Simulation And Verification Of Thermal Modelling To Prevent From Damages Caused By The Use Of HH Fuses

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Summary of ICEFA 2015 Contribution

4 years ago

Damage avoidance due to the use of high voltage hrc fuses and temperature monitoring

TECHNISCHE UNIVERSITÄT DRESDEN 2015 ICEFA
10th International Conference on Electric Fuses and their Applications

Damages Caused By Hrc Fuses

Destroyed fuse tube

Exploded fuse

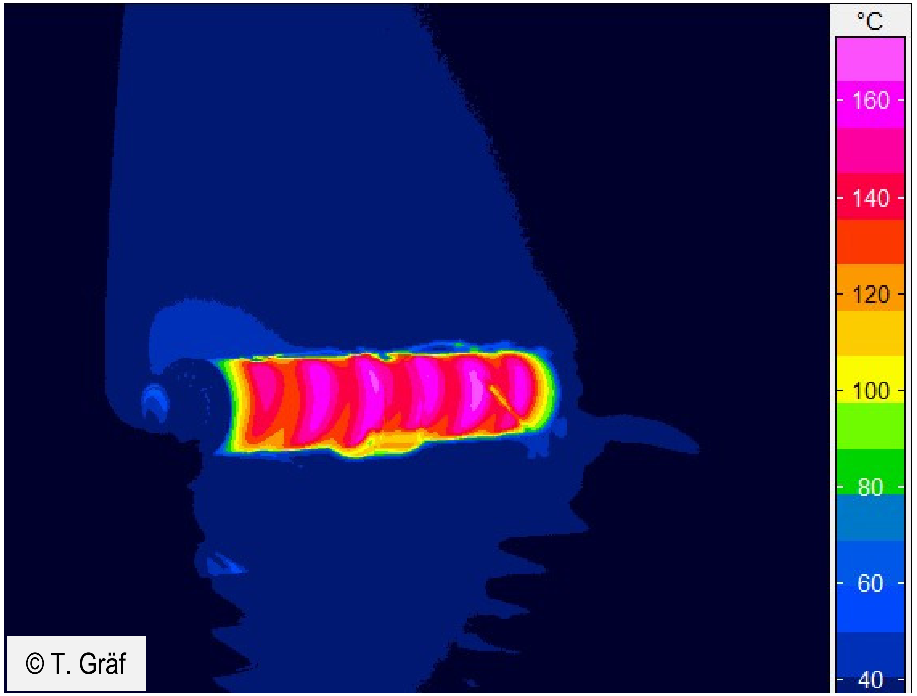
Gis switchgear

Ais switchgear

destroyed medium voltage switchgear as a result of a blown-up hv hrc fuse with the occurrence of arcing

Detection Of Degraded Fuses By Thermography

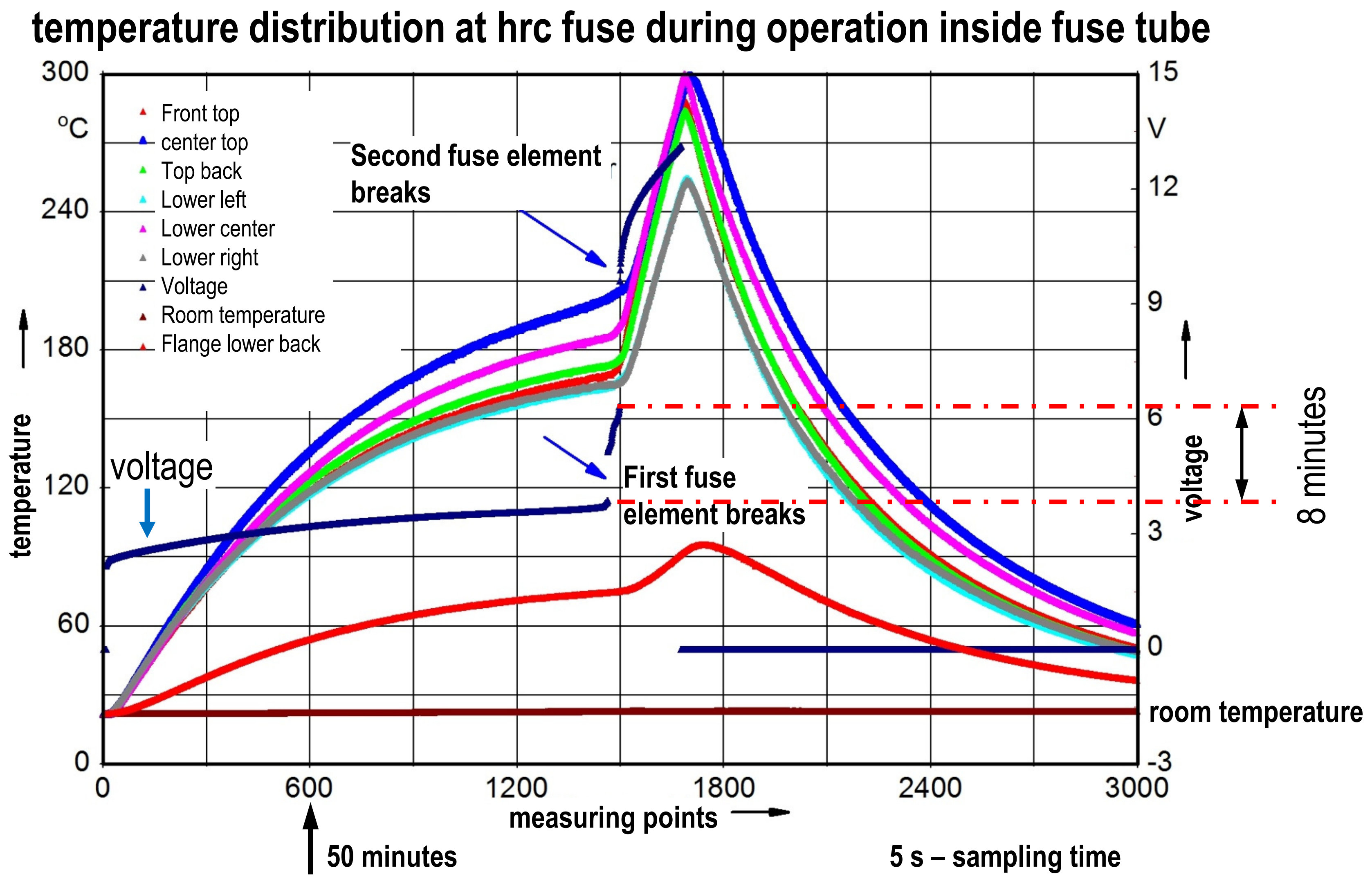
Thermograpy of a fuse with four fuse elements.
One broken fuse element.



How is it possbile to detect
Fuses with broken fuse elements
While there is high voltage present?

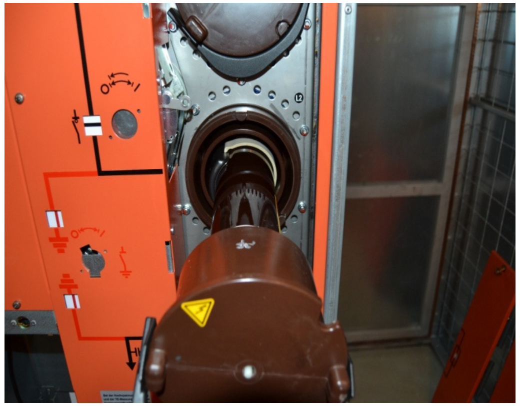
The detection of degraded fuses is possbile only while the hrc fuse heats up.

Temperature profile at Hrc Fuse with breaking fuse elements

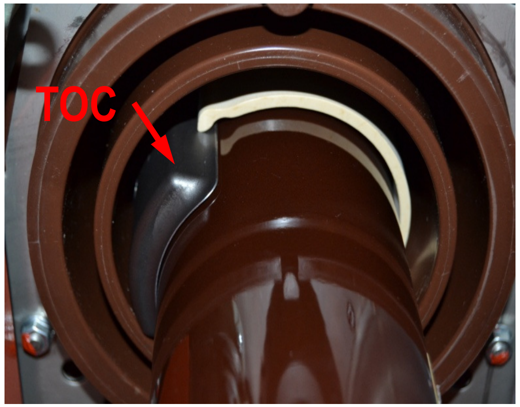


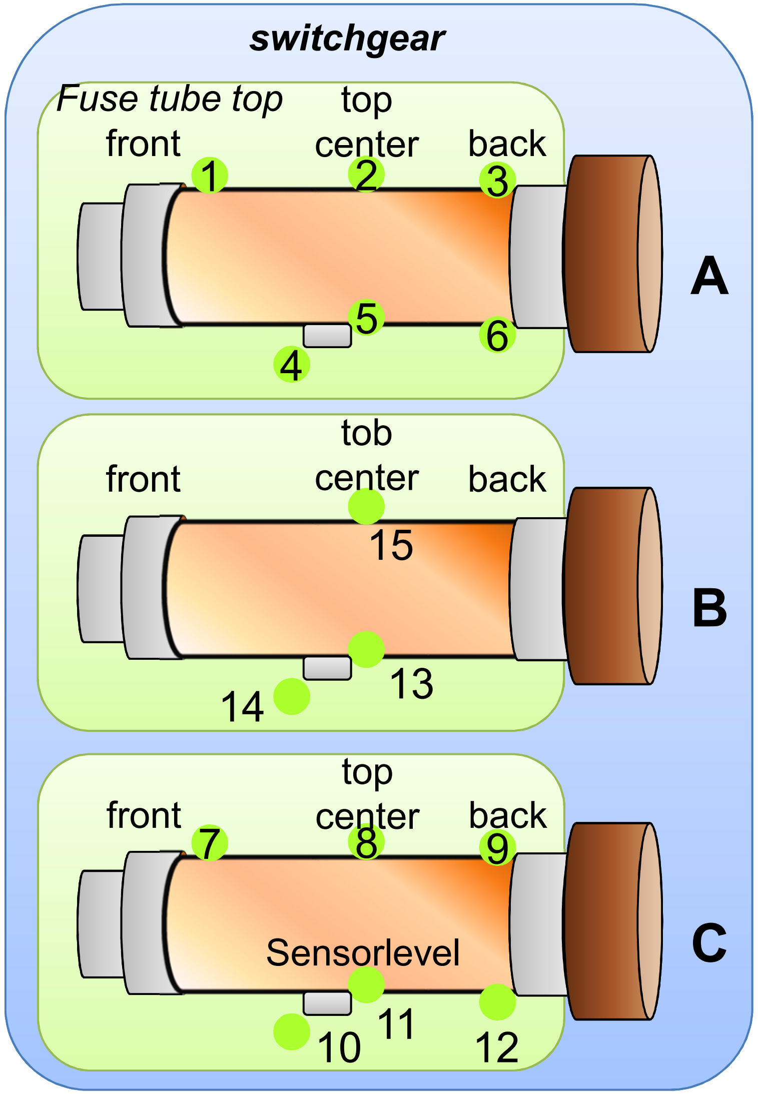
Temperature Measurement Inside Switchgear With TOC fuse Sensor

Fuse with switchgear



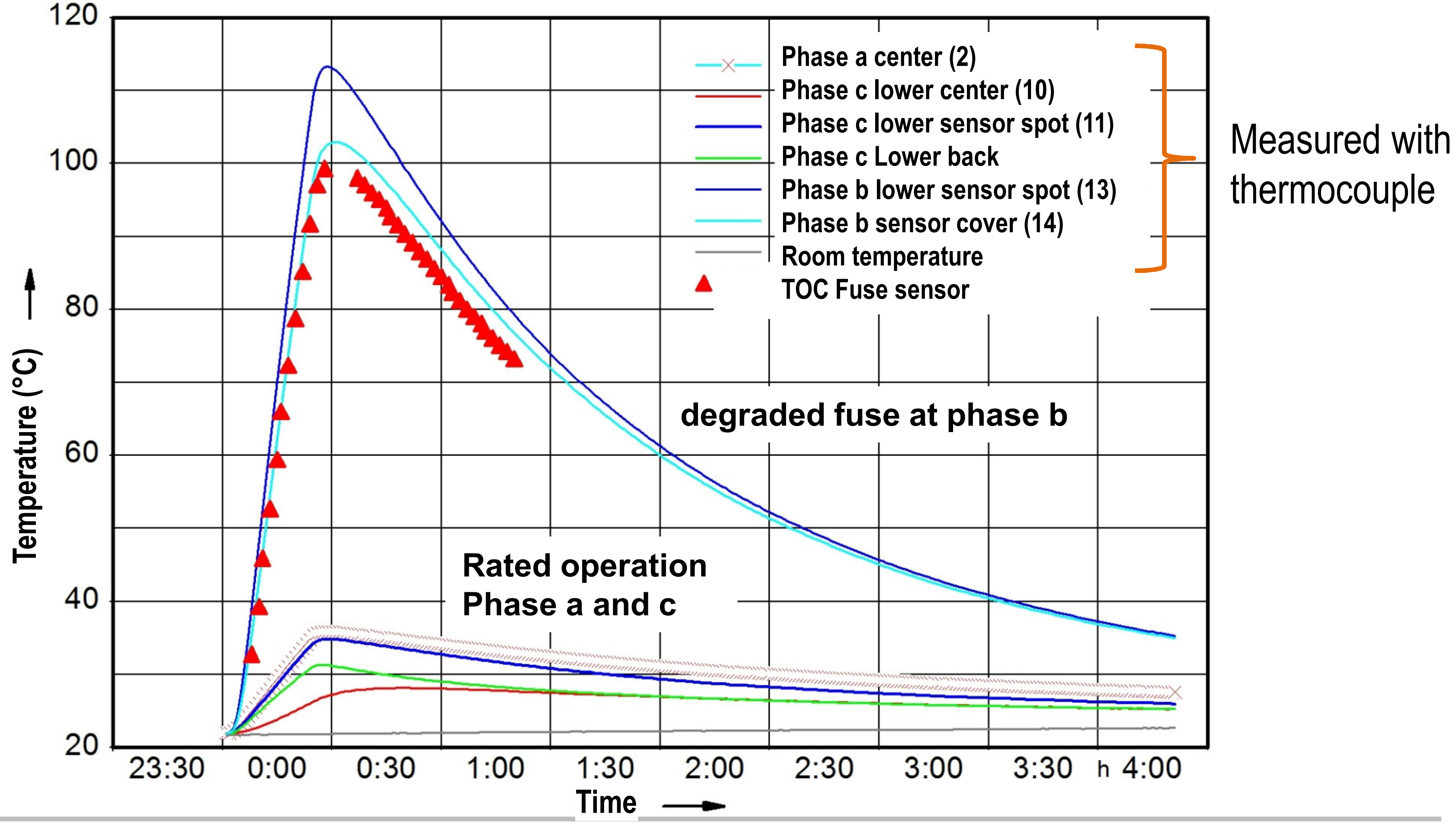
TOC at hrc fuse



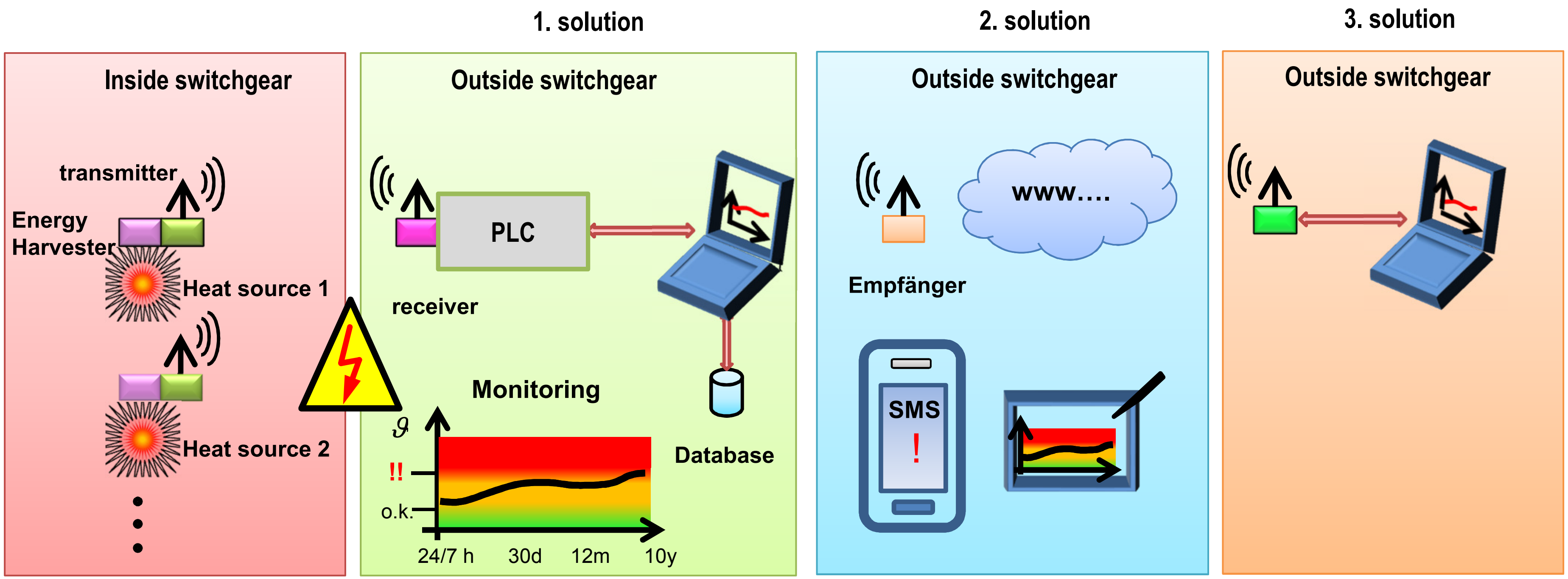


Temperature Measurement Inside Switchgear With TOC fuse Sensor

temperature distribution at hrc fuse during operation inside fuse tube with one broken fuse element



Temperature Measurement Inside Switchgear



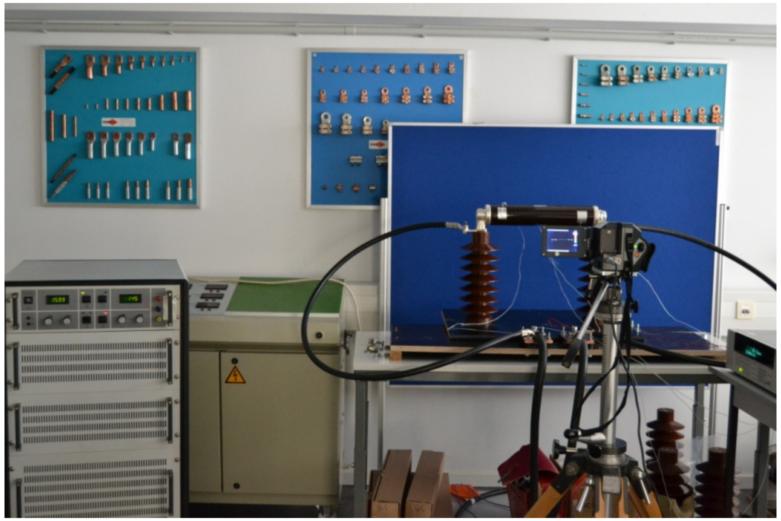
Long-term monitoring for creepage changes

Short-term monitoring notification
SMS, Email

Punctual short-term oberserv.
Service
Datalogging

Temperature Measurement At HV Hrc Fuse In The Lab

20 minutes later in the lab …



Root cause for the explosion

„Quartzsprung“ at 573°C which means an increase of the density by 0,8 % from alpha-quartz to beta-quartz in conjunction with a high rate of temperature rise

And the porcelain body does not give in, is not elastic.

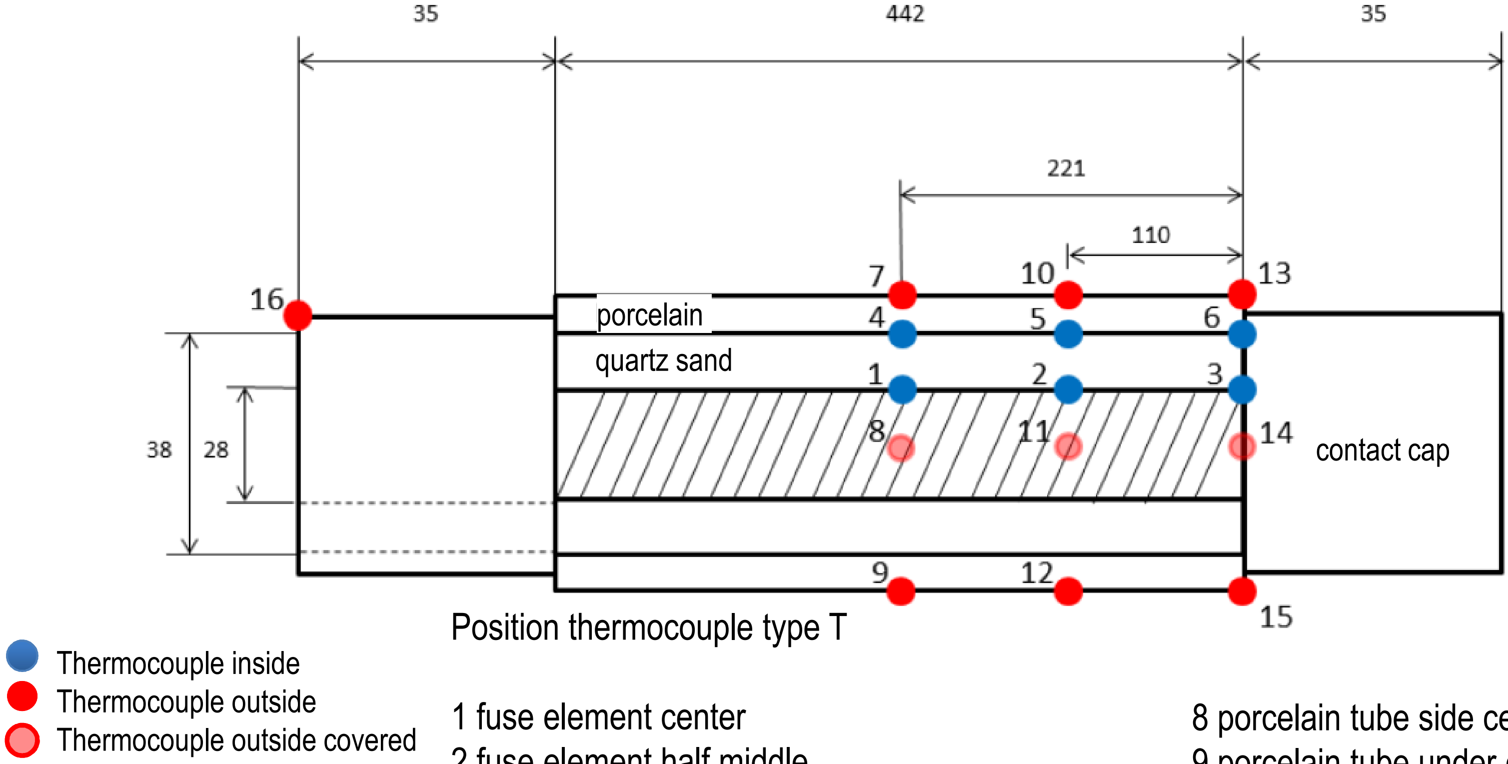
Motivation To Continue The Research …

1. Sensor system is available for temperature measurement at high voltage level
2. It is possible to measure the rate of rise of the degraded hrc hh fuse to judge the condition of the fuse at their surface

But it is necessary to know the temperature at the fuse elements to know the internal temperature and to avoid the critical temperature at 573°C.

How is it possible to get to know the internal temperature of the fuse elements?

Temperature Metering Points For Measurement And Simulation

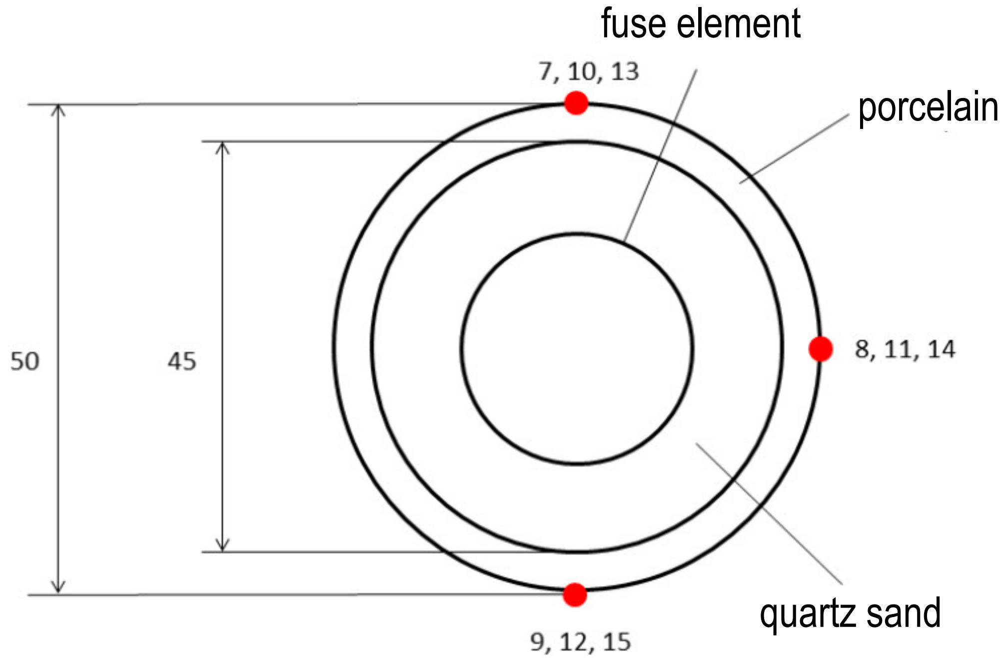


Position thermocouple type T

1 fuse element center
2 fuse element half middle
3 fuse element outside
4 inside porcelain tube
5 inside porcelain tube half middle
6 inside porcelain tube outisde

Position Thermocouple Typ K
7 porcelain tube center
8 porcelain tube side center
9 porcelain tube under center
10 porcelain tube top half middle
11 porcelain tube side half middle
12 porcelain tube under half middle
13 porcelain tube top outside
14 porcelain tube side outside
15 porcelain tube down outside
16 contact top

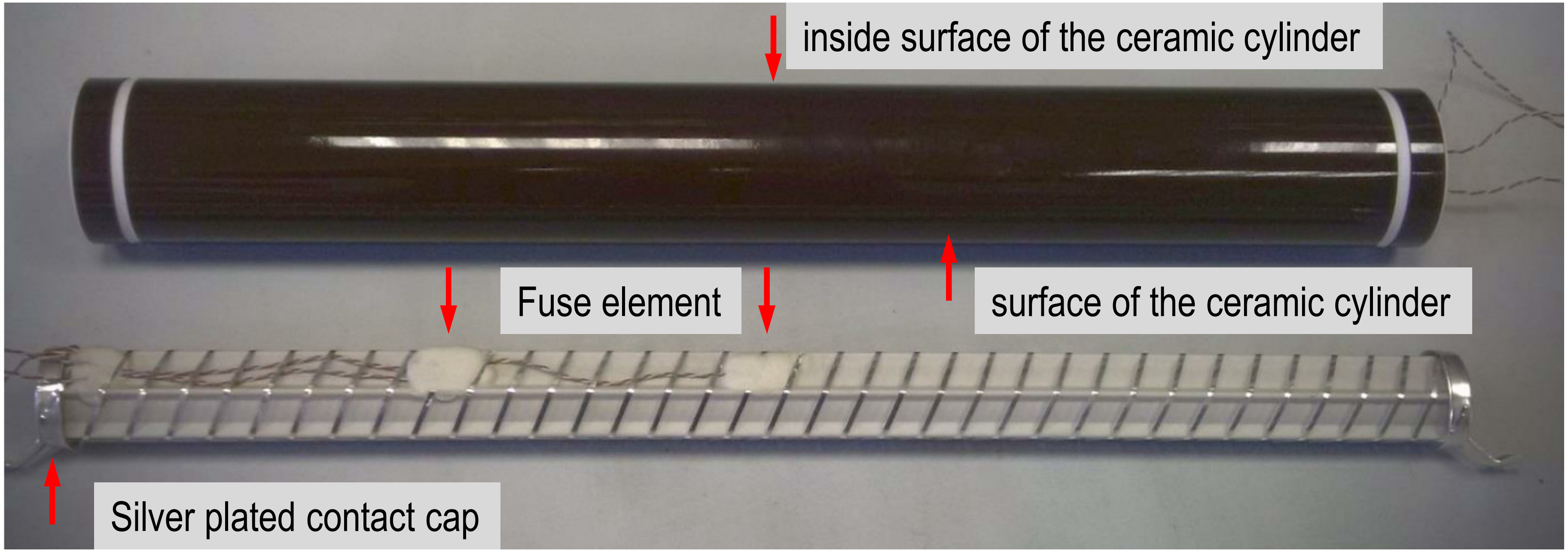
Temperature Metering Points For Measurement And Simulation



Position of the thermocouple and cross section of the fuse

Preparation Of Hrc Fuse With Thermocouple

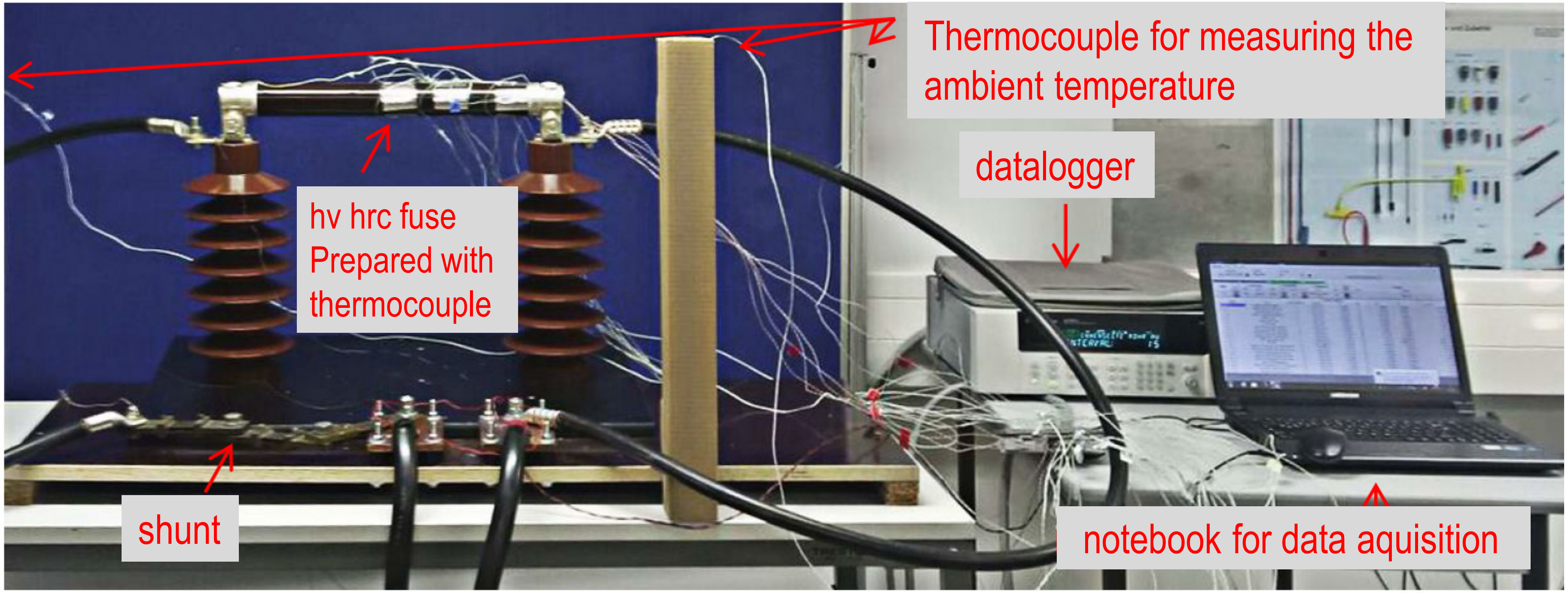
Different locations of fixed thermocouple



SIBA HHD 40 A BU 10/24 kV

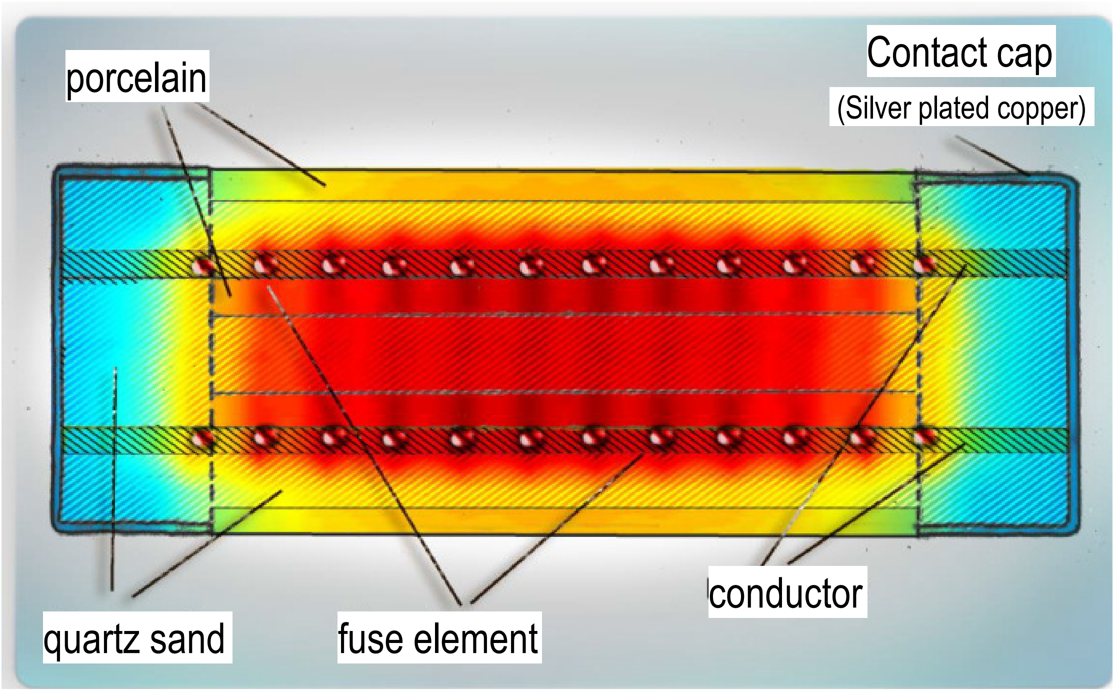
Provisions for comparison of simulation and measurement

Test Set-up For The Verification Of The Thermal Model



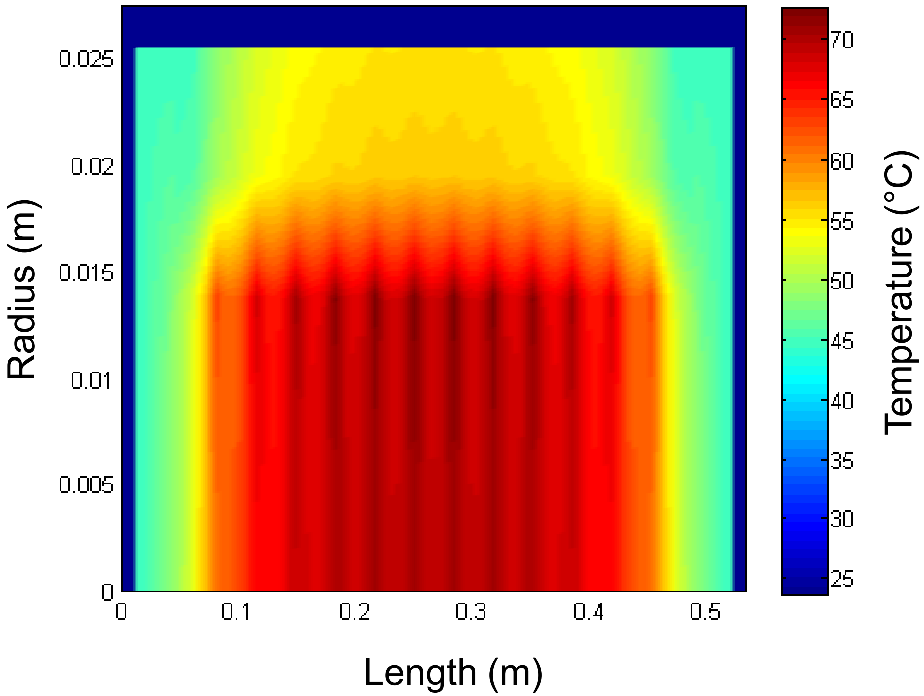
Test set-up with prepared fuse **datalogger**

Cross Section Of The Investigated Modell And Fuse

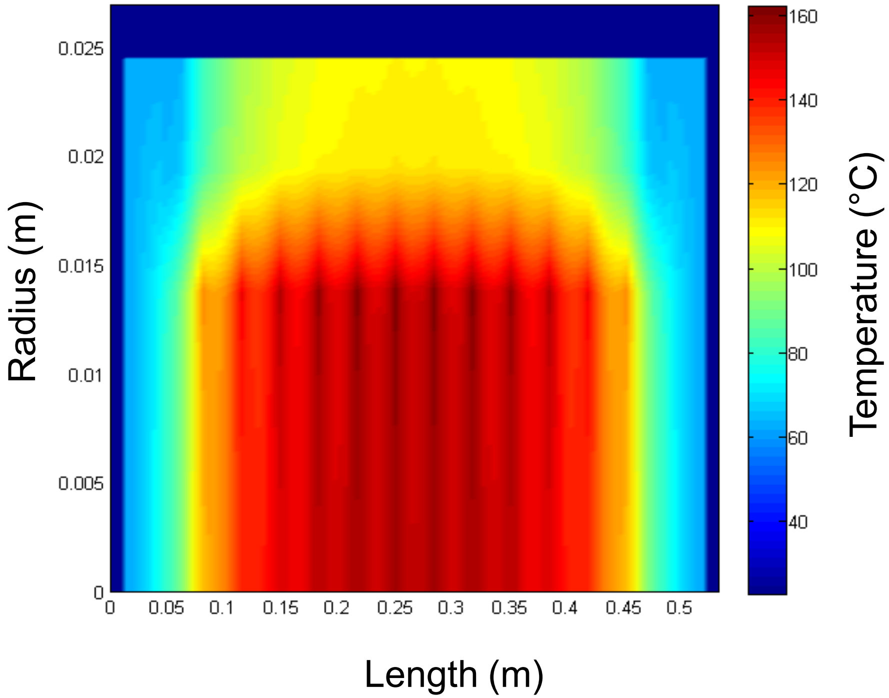


Simulated Temperature Distribution At 20 A And 35 A

Simulation with 20 A



Simulation with 35 A



Considerations For The Thermal Simulation - Modelling

Use of the finite volume method

Equation for heat transfer of rotational symmetrical bodies

$$\Delta\vartheta = \frac{1}{r}\cdot\frac{\partial}{\partial r}\left(r\cdot\frac{\partial}{\partial r}\right) + \frac{1}{r^2}\cdot\frac{\partial^2\vartheta}{\partial\varphi^2} + \frac{\partial^2\vartheta}{\partial z^2}$$

$$\rho\cdot c_p\cdot\frac{\partial\vartheta}{\partial t} = \lambda\cdot\left(\frac{1}{r}\cdot\frac{\partial}{\partial r}\left(r\cdot\frac{\partial\vartheta}{\partial r}\right) + \frac{\partial^2\vartheta}{\partial z^2}\right) + \dot{W}$$

c_P	spec. heat capacity	$\frac{J}{kg\cdot K}$
λ	heat conductivity	$\frac{W}{m\cdot K}$
φ	angle	$°rad$
r	radius [m]	m
ρ	density	$\frac{kg}{m^3}$
t	Ttme	s
$\dot{W}$	power density	$\frac{W}{m^3}$
z	length in axial direction	m

Considerations For The Thermal Simulation – Energies

Calculation of the energies from solid to fluid media

Energy tranfer by convection

$$\dot{Q}_{con} = \alpha_{con} \cdot A_0 \left(T_\infty - T_{i,n} \right)$$

Energy tranfer by radiation

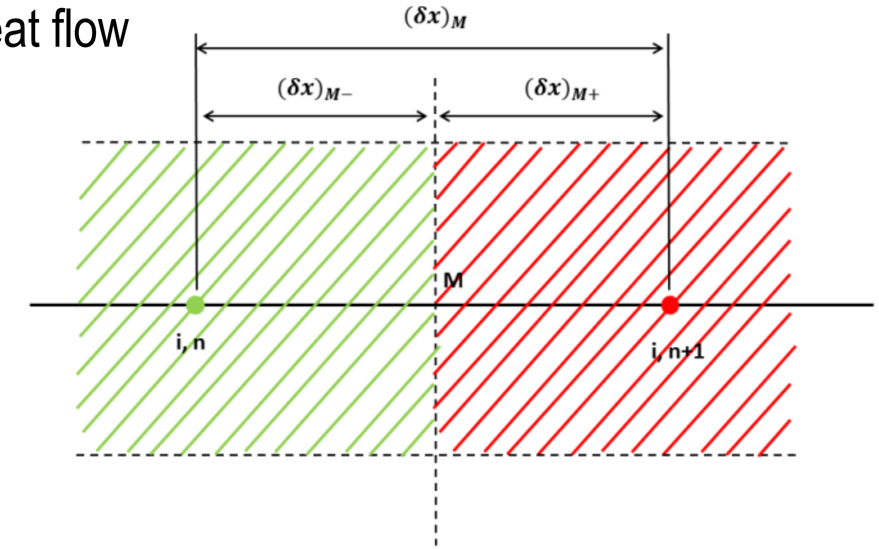
$$\dot{Q}_{rad} = \varepsilon_{12} \cdot A_0 \left(T_\infty^4 - T_{i,n}^4 \right)$$

α_{con}	heat transfer coefficient	$\frac{W}{m^2 \cdot K}$
A_0	surface	m^2
ε_0	emission ratio	$\frac{W}{m^4 \cdot K^4}$
r	radius [m]	m
$\dot{Q}_{rad}$	heat flow	W
T_∞	ambient Temperature	K
$\dot{Q}_{con}$	heat flow	W

Considerations For The Thermal Simulation – Temperature Depending Coefficients

Calculation of the heat transfer from the heat flow

$$q_{rad} = \frac{\lambda_m}{\delta x_m} \cdot \left(T_{i,n} - T_{i,n+1}\right)$$



Calculation of the thermal leakage power

$$P = I^2 R_{ges}$$

$$R_{ges} = R_{20} \cdot (1 + \alpha \cdot (\theta - 20°C) + \beta \cdot (\theta - 20°C)^2)$$

P	thermal leakage power	W
I	Current	A
α	temperature coefficient	$\frac{1}{K}$
β	temperature coefficient	$\frac{1}{K^2}$
R	Resistance	Ω
T	ambient temperature	K

Considerations For The Thermal Simulation – Temperature Depending Coefficients

Calculation of the heat transfer coefficient α_{con}

Nusselt number $$Nu = \frac{\alpha(T_m) \cdot L}{\lambda(T)}$$

Prandl number $$\Pr = \frac{\nu(T_m)}{a(T_m)}$$

Raleigh number $$Ra = \frac{g \cdot \beta \cdot L^3 \cdot |\Delta T|}{\lambda(T)}$$

α	heat transfer coefficient	$\frac{W}{m^2 \cdot K}$
L	length of the melt flow way	m
ν	kinematic viscosity	$\frac{m^2}{s}$
g	gravitation constant	$\frac{m}{s^2}$
β	expansion coefficient	$\frac{1}{K}$
T_u	temperature of the fluid	K
ΔT	temperature difference	K
a	conductibility of temperature	$\frac{m^2}{s}$

Considerations For The Thermal Simulation – Temperature Depending Coefficients

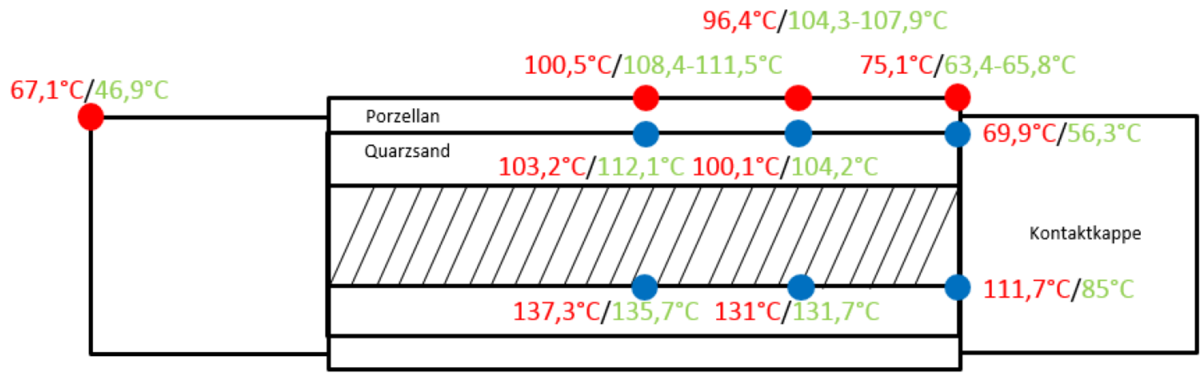
Calculation of the temperature depending heat transfer coefficient $\alpha_m(T)$

$$\alpha_m(T) = \frac{\lambda(T)}{L} \cdot \left(\left(0{,}825 + 0{,}387 \cdot \left[\frac{g \cdot L^3 \cdot |\Delta T|}{\nu(T_m) \cdot a(T_m) \cdot T_U} \cdot \left(1 + \left[\frac{0{,}492 \cdot a(T_m)}{\nu(T_m)} \right]^{\frac{9}{16}} \right)^{-\frac{16}{9}} \right]^{\frac{1}{6}} \right)^2 + 0{,}87 \cdot \frac{L}{d} \right)$$

Nusselt number Raleigh number Prandl number

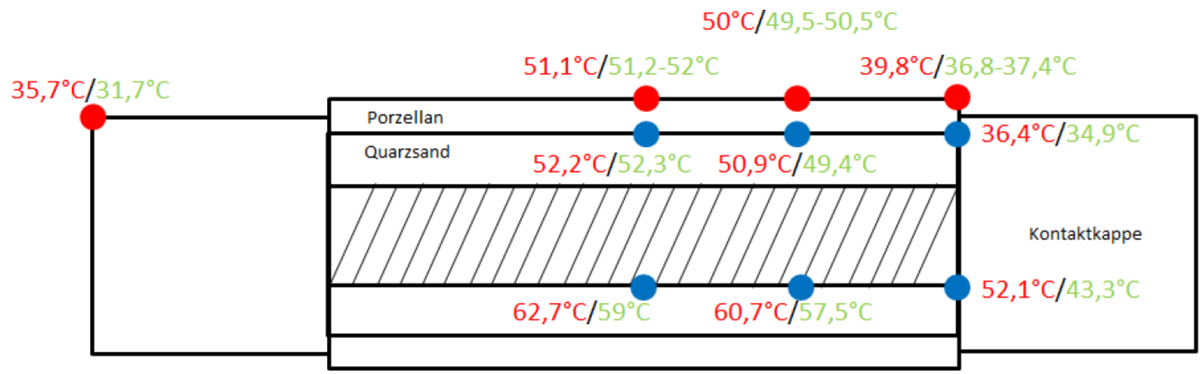
It´s necessary to calculate for vertical and horizontal direction of the fuse different heat transfer coefficients $\alpha_m(T)$!

Comparisson Between Simulation And Measurement



Load current 35 A

- Thermocouple inside
- Thermocouple outside
- Calculated Temperature
- Measured Temperature



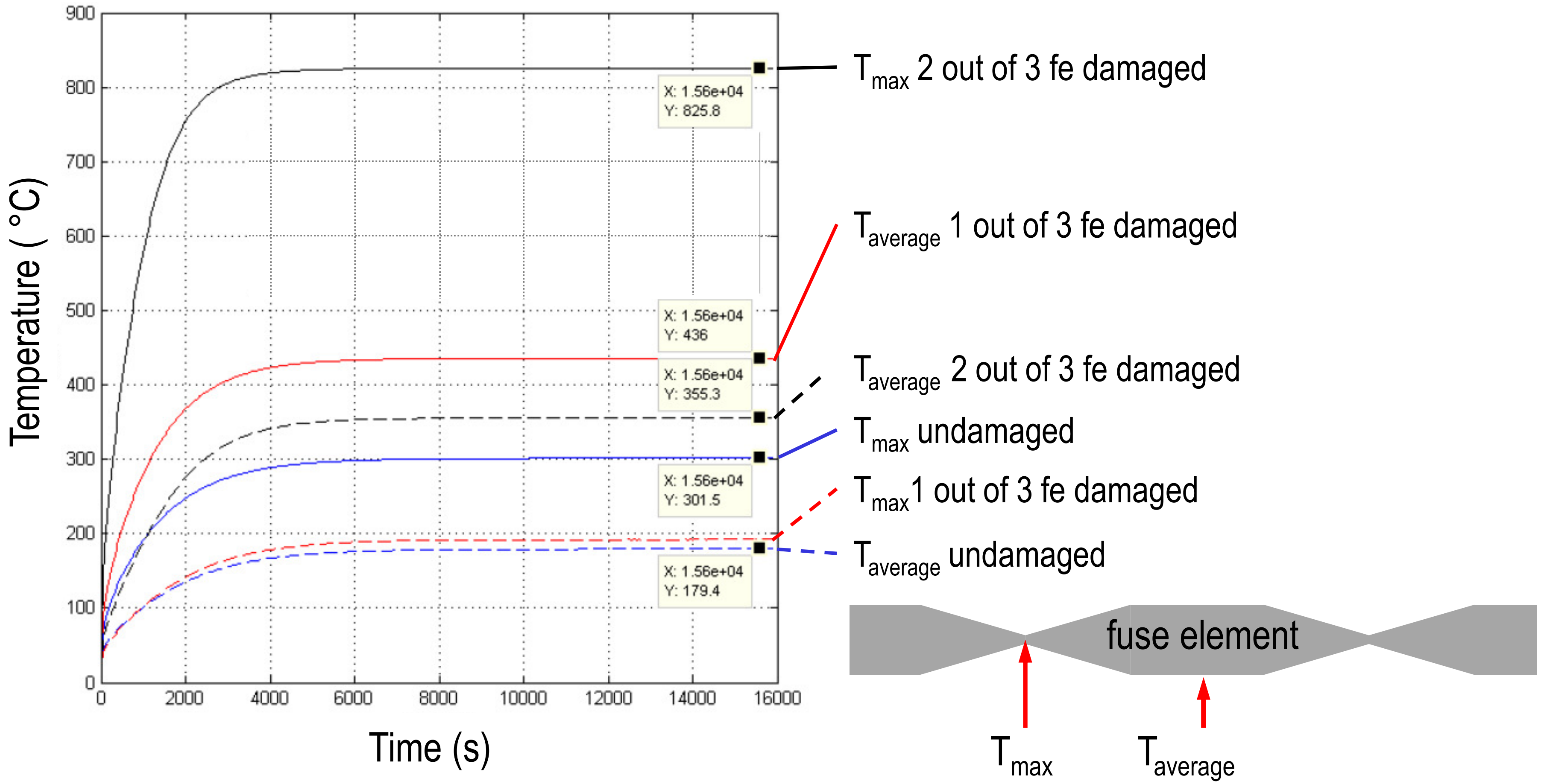
Load current 20 A

- Thermocouple inside
- Thermocouple outside
- Calculated Temperature
- Measured Temperature

At high load increasing differences between calculated and measured temperatures.

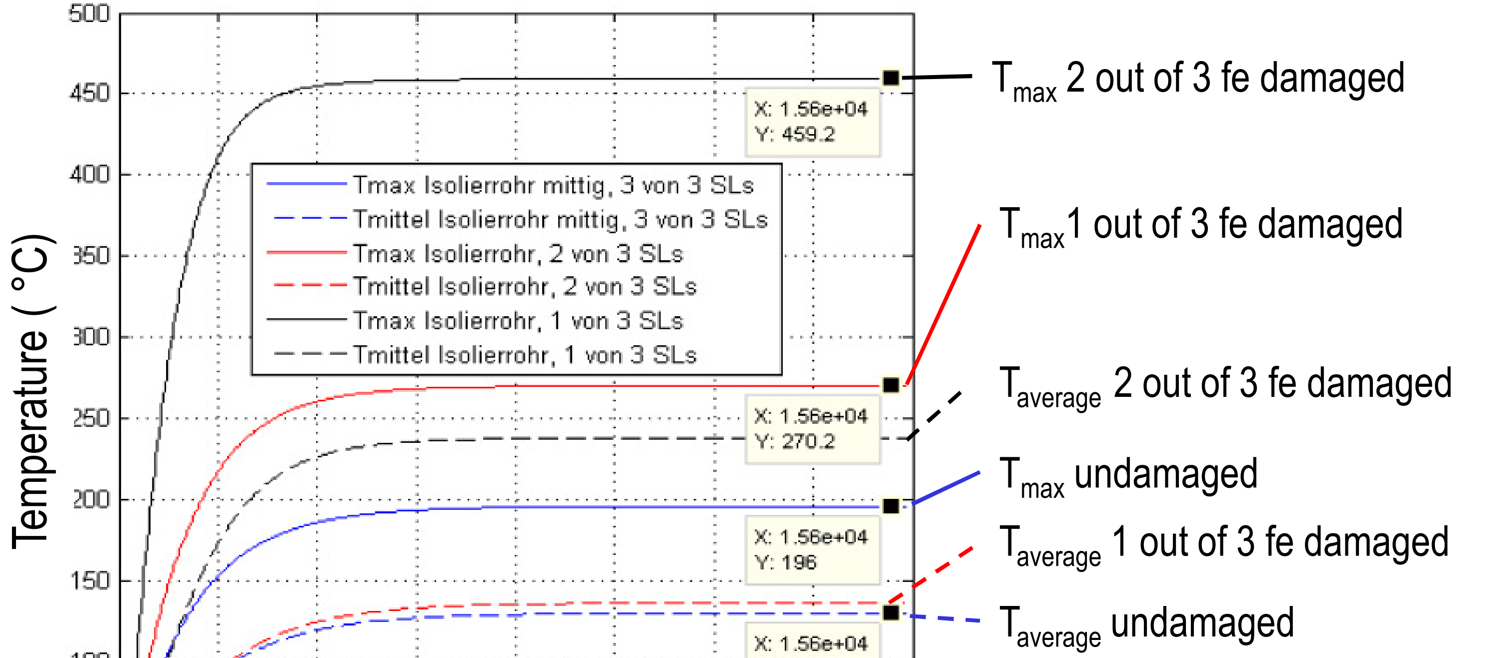
Comparisson Between Simulation And Measurement

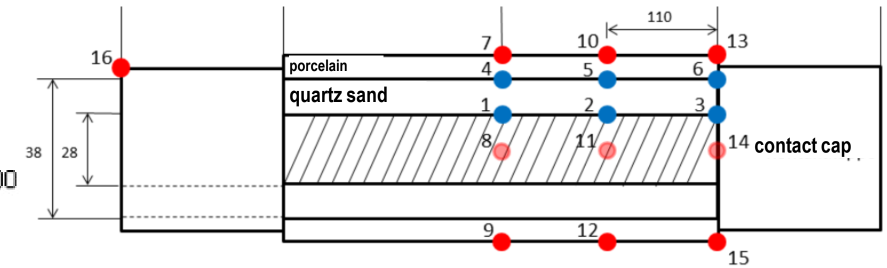
Calculation of the temperature of the fuse elements
(position 1) at different number of damaged fuse elements (fe) and load 40 A



Considerations For The Simulation And Measurement Of Fuses

Calculation of the temperature at the surface of the porcelain tube (position 7) at different number of damaged fuse elements (fe) and load 40 A





Conclusion

- Thermal Modelling allows forecast of internal temperature distribution and the avoidance of failures
- Variations of the quartz sand density while the fuse is in production leads to high variation in the thermal conductivity and thermal behaviour
- Rate of temperature rise indicates the degradation of hv hrc fuses and is a good criteria for degradation detection by TOC fuse sensor system
- Available TOC fuse sensor system is ready for industrial application
- Online calculation at the moment not possible due to the needed calculation power

Acknowledgment

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SIBA
Sicherungen | Fuses

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Thank you for your attention!