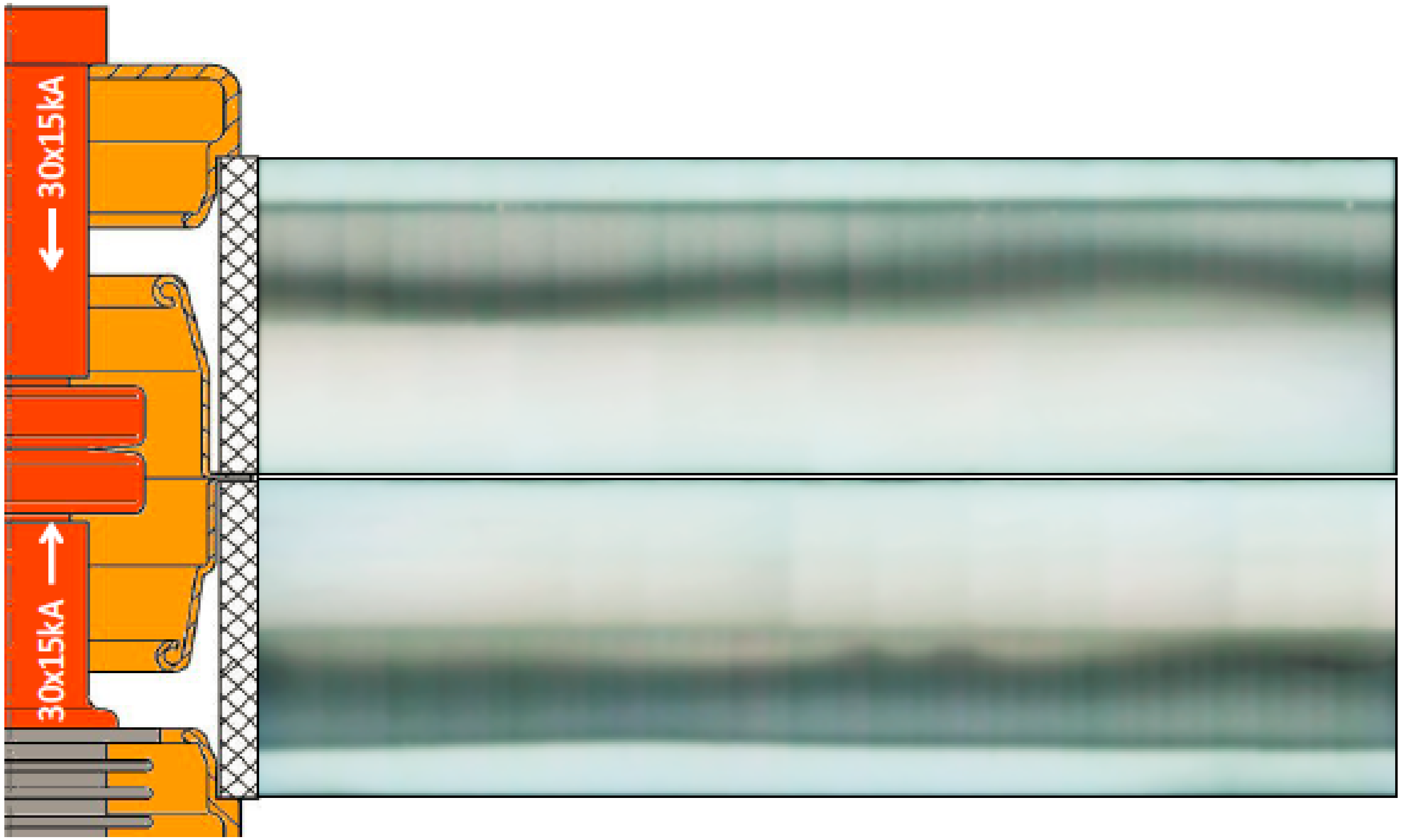
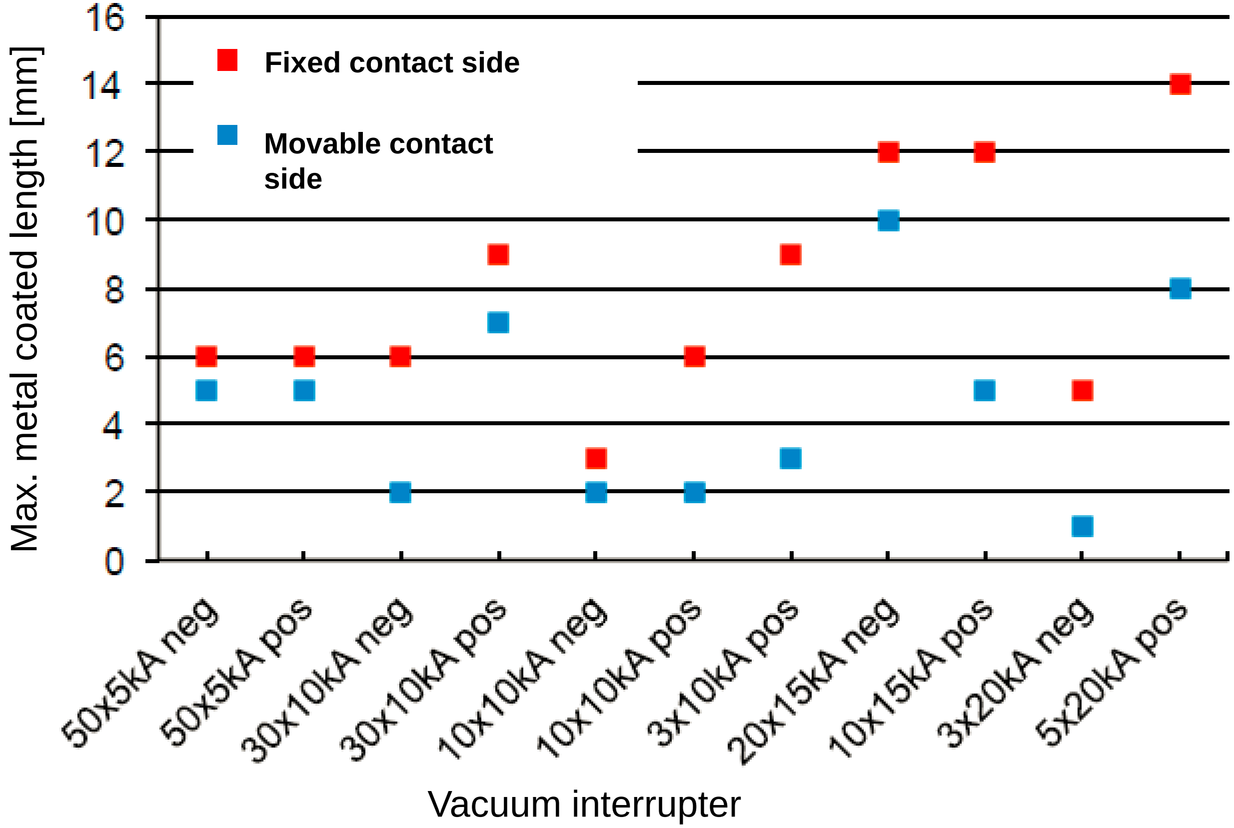
Vacuum interrupter principle
Dielectric performance new and after load interruption



Vapor deposition profile of a vacuum interrupter after 60 interruption operations under load @ **15kA**$_{\mathbf{eff.}}$ with alternating current polarity, shown in a 360 ° developed view

Vacuum interrupter principle
Dielectric performance new and after load interruption



Comparison of the maximum metal coated length on vacuum interrupter (VI) ceramics of the fixed- and movable- contact side after interruption operation with positive / negative current polarity, VI opened after a specified number of operations

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Technical data and test results

Technical details of surface layer

SEM (scanning electron microscopy) image of a ceramic surface at 1000x “as fired“ condition direct after production

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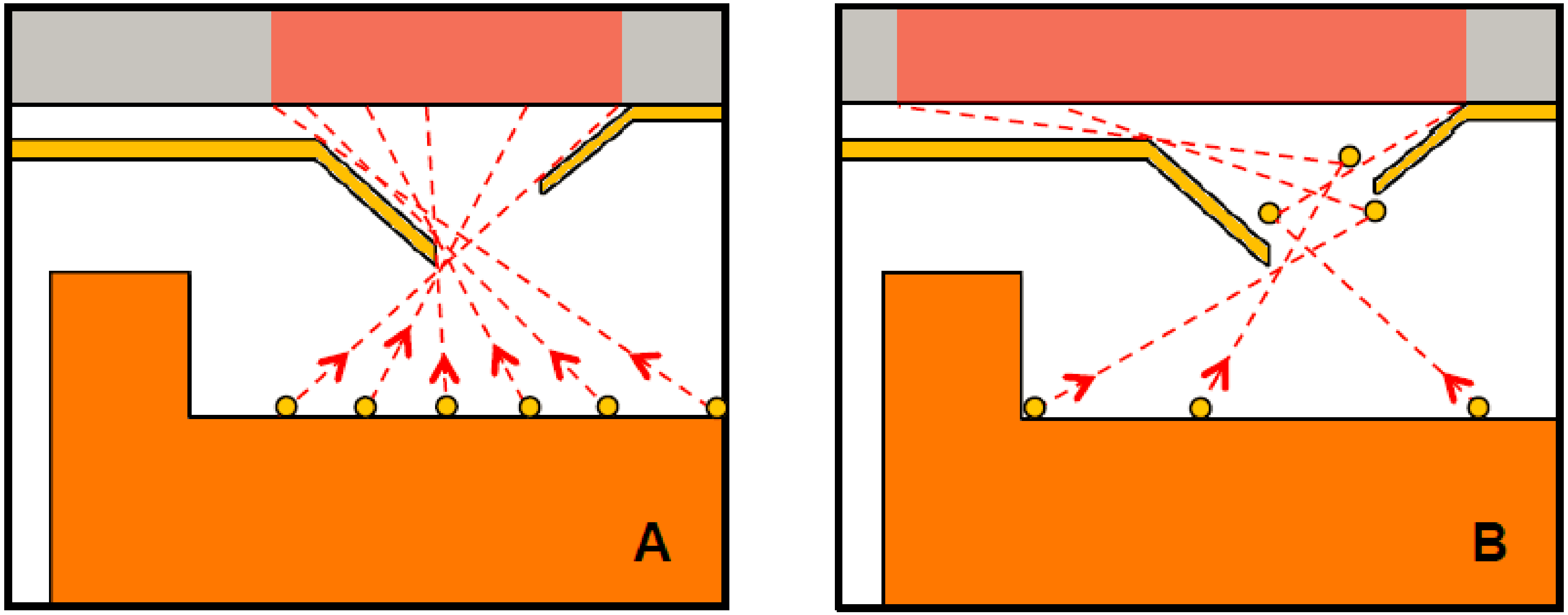
Technical data and test results

Technical details of surface layer



Possible particle motion to the ceramic surface within a vacuum interrupter between shielding without **particle-particle collisions (A)** and **particle-particle collisions (B)**

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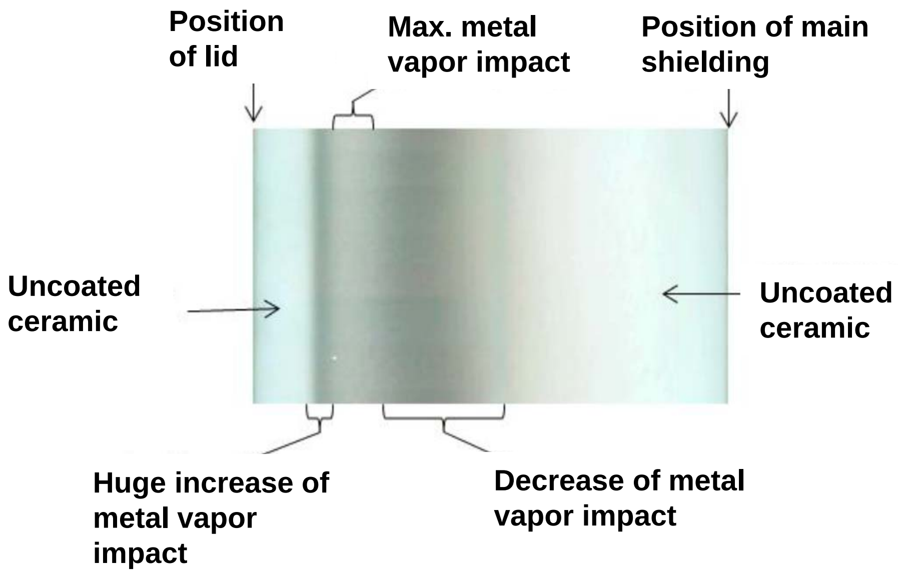
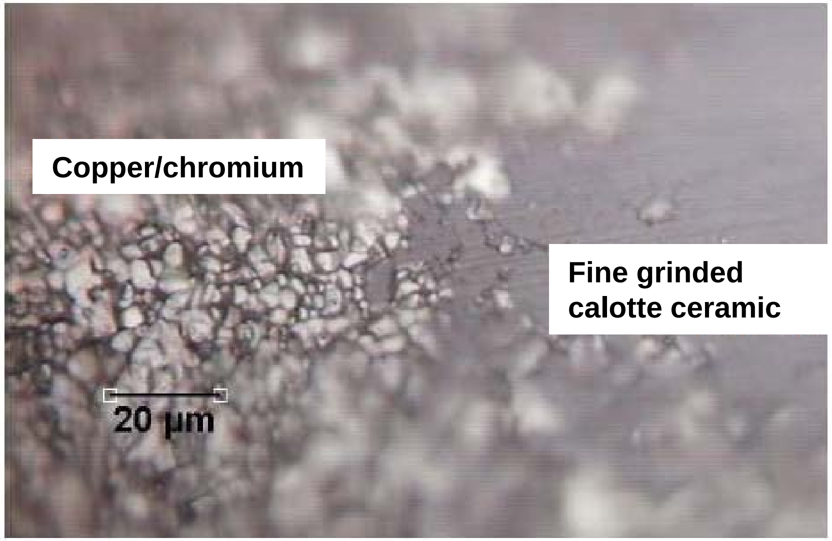
Technical data and test results
Technical details of surface layer

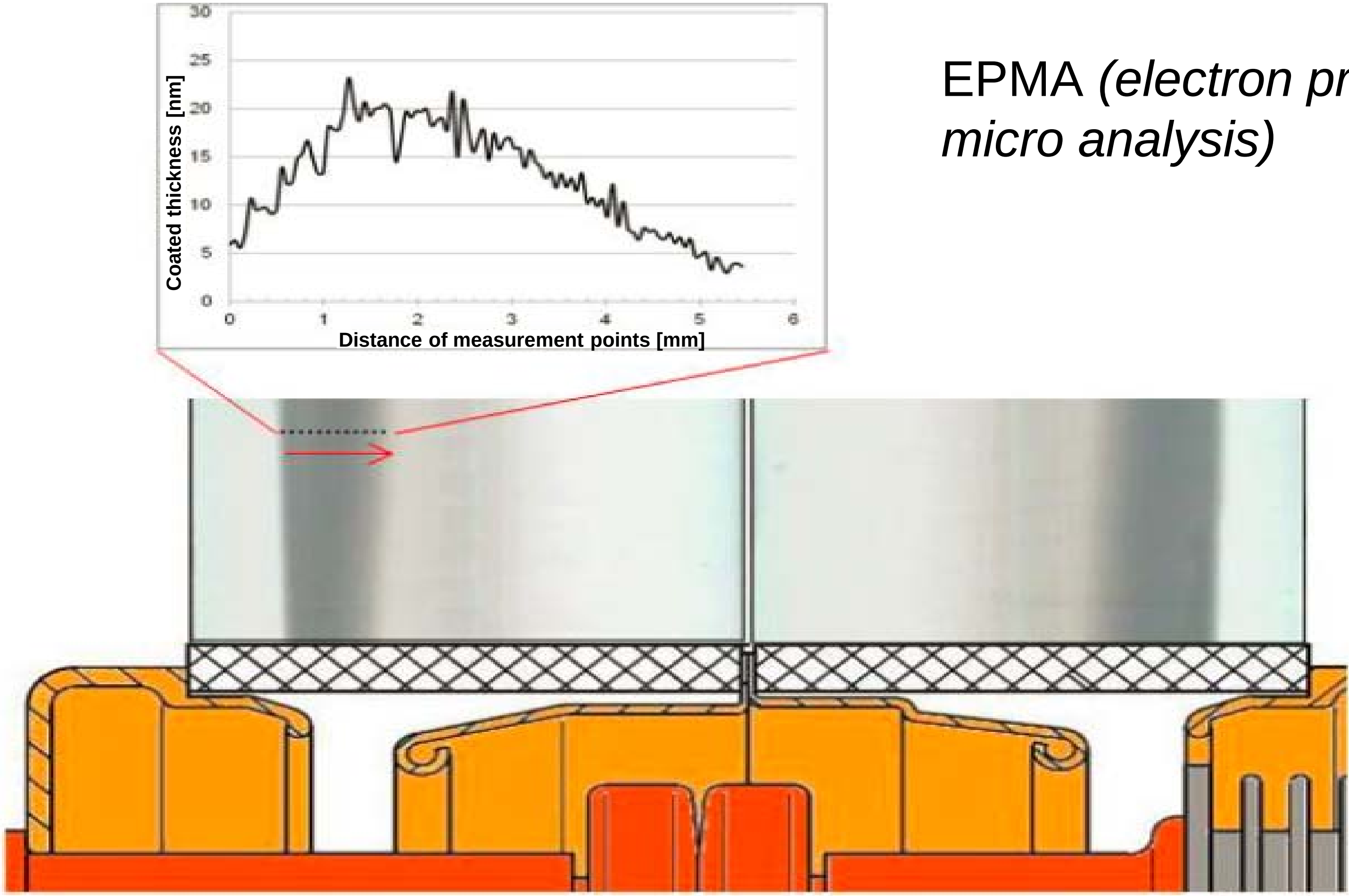


Characteristically gradient of metal vapor impact along a vacuum interrupter ceramic part

Micrograph of the edge region a calotte grinding of with copper - chromium vapor coated ceramic vacuum interrupter



Technical data and test results
Technical details of surface layer

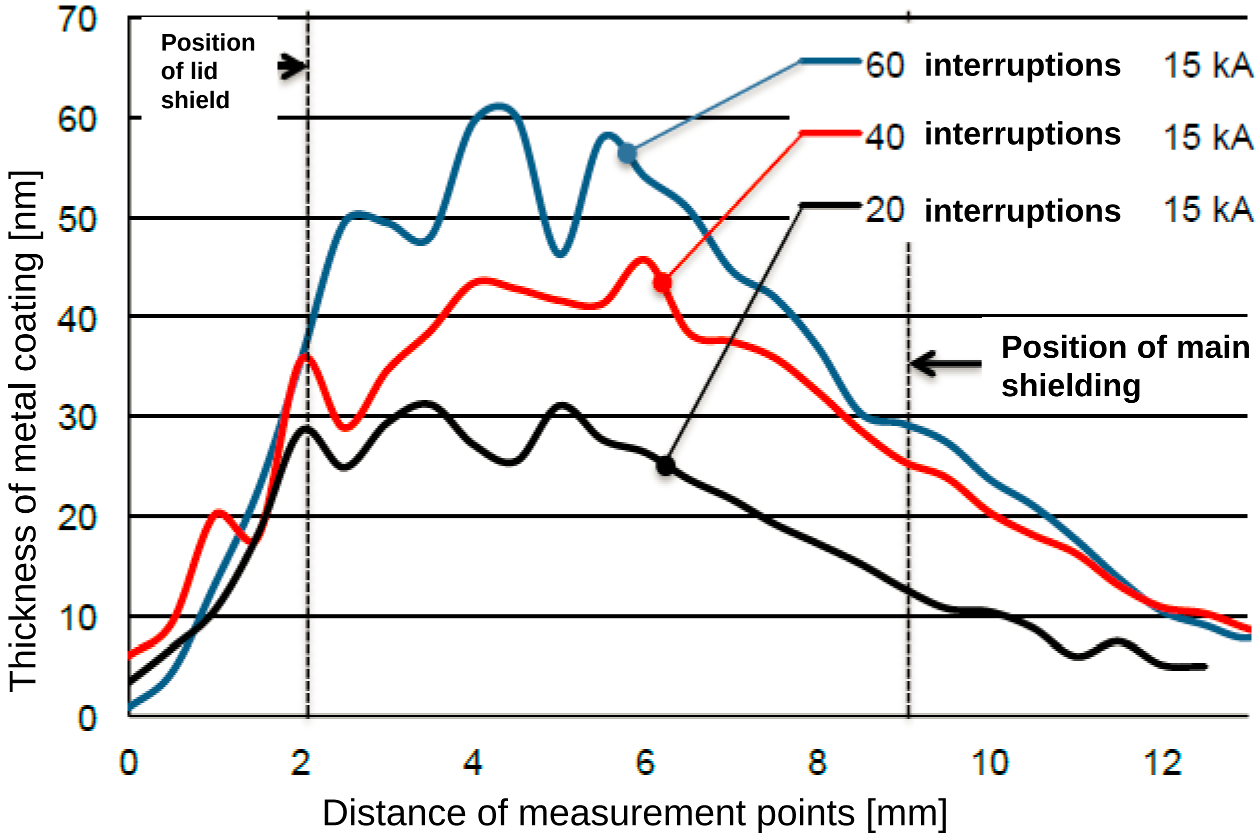


EPMA *(electron probe micro analysis)*

Principle of thickness measurement with EPMA along a line scan shown at 30 ° from the ceramic cylindrical tube section-unwinding

Technical data and test results

Technical details of surface layer



Developing of metal vapor coating thickness on the surface of the fixed contact side ceramic, three vacuum interrupters according to a **different number of interruption operation** under load @ **15kA$_{eff.}$**

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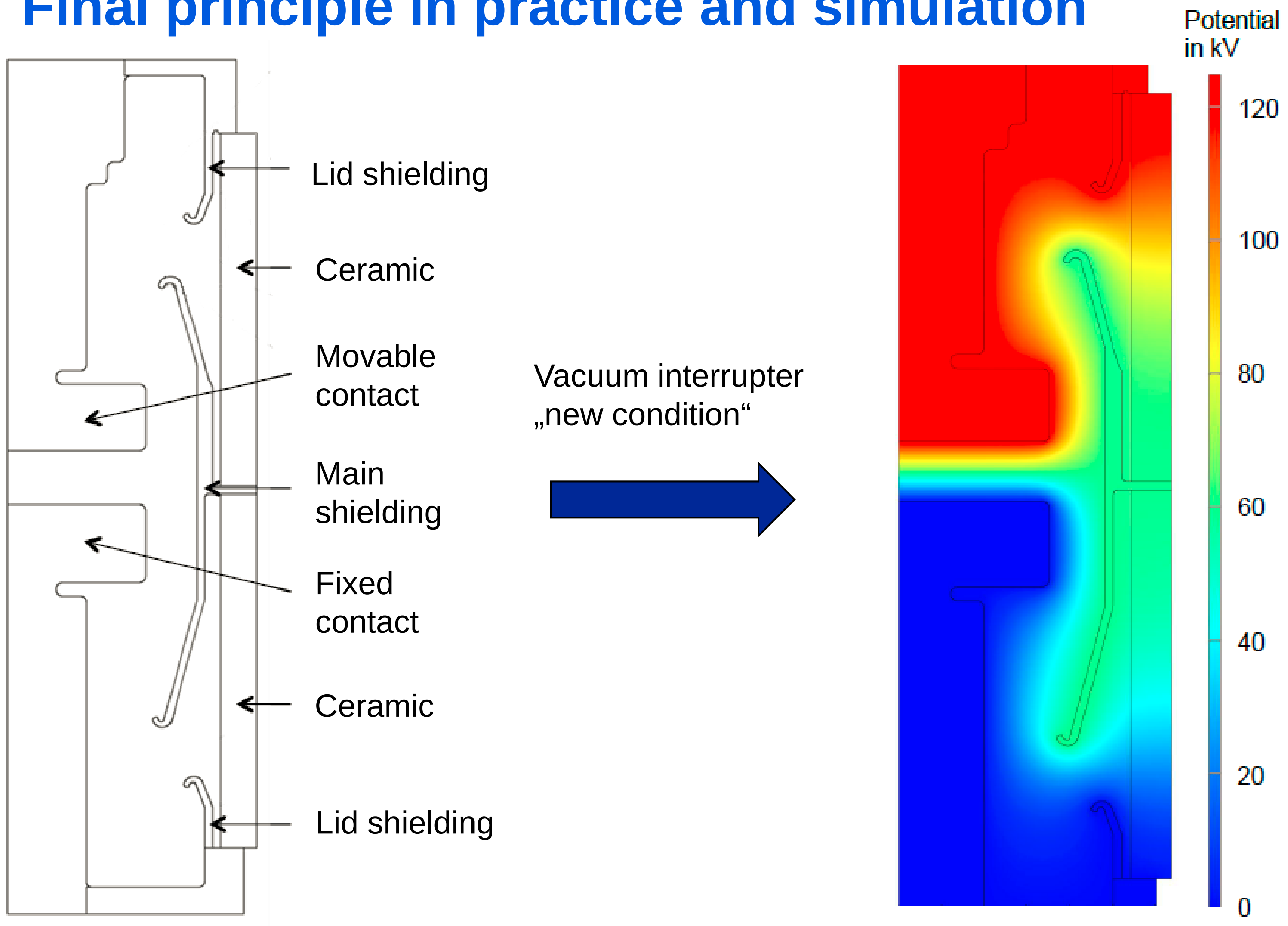
Technical data and test results

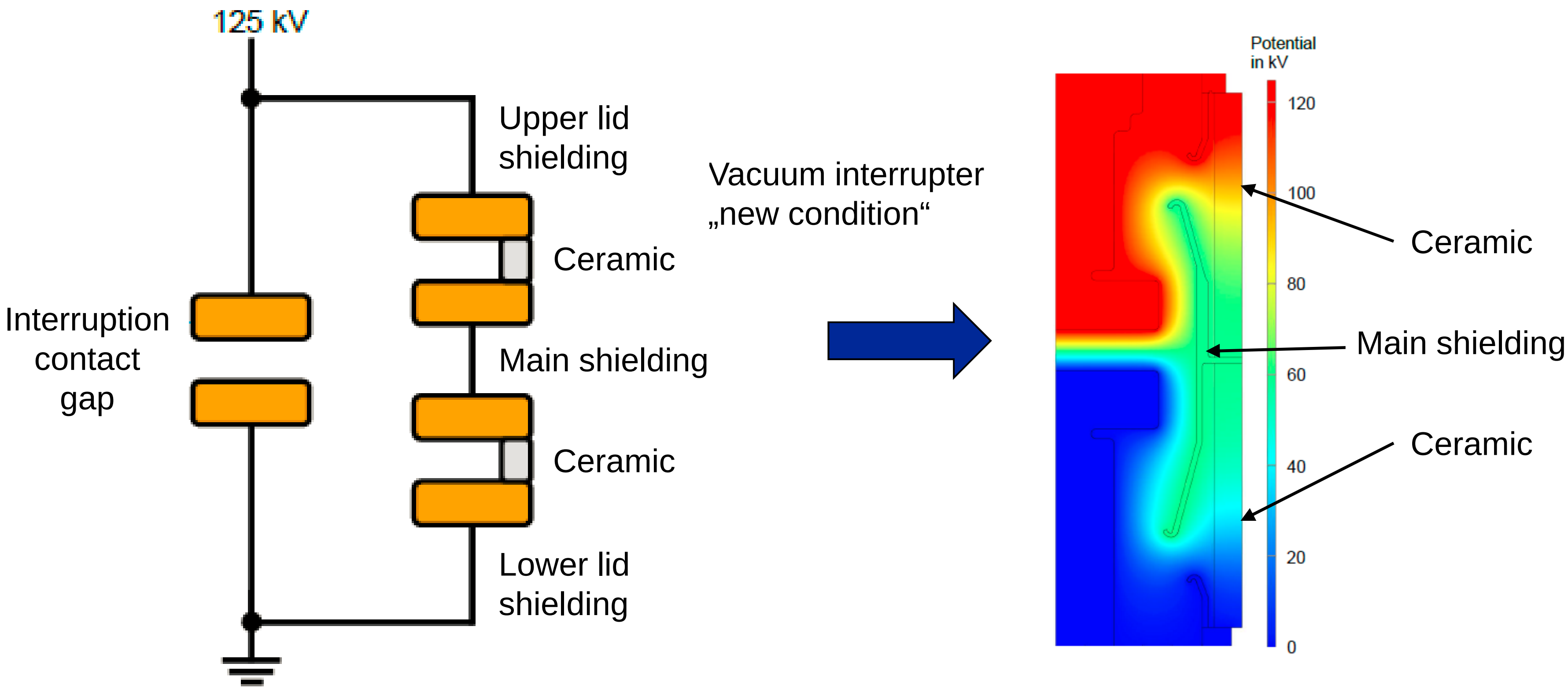
Final principle in practice and simulation



Simulation geometry of the investigated vacuum interrupter in Comsol

Technical data and test results

Final principle in practice and simulation



Simplified representation of vacuum interrupter as interconnection possible breakdown routes.

Simulation geometry of the investigated vacuum interrupter in Comsol

Technical data and test results

Final principle in practice and simulation

- In new condition the lightning impulse withstand voltage of the investigated vacuum interrupter can be easily reached within the "open – gap" design.
- The influence of short circuit current interruption on the lightning impulse withstand voltage of vacuum interrupter can be seen at the "open – gap" shield design.
- Metal vapor impact at the inner ceramic surface in the vacuum interrupter shows a significant influence on reducing the lightning impulse withstand voltage.
- The investigation on the gap between the contacts and the knowledge of the shielding concept and design is linked.
- The main influence of the shielding design is an important point to keep the dielectric performance on high dielectric strength.

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Technical data and test results
Practice application and final practise

- Based on more than 30 years of experience the shield design is optimized for all vacuum are being introduced for use in the medium voltage range.

- The vacuum interrupter are divided into two main groups: In order to create cost optimized solution the “open – gap” between the lid shielding and the main shielding (on floating potential) is based on this investigation enhanced and the dielectric performance could be significantly increased.

- In case there is enough space between the shielding -in radial direction- the shielding design concept will by far improve the situation.

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Vacuum interrupter principle
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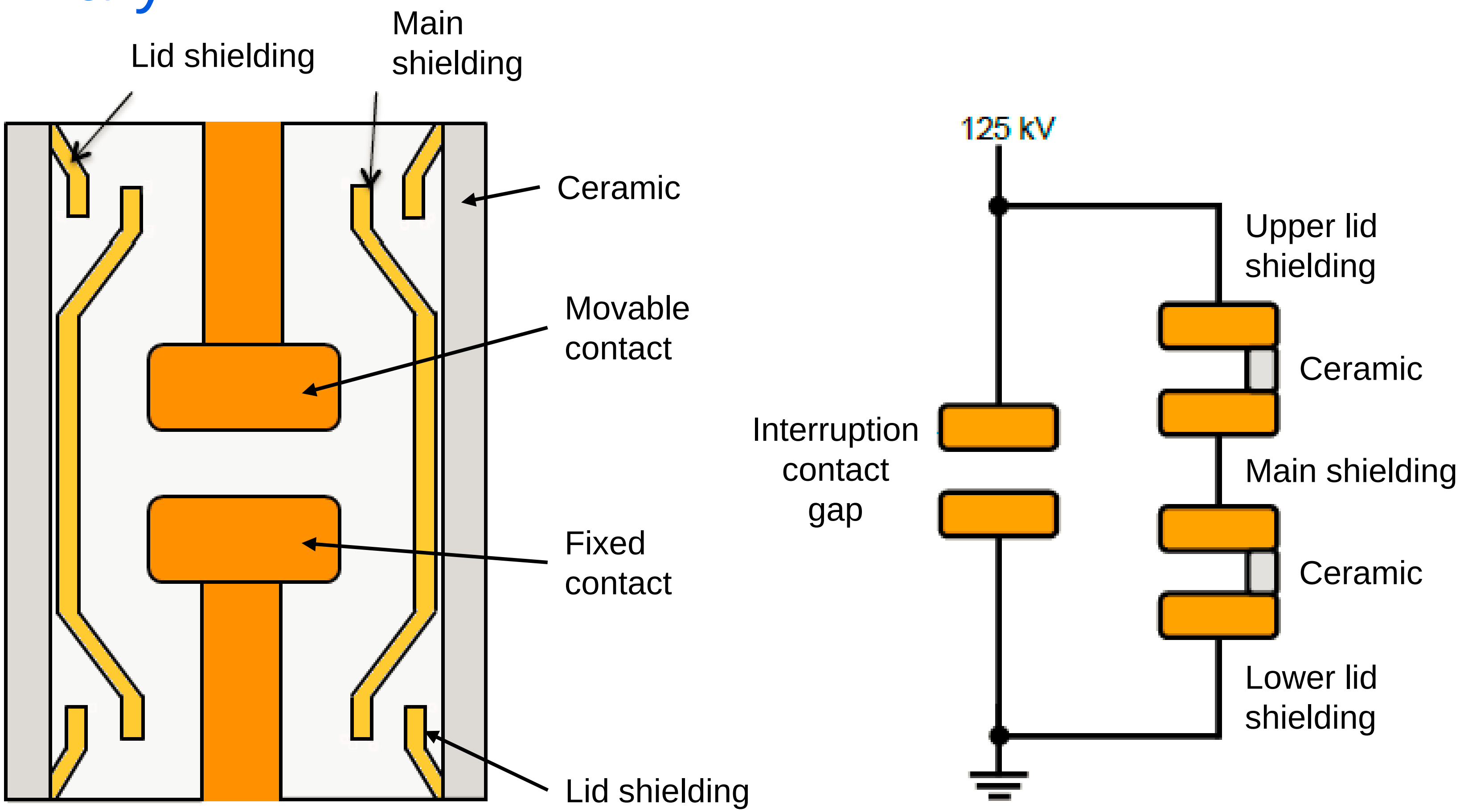

Schematic diagram of overlapping (concentrically shielding) condensation shielding

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