Investigation of **mechanical degradation mechanism** onto the quench heater insulation to Nb_3Sn coil

TE-MSC-LMF
Felix Wolf, Arnaud Foussat and Jan Petrik
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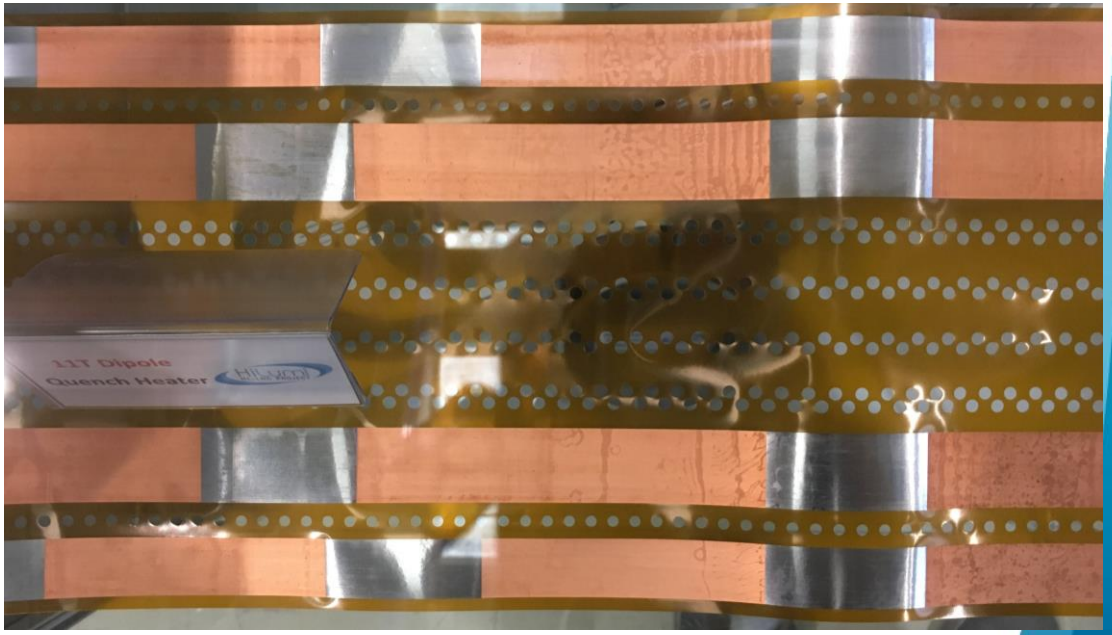


Quench heater of the 11T dipole magnet, placed in the show box in front of the winding hall in bldg. 180.

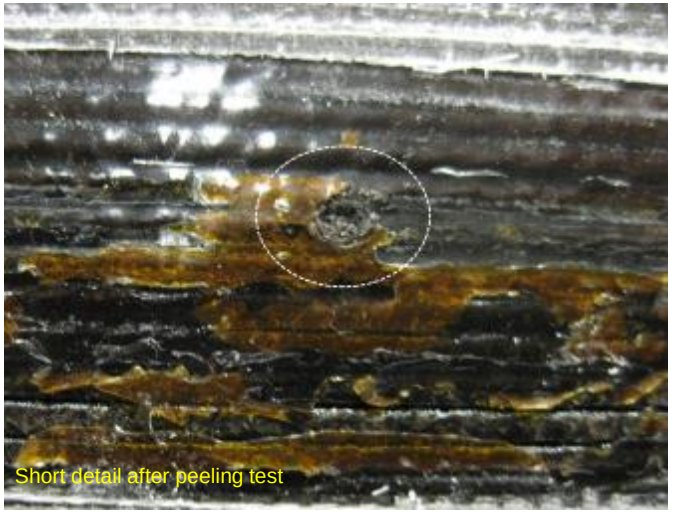
Investigation of mechanical degradation mechanism onto the quench heater insulation to Nb_3Sn coil

Introduction

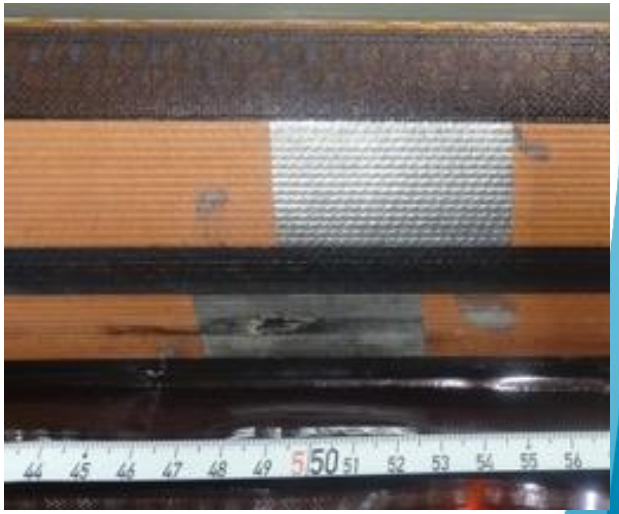
Findings on MBHP001 - CR06-07

- Direct shorts provoked in collared coil state was found in **same cross sections on paired coils**, residual resistance of few Ohms.

Short after successive C bank discharges in CR06



Short detail after peeling test



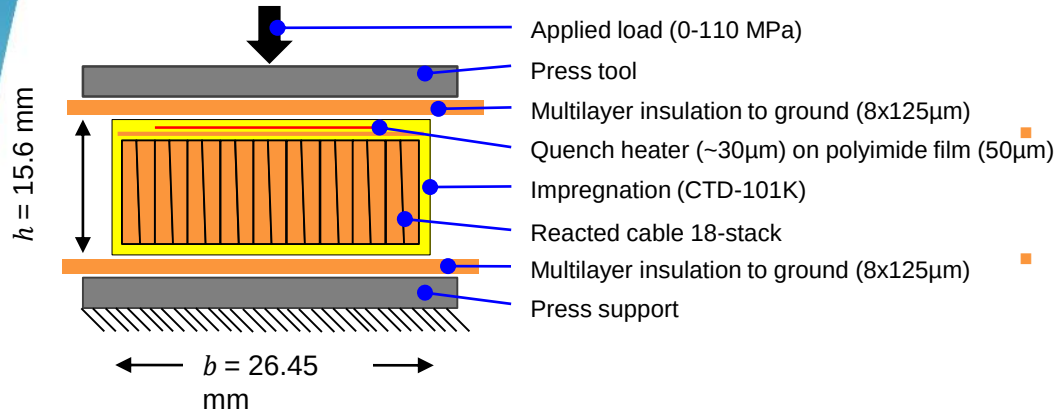
Type of direct short defect created in extended Hi-pot test on CR07, (hole diam 2 mm, dumped E tot > 1kJ)

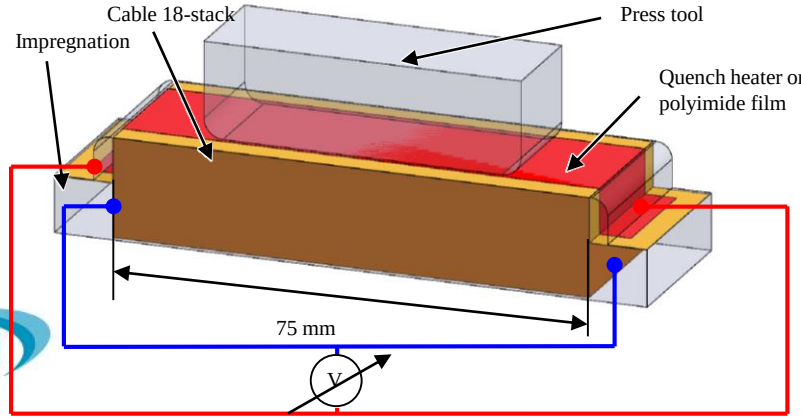
Objective of the study:

Study of **failure mechanism** of the insulation system between quench heater and cable under **compressive load.**

Courtesy of Jan Petrik, 11/01/2019
https://indico.cern.ch/event/778100/

Investigation of mechanical degradation mechanism onto the quench heater insulation to Nb_3Sn coil Compressive load





- **Objective:**
  - Study of **failure mechanism** of the insulation system between quench heater and cable under **compressive load**
- **Test:**
  - Compressive test + online leakage current measurement
- **Sample:**
  - 11T Nb_3Sn Rutherford cable (H150 C02 244A)
  - Mica insulation + fibre glass braiding (identical to coil 108)
  - 18-stack with cancelling keystone angle
  - Impregnated quench heater (11T Non-Conform 1st Trackwise piece 08.03.2018)
- **Test machine:**
  - 180 kN hydraulic press, equipped with calibrated load cells Burster type 8526 (0-200kN)
  - Steel press tool, insulated with multilayer 0.125mm polyimide film
  - Electrical measurement device (Keithley 6487 pico amper meter)

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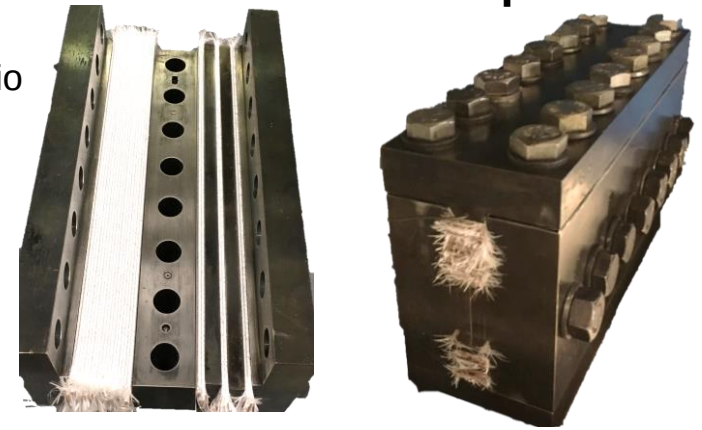
Status of sample preparation for compressive load scenario

Ceramic binder curing
- Cycle 80ºC (1h), 150ºC (2h)

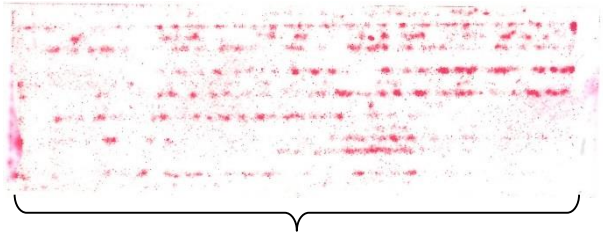
Reaction heat treatment
- Cycle 20ºC/h to 650ºC (20h) (Bldg. 927)

Impregnation
- New mould to apply radial and transversal compression
- Vacuum impregnation with CTD-101K

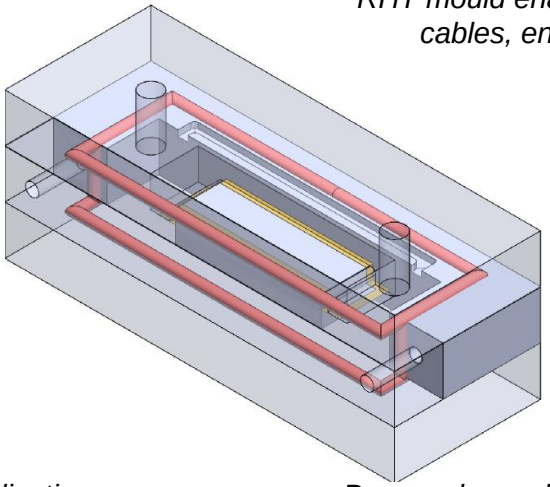
Samples with varying insulation thickness (S2-glass fibre)
- 250 µm (2 samples)
- 250-200 µm (2 samples)
- 200 µm (3 samples)
- <150 µm (3 samples)



RHT mould enabling clearance variation for up to 18 cables, enables ceramic binder application



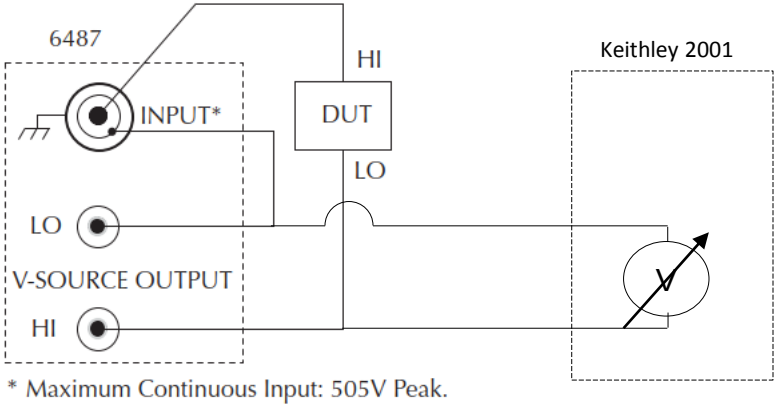
Pressure sensitive film FUJI-LW indicating a pressure range between 2.5-10 MPa during a test assembly.



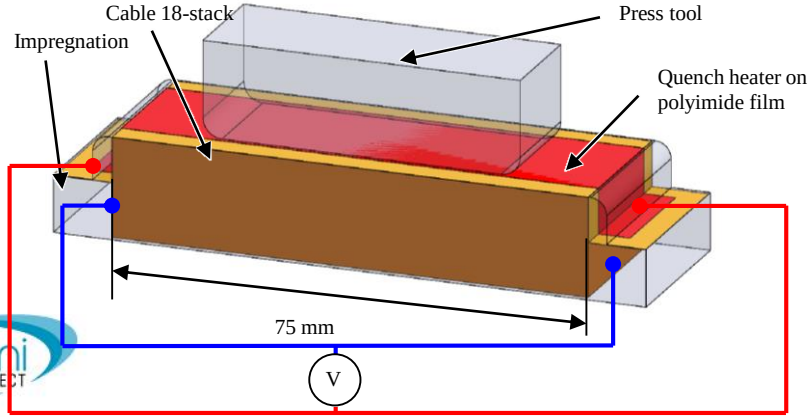
Prepared sample in the impregnation mould which enables radial and transversal compression

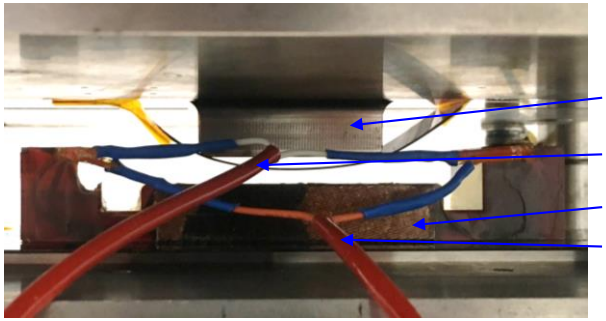
Investigation of mechanical degradation mechanism onto the quench heater insulation to Nb_3Sn coil

Test equipment

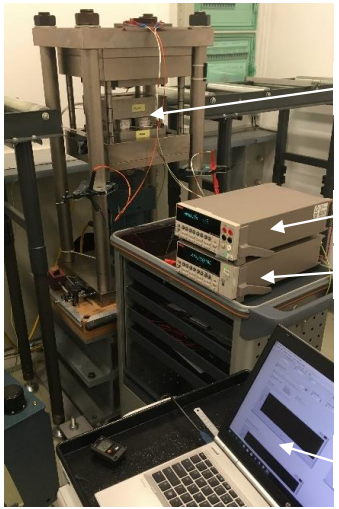


* Maximum Continuous Input: 505V Peak.





Sample with electrical connections installed in the press gap

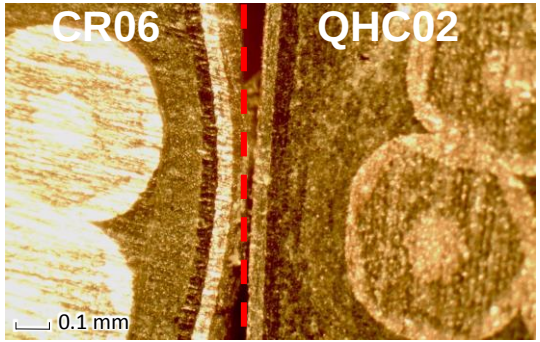


Test machine with measurement equipment

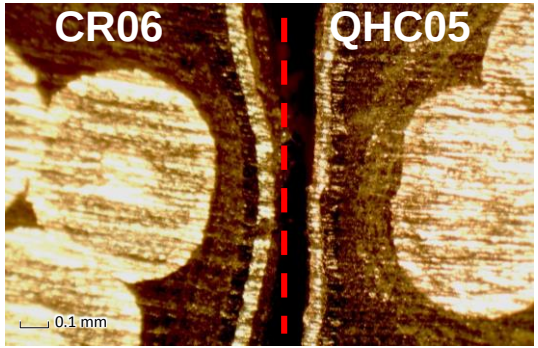
Investigation of mechanical degradation mechanism onto the quench heater insulation to Nb_3Sn coil

Microscopic analysis of the insulation thickness

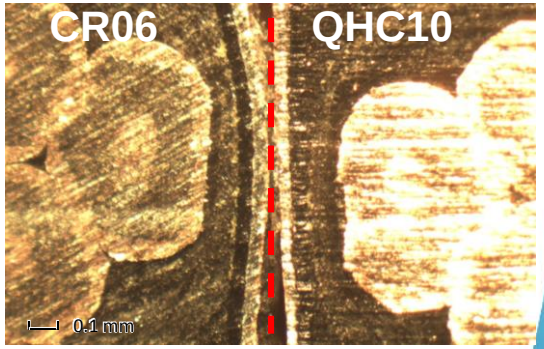
- Samples prepared with varying insulation thickness adjusted by impregnation mould clearance
- Insulation thickness determined by microscopy (**fibre glass + polyimide**)
- Contact pressure determined with LW Prescale film



150µm insulation CR06
250µm insulation QHC02
Contact pressure <2.5 MPa (local)



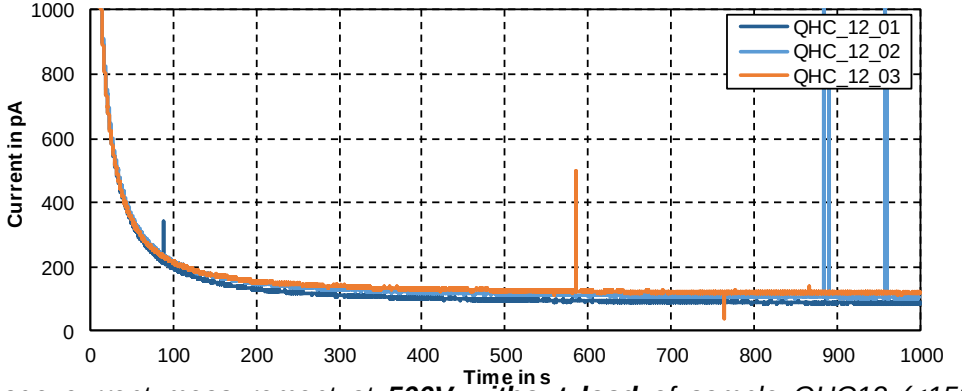
150µm insulation CR06
200µm insulation QHC05
Contact pressure >2.5 <10 MPa (local)



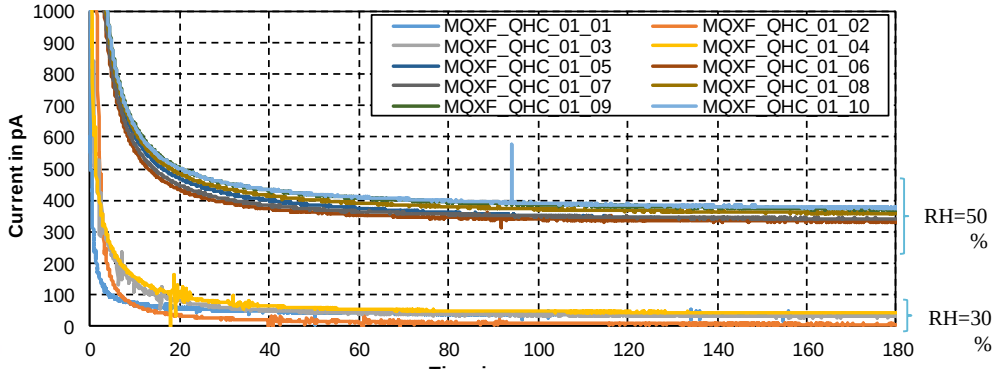
150µm insulation CR06
150µm insulation QHC10
Contact pressure >2.5 <10 MPa (local)

Investigation of mechanical degradation mechanism onto the quench heater insulation to Nb_3Sn coil

Leakage current measurement **without applied** pressure



*Leakage current measurement at **500V without load** of sample QHC12 (<150µm), determined resistance about 3.5 TΩ.*

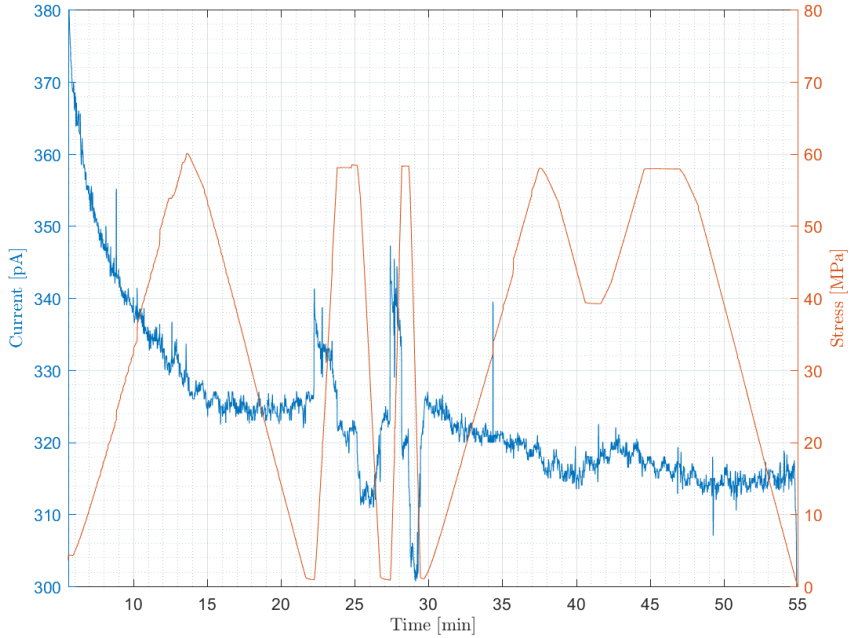


*Leakage current measurement at **500V without load** of sample MQXF_QHC01 (<150µm).*

- Good repeatability of the leakage current measurements at stable ambient conditions
- Leakage current decreases towards an plateau value
- Leakage current is very sensitive to:
  - Ambient conditions
  - Time gap between measurements

Investigation of mechanical degradation mechanism onto the quench heater insulation to Nb_3Sn coil

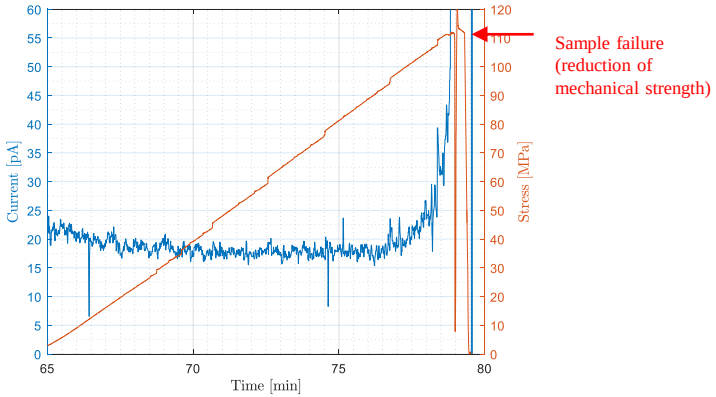
Leakage current measurement **with applied** pressure



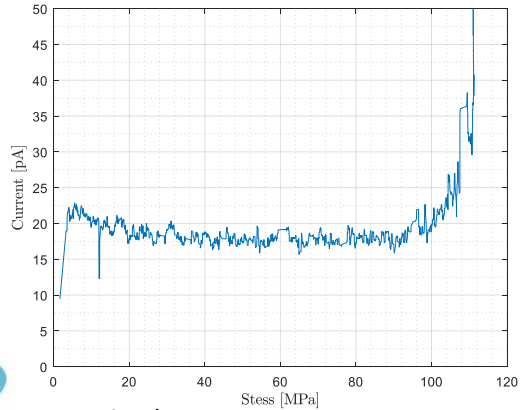
Leakage current measurement at 500V with varying load and varying load ramp rate of sample QHC07 (<150µm), determined resistance about 1.5 TΩ.

- Leakage current plateau after 25 minutes
- No change in the leakage current if the load ramp is below 0.1 kN/s
- No permanent degradation of the insulation up to 60 MPa
- Reversible changes of the resistance if the load ramp is above 0.5 kN/s

Sample QHC07 (Insulation thickness < 150µm) loaded up to 110MPa



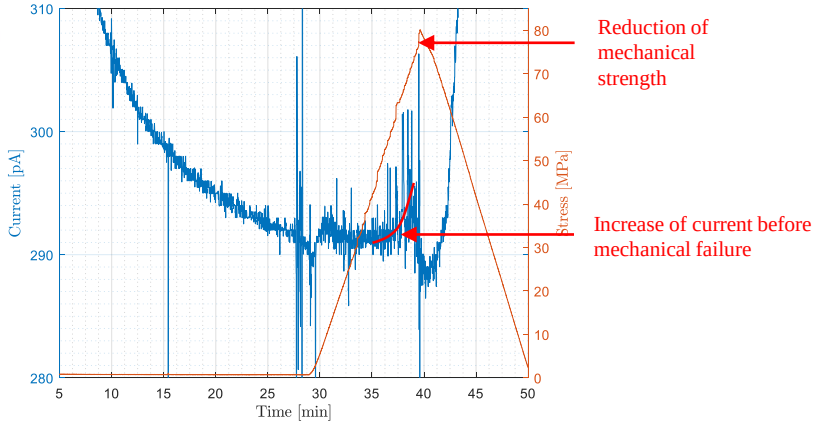
Leakage current measurement at 500V with load ramp rate 0.13MPa/s QHC07 (<150µm insulation thickness).



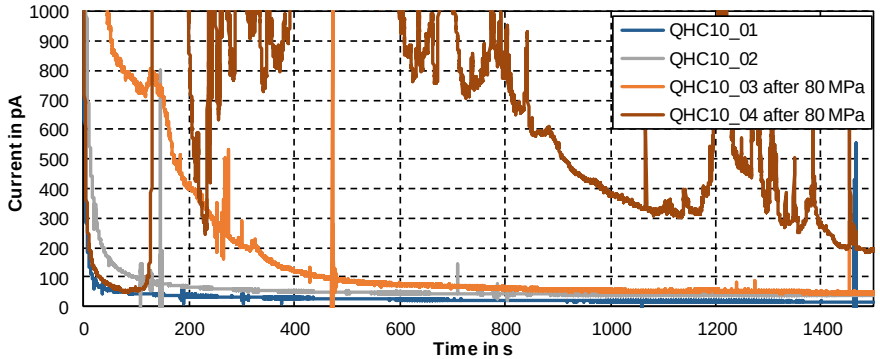
Leakage current measurement vs. applied pressure.

- No permanent degradation of the insulation up to 60 MPa
- Leakage current increases before the sample looses mechanical strength
- Leakage current increases above an applied load of 90 MPa
- Sample loses mechanical strength and delaminates

Sample QHC10 (Insulation thickness < 150µm)



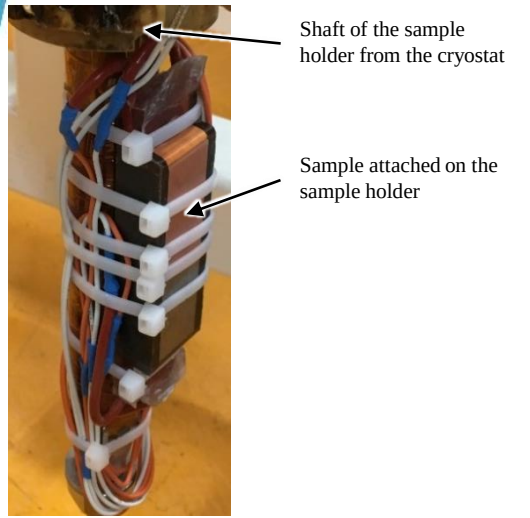
*Leakage current measurement **at 500V** with load ramp rate 0.13MPa/s QHC07 (<150µm insulation thickness).*



*Leakage current measurement at **500V without load** of sample QHC10 (<150µm), determined resistance about 5 TΩ.*

- Sample prepared with higher compression (extra 100µm polyimide shim).
- Leakage current increases with at load above 60 MPa.
- Time dependent leakage current increase, even at decreased load.
- Clear change of the leakage current behaviour without applied load after 80MPa loading.

Thermal cycle of one sample to 1.9K

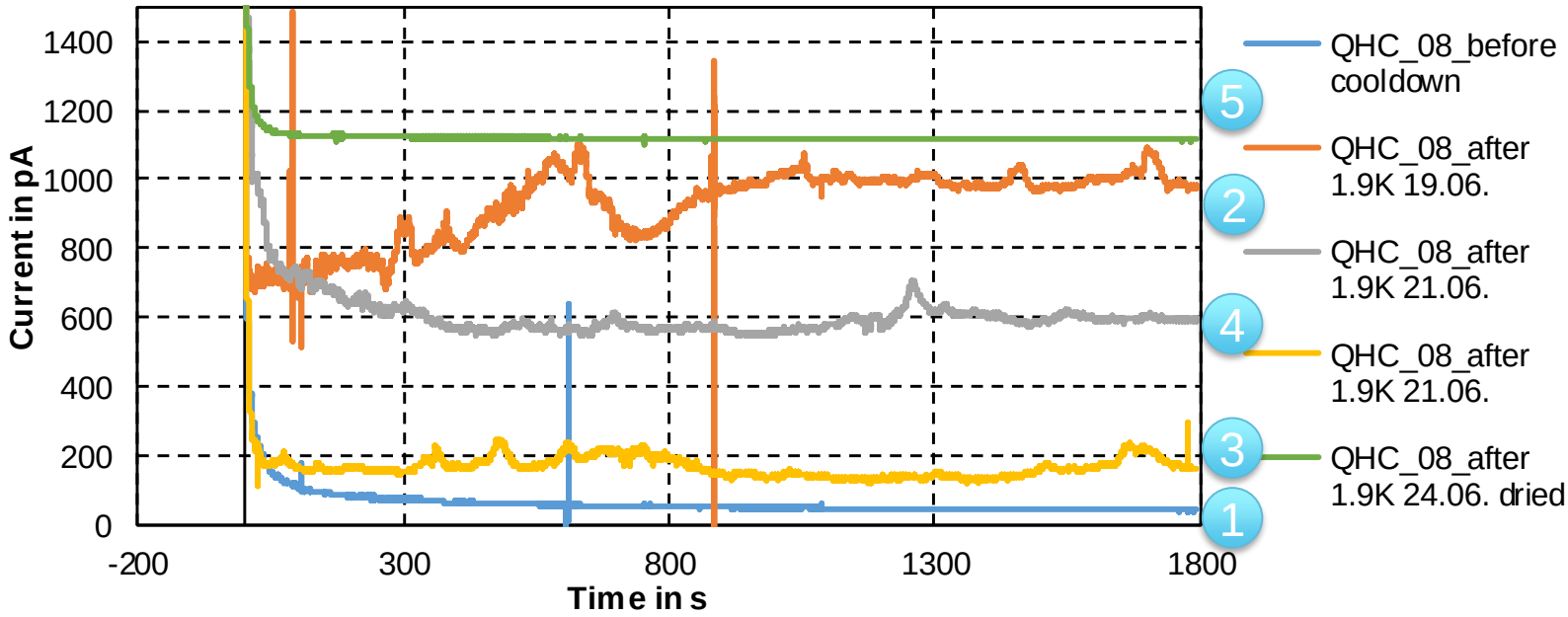


Sample installed at the sample holder of the cryostat in Bldg. 163 for cool down to 1.9K.

Cracks in the insulation system (bottom surface of the sample) after cool down to 1.9 K.

- Cryogenic cool down in a cryostat with liquid helium to 1.9 K
- cooling rate of about 75 K/h
- warm up rate about 100 - 150 K/h

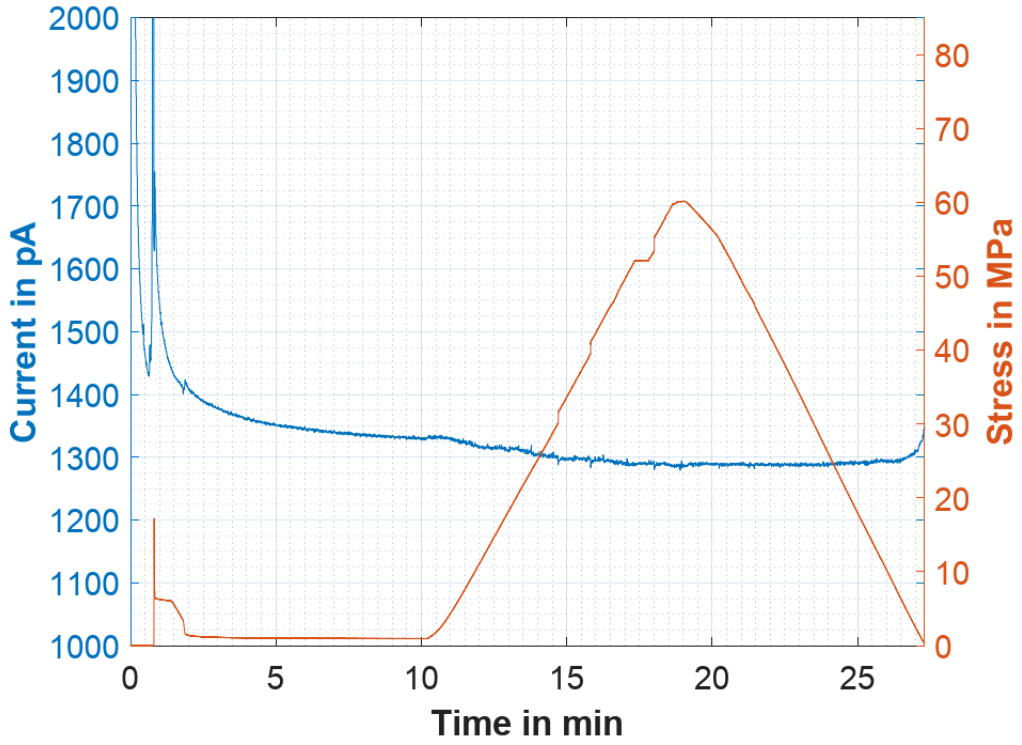
Leakage current measurement after thermal cycle to 1.9K without load



*Leakage current measurement at **500V without load.***

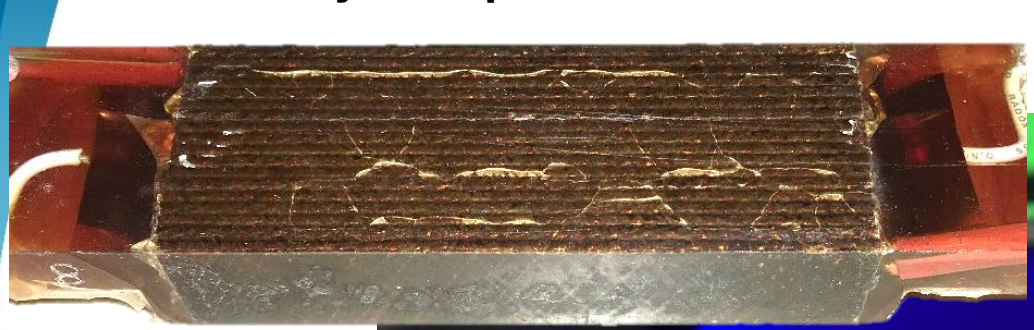
- No effect on the leakage current after sample drying
- Absolute value is influenced by the ambient conditions

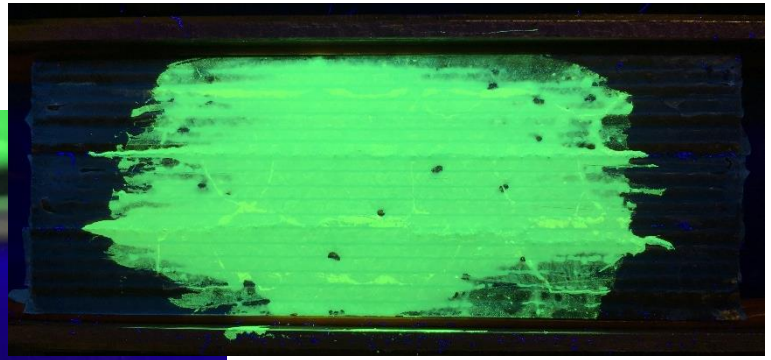
Leakage current measurement after thermal cycle to 1.9K under applied load

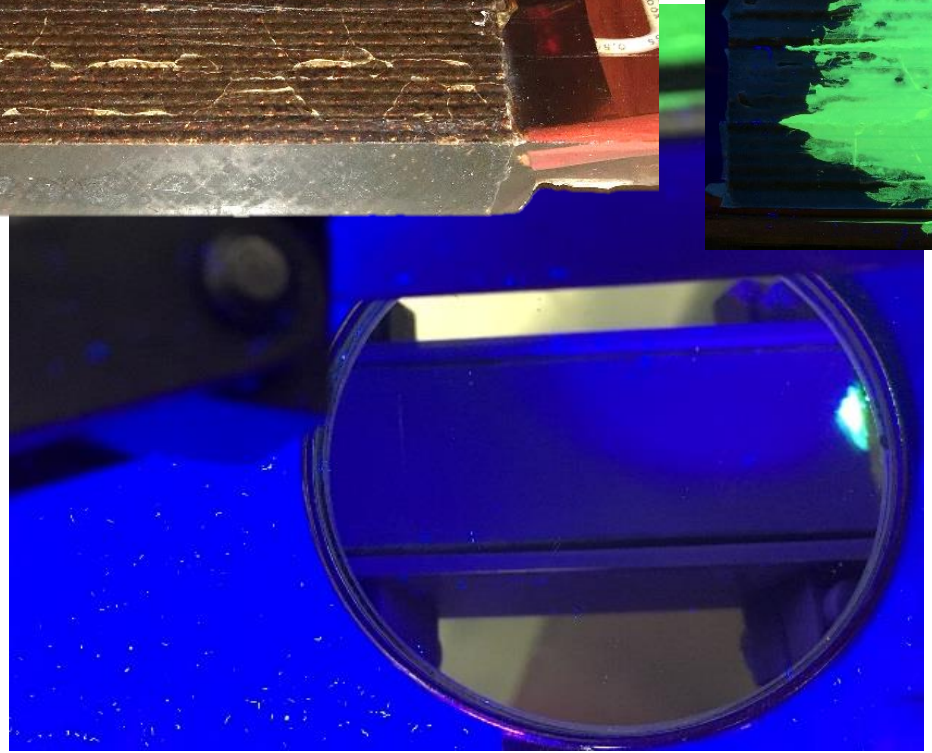


- No effect on the leakage current under applied load up to 60 MPa

Dye ink penetration test with the cryogenic cooled samples







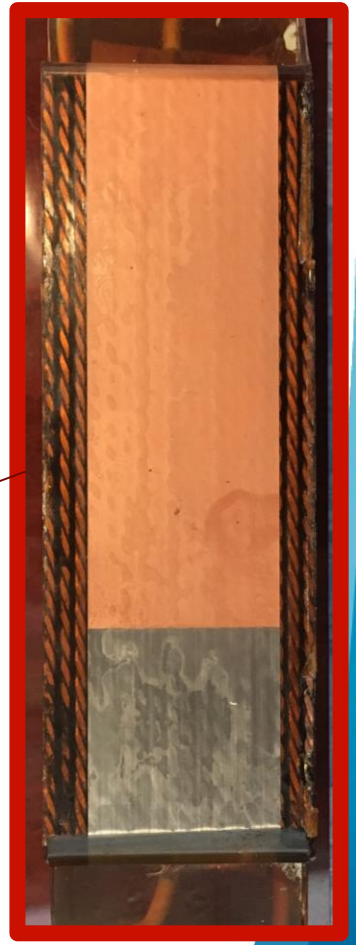
Dye ink penetration test of the sample after cool down to 1.9K

Dye ink penetration test with the cryogenic cooled samples

Sample with peeled off quench heater after cryogenic cycle to 1.9 K.

Overview of the 11T type samples

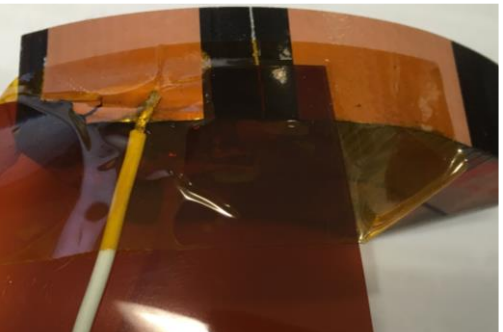
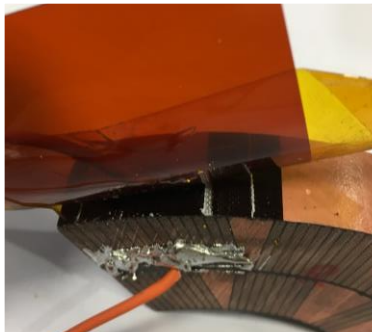
ample ID	Insulation thickness [µm]	Status	Tests	HV test 3.2 kV for 120s	HV test 3.2 kV for 120s
HC01	~250	Ok	7.3 kV@ 0 MPa, 5.2kV@ 80MPa, 4.1kV @ 0MPa	Passed	
HC02	~250	Cut – Microscopy	4.9 kV @ 0 MPa, 5.5kV@ 80 MPa –cut	Passed	
HC03	~200	Ok	Tested up to 60 MPa	Passed	
HC04	200-250	Ok	Tested up to 60 MPa	Passed	
HC05	~200	Cut-Microscopy	Cut	Not tested	
HC06	200-250	Ok	Tested up to 60 MPa	Passed	
HC07	<150	Destroyed	Failed at 110 MPa	Not tested	
HC08	~200	Peeled after 1.9K	Tested up to 60 MPa	Not tested	
HC09	<150	Destroyed	Failed at 90 MPa	Not tested	
HC10	<150	Cut for Microscopy	Tested up to 80 MPa	Not tested	
HC11	<150	Ok	Without glass fibre / mica, Tested up to 60 MPa	Passed	
HC12	<150	Pending repair	Spare sample (defect after demoulding)	Failed at 2.67kV	
HC13	<150	Ok	Spare sample	Passed	After 1.9K passed



Outlook on 11T samples

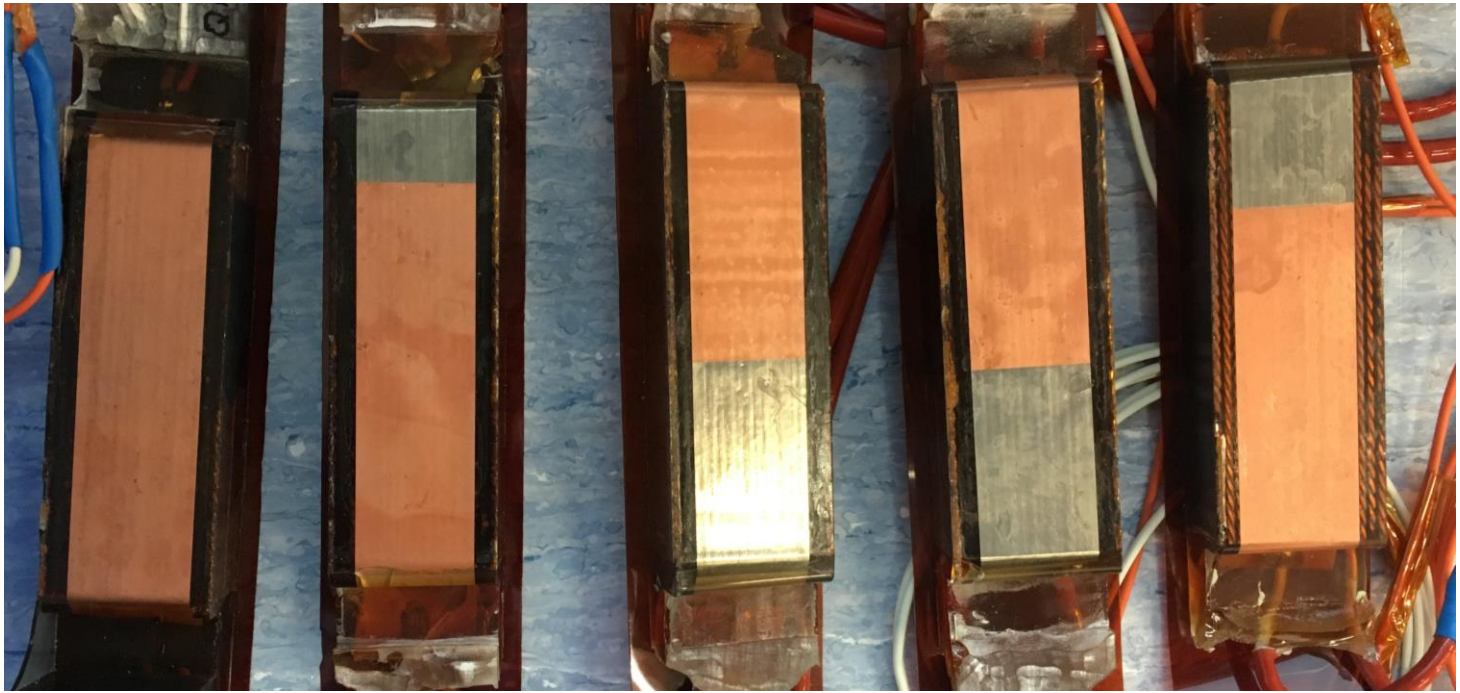
Objective: Reproduce and determine the failure mechanism in the insulation system after thermal cycle

- Manufacture samples with defects in the impregnation system
  - Realized by a vacuum during the sample curing
- Manufacture samples where the heaters can be fired
- Perform the test in the collaring mock up with coil segments
  - To be discussed
- Update the test station for leakage current investigations at 3.7kV
  - Work in progress

Outlook on 11T samples

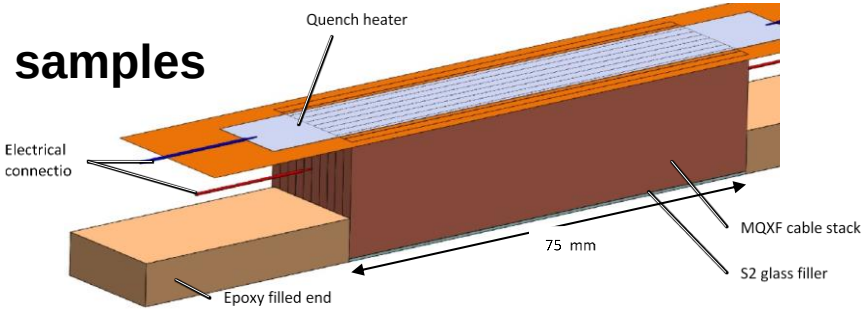
- Can we fire the heater?
  - Not designed/manufactured for this approach



Stainless steel part the quench heater in the samples placed at the edge of the cable stack.

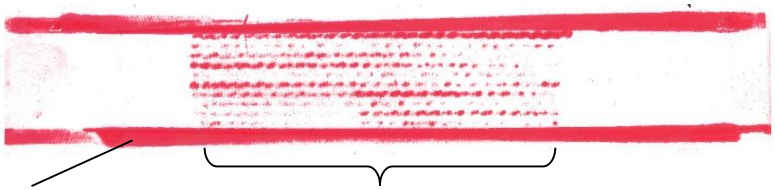
The MQXF samples

- Investigation of the MQXF insulation system without mica
- Target insulation thickness (205µm)
  - 145µm S2 glass + 50µm QH polyimide



Simplified model of the impregnated MQXF sample with quench heater, soldered electrical connections and residual epoxy block

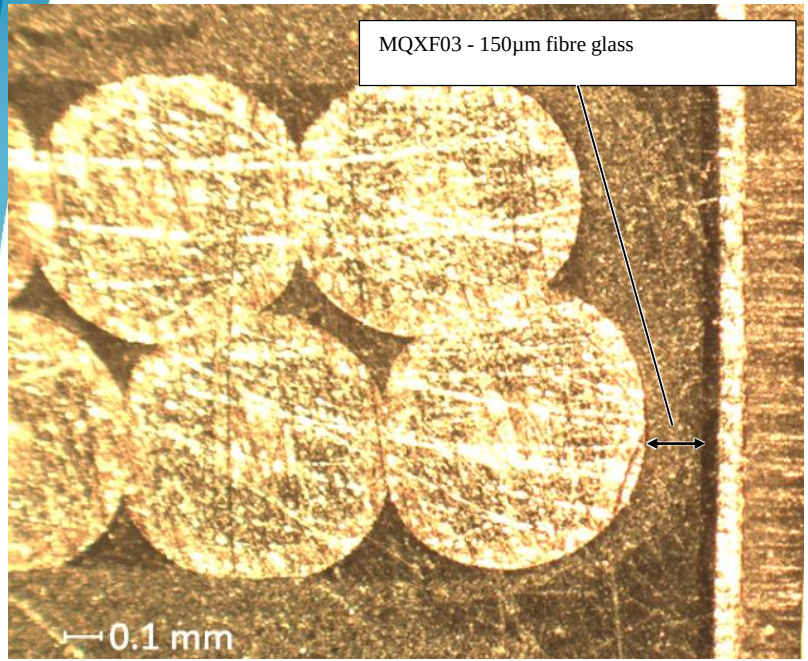
Impregnation mould for the investigation of the MQXF impregnation system.



Pressure on sample MQXF_01 applied by the impregnation mould during a test assembly, visualized by pressure sensitive film FUJI LW indicating a pressure range between 2.5-10 MPa.

Impregnated MQXF sample.

The MQXF samples

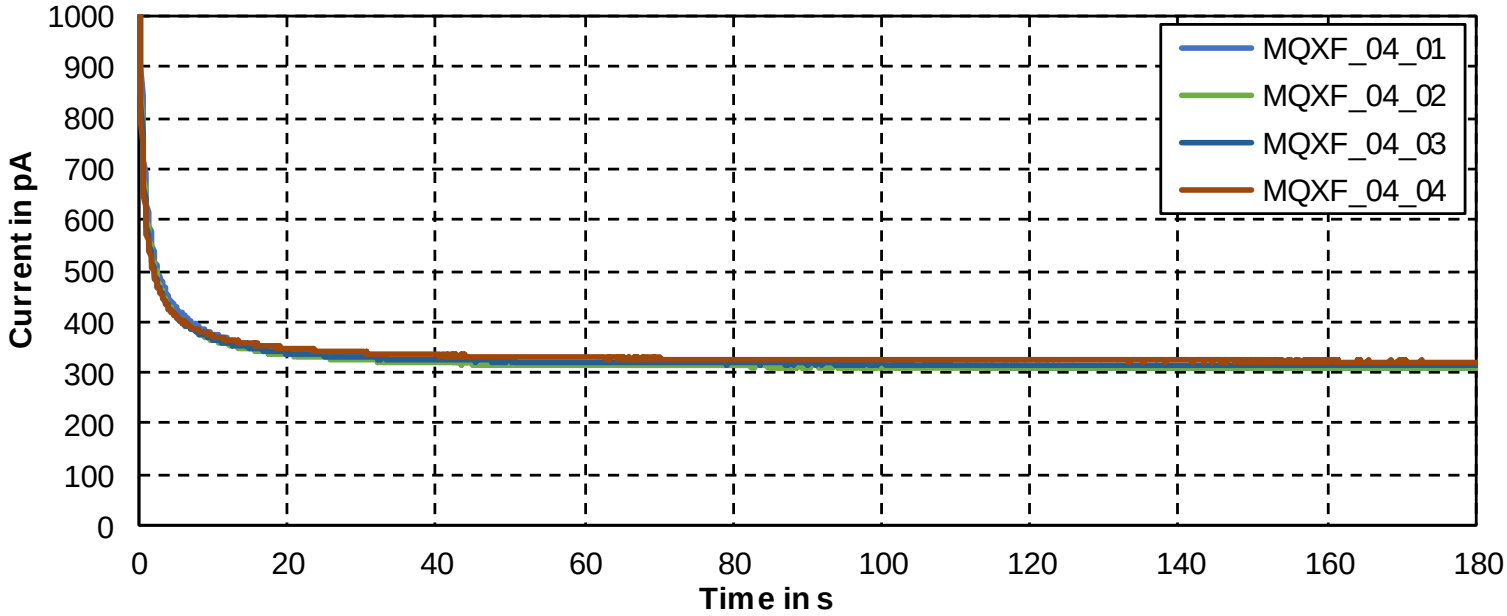


Cross section of sample MQXF-QHC-03 with insulation thickness of 150 µm (glass fibre).

MQXF sample overview

Sample ID	Expected S2 insulation th. [µm]	Tests	HV test 3.7 kV for 120 sec.	1.9K HV test 3.7 kV for 120 sec. Ramp 1kV/min
MQXF_01	150 µm	Tested up to 60 MPa	Passed	Break down 1. 2026 V 2. 1608 V 3. 1533 V 4. 1536 V 5. 1600 V
MQXF_02	150 µm	Tested up to 60 MPa	Passed	
MQXF_03	150 µm	Tested and cut	Not tested	
MQXF_04	150 µm	Tested up to 60 MPa	Passed	
MQXF_05	150 µm	Tested up to 60 MPa	Passed	
MQXF_06	150 µm	Tested up to 60 MPa	Passed	

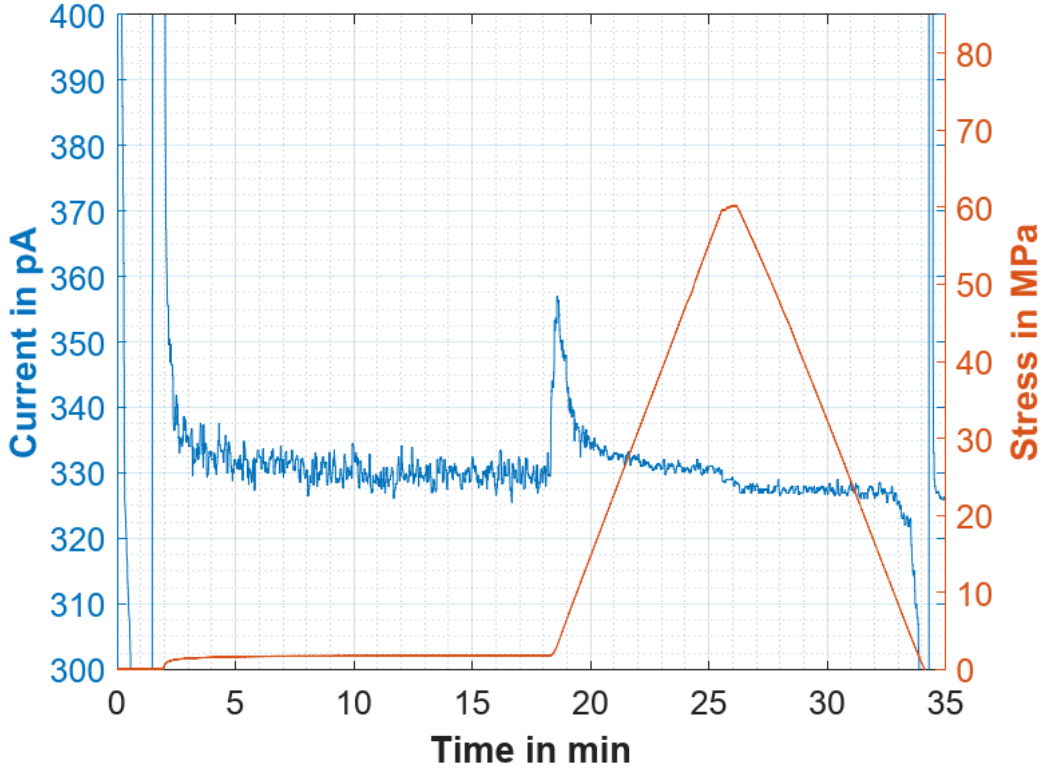
Leakage current measurement without load (MQXF samples)



Leakage current measurement of the sample MQXF-QHC04 without applied load at 500 V DC.

- Good repeatability at stable ambient conditions

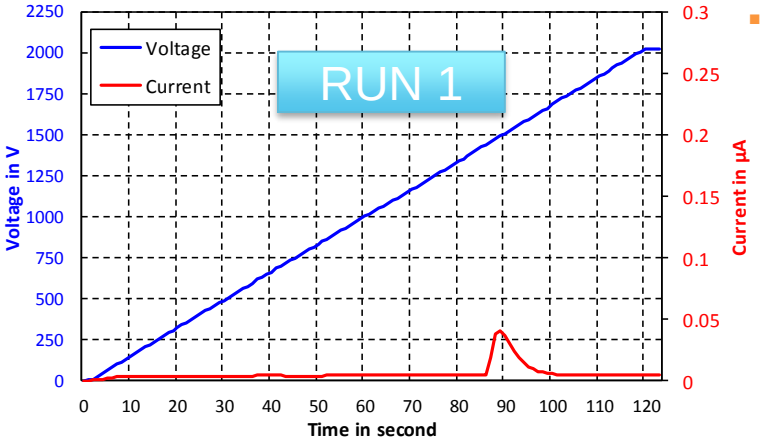
Leakage current measurement loaded up to 60 MPa (MQXF samples)



Leakage current measurement under radial applied load over time of sample MQXF-QHC04 at 500V DC test voltage.

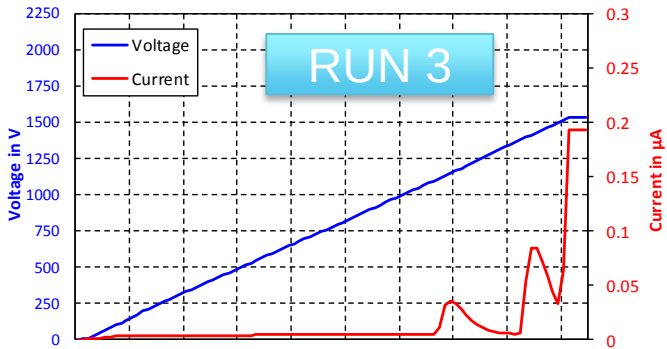
- No permanent impact on the leakage current due to applied load.

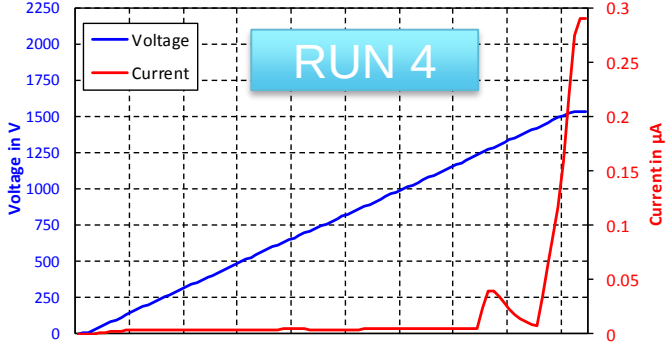
High voltage test after cool down (1.9K) MQXF_01



Leakage current activity can be observed before the break down.

Break down location on the MQXF-01.





Thank you for your attention.