DC extruded Cable Development Testing

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DEFINITION OF DEVELOPMENT TESTS

Development testing of a cable system is defined in CIGRE brochure 496

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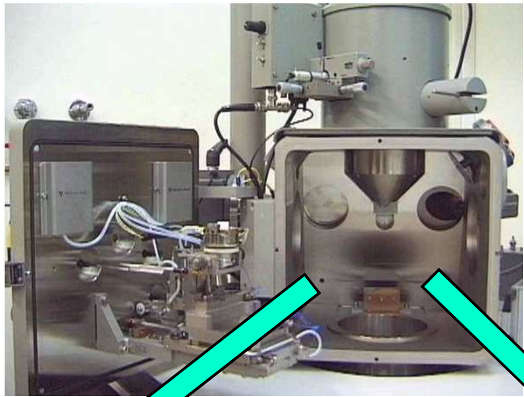
- An **evaluation of the materials** and processes employed. Such evaluations would normally include **electrical resistivity** assessments, **breakdown tests** and **space charge** measurements.
- An analysis of the **electric stress distribution** within the cable system insulation for a range of typical installation and loading conditions.
- An assessment of the **long-term stability**, possibly involving factory experiments to assess the ageing effects of various parameters, e.g., electrical stress, temperature, environmental conditions etc.
- An assessment of the **sensitivity** of the electric stress distribution to the **expected variations** in cable dimensions, material composition and process conditions (extrusion, post extrusion treatments and finishing.
- Any additional development test is of course welcome.

Evaluation of materials

- Insulation alone
- Insulation and electrodes
- Semi-conductive material
- Insulation system

insulation alone

Mirror Method



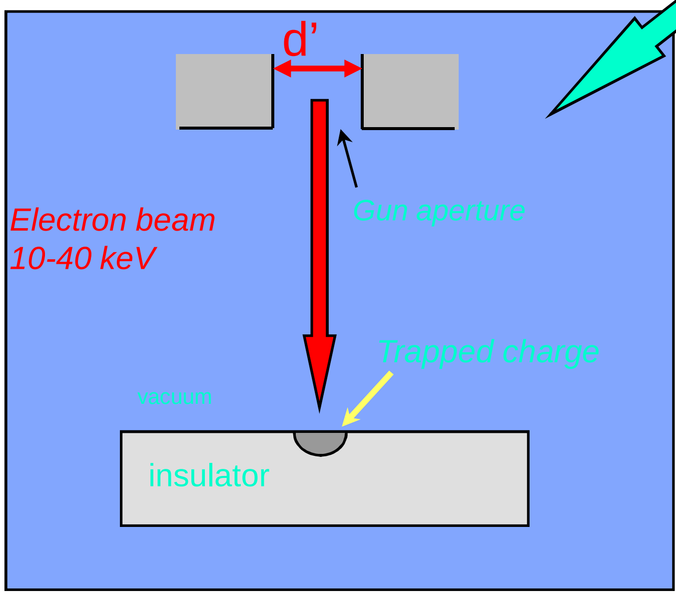
Scanning Electron Microscope

1st step

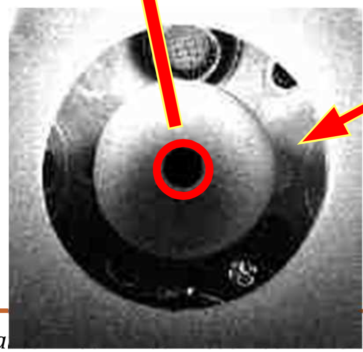
Injection

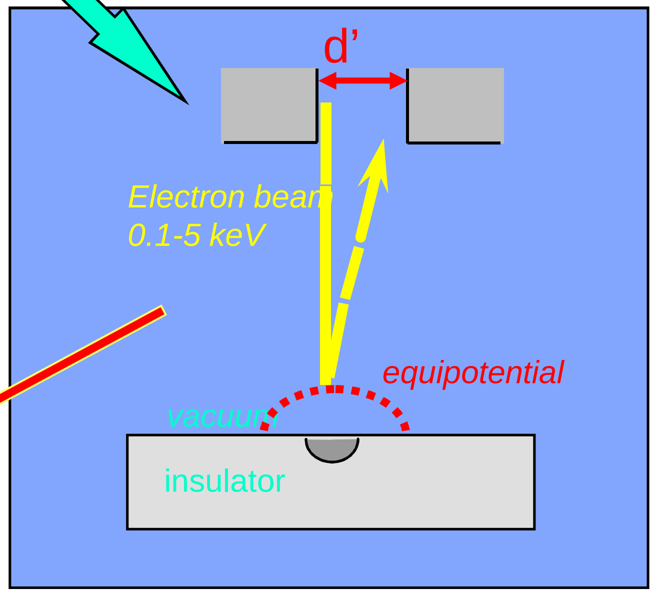
2nd step

Observation



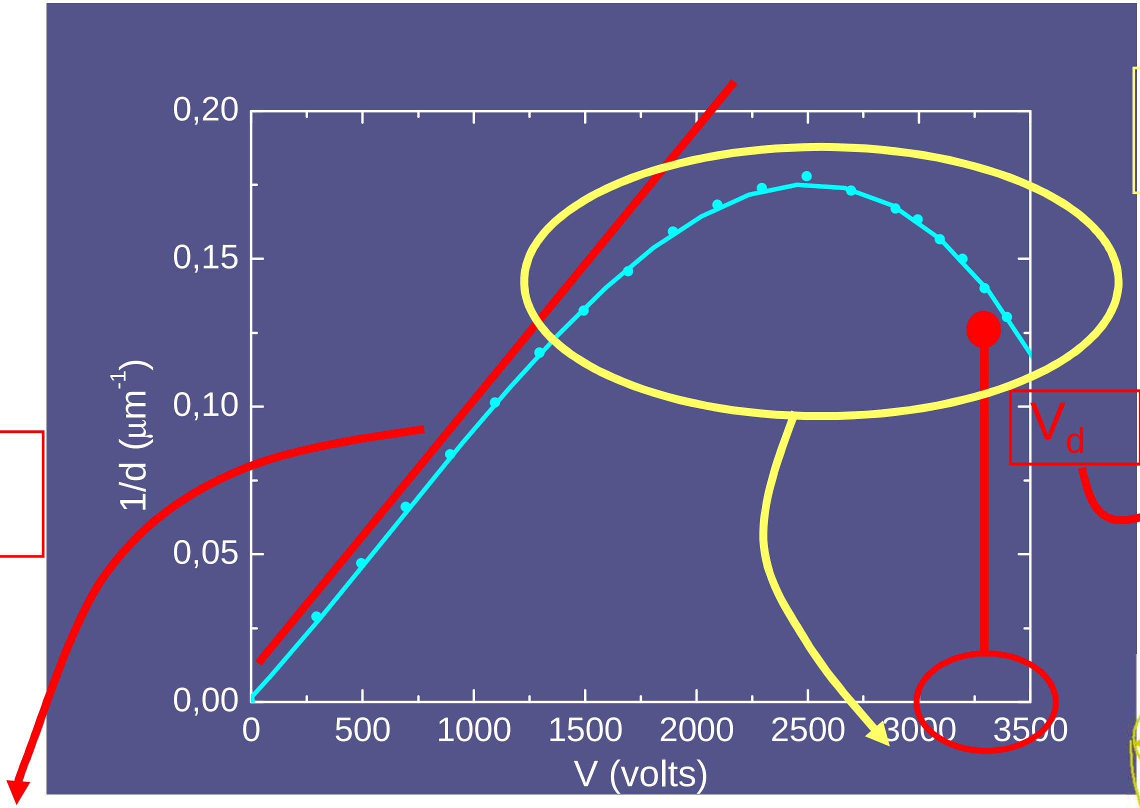
Dark spot diameter d as a function of potential





Analysis of the Mirror curve

Linear part



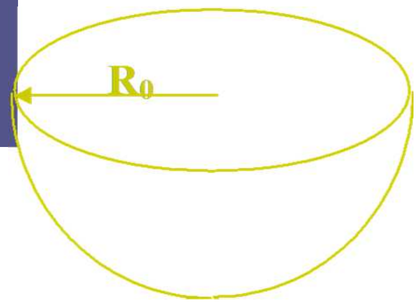
Non-linear part

Classical optics / electrostatics

$$\frac{1}{d} = \frac{4L}{d'} \frac{V}{AQ_P}$$

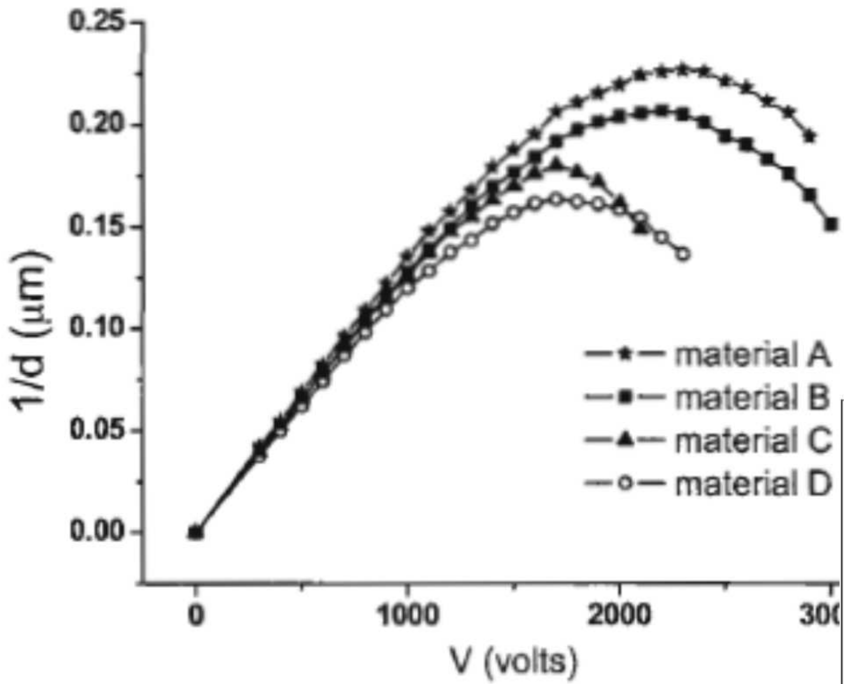
with $A = \frac{1}{2\pi\varepsilon_o(\varepsilon_r + 1)}$

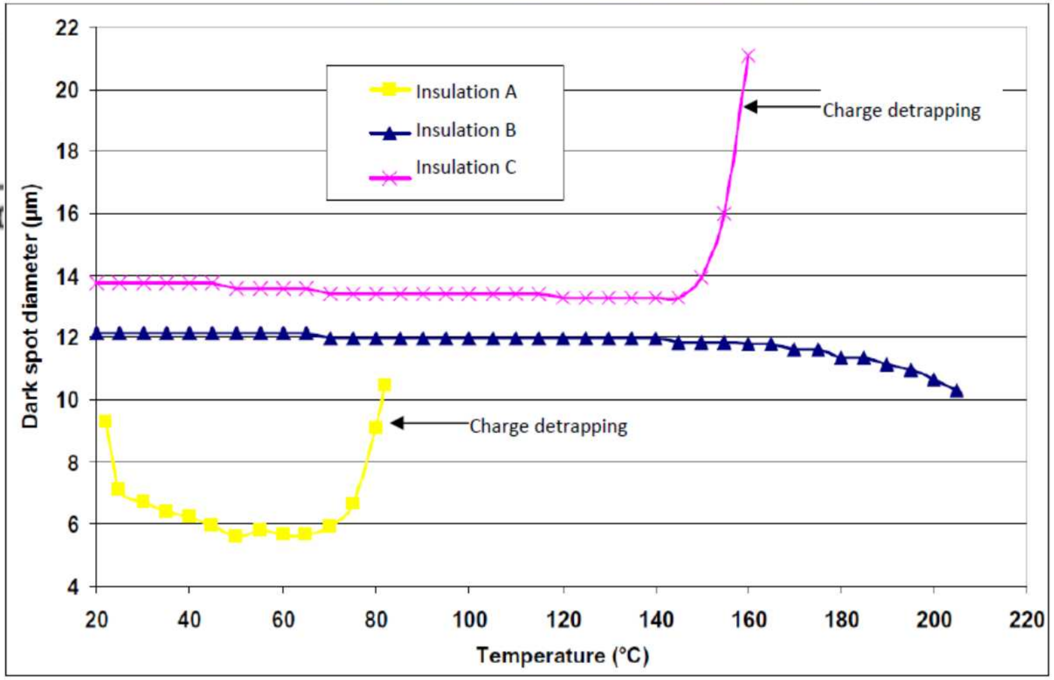
Hemispheric distribution



$$\frac{1}{d} = \frac{4L}{d'}\left(\frac{V}{AQ_P} - 2\beta R_0^2 \left(\frac{V}{AQ_P}\right)^3 \cdots\right)$$

Mirror method results

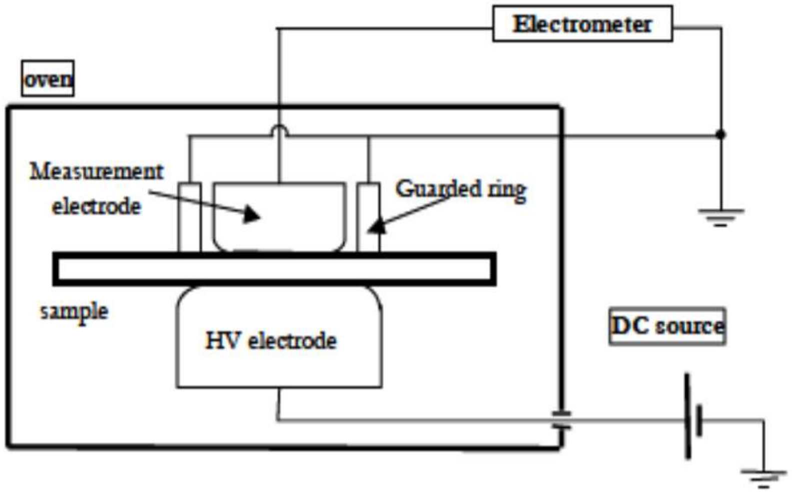




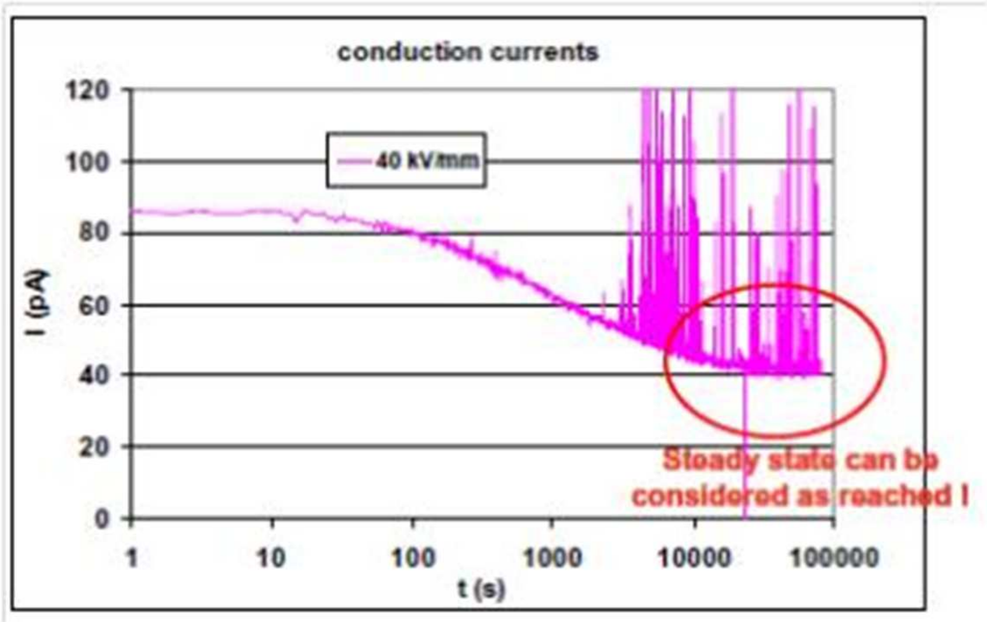
The association electron – phonon
Is named a **POLARON**

insulation and electrode

Conductivity measurements



example of arrangement for conductivity measurement on films



example of current recording during a conductivity measurement.

Conductivity measurements can also be addressed using miniature cables.

semi-conductive materials

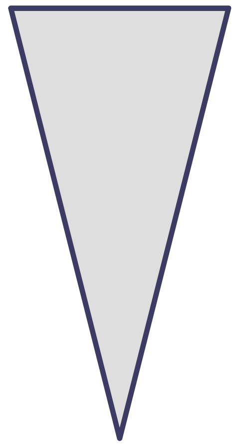
The main dielectric properties of semi-conductive materials are:

- Conductivity, to screen the insulation during impulse tests, classical techniques are used for this measurement.
- Charge injection and recombination. This is measured as insulation system arrangement because the result is strongly depending on the insulation material.

Insulation system

- Test objects
  - Films (0,5mm)
  - Miniature cables (1,5mm)
  - Model cables (5mm)
  - Full size cables (20mm)

Number of combinations



Films

Typical thickness is 0,5mm

- They are mainly used in order to do **a first selection** between a huge number (more than 10) of different materials and/or of different combinations of semi-conductive materials and insulations.
- Typical tests performed on films are:
- **SPACE CHARGES** measurements (usually, during polarization with both polarities and in "volt off" conditions to evaluate the dynamic of the decay of the trapped charges. Such tests can be performed at ambient temperature and as a function of different temperatures).
- **HVDC TEST UP TO BREAKDOWN** (vs. different thermal conditions) see above paragraph on insulation.

Miniature cables

Typical thickness is 1,5mm

- They are used to:
  - **confirm results** obtained by means of film model (but on a number of combination less than 10)
  - establish the main parameters used in the mathematical models (thermal conductivity / electric conductivity «ALFA» / «BETA»).
- Typical tests performed on miniature cables are:
- **SPACE CHARGES** measurements (usually, during polarization with both polarities and in "volt off" conditions to evaluate the dynamic of the decay of the trapped charges. Such tests can be performed at ambient temperature and as a function of different temperatures).
- **HVDC TEST UP TO BREAKDOWN** (vs. different thermal conditions)
- **ELECTRICAL CONDUCTIVITY** vs. ELECTRICAL FIELD AND THERMAL CONDITION
- ELECTRO THERMAL **AGEING**
- **REVERSAL POLARITY** TEST

Model cables

Typical thickness is 5mm

- They are used to:
  - **confirm results** obtained by means of miniature cable
  - verify the **production technology**
  - better verify electro-thermal ageing performance
- Typical tests performed on MODEL CABLES are:
- **SPACE SCHARGES** measurements (usually, during polarization with both polarities and in "volt off" conditions to evaluate the dynamic of the decay of the trapped charges. Such tests can be performed at ambient temperature and as a function of different temperatures).)
- **HVDC TEST UP TO BREAKDOWN** (vs. different thermal conditions)
- LOADING CYCLES VOLTAGE TEST UP TO BREAKDOWN (voltage is increased once a week or once a month. If a thermal instability condition is reached the voltage is reduced and Model cable will be aged at that voltage level for 1 year)
- **IMPULSE** TEST
- **IMPULSE TEST SUPERIMPOSED** ONTO HVDC
- **REVERSAL POLARITY** TEST

Prototype cables

Typical thickness is 20mm

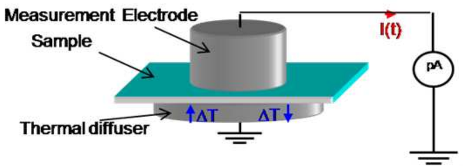
- They are used to:
  - **verify** realaibility of the **production technology**
  - better **verify** electro-thermal ageing performance
- Typical tests performed on PROTOTYPE CABLE
- **LOADING CYCLES VOLTAGE TEST** UP TO BREAKDOWN (voltage is increased once a week or once a month. If a thermal instability condition is reached the voltage is reduced and Model cable will be aged at that voltage level for 1 year)
- **IMPULSE TEST**
- **IMPULSE TEST SUPERIMPOSED** ONTO HVDC
- **TYPE TEST** IN ACCORDANCE TO CIGRE TB 496
- **PREQUALIFICATION TEST** IN ACCORDANCE TO CIGRE TB 496

Space charges

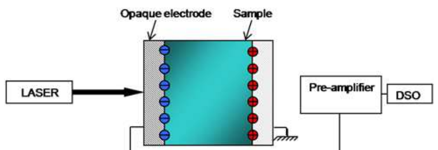
Thermal Methods

Principle:
The insulator is subjected to a variation of temperature on one of its faces;
The heat diffusion through the insulator expands the material in a non-uniform manner which displaces the charges;
This motion induces an ***electrical response*** which is measurable from adjacent electrodes.

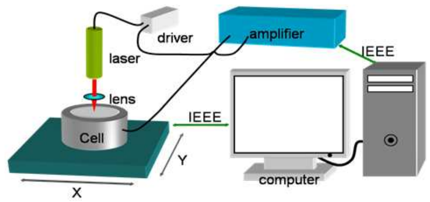
Thermal Step Method (TSM)



Thermal Pulse Method (TPM)



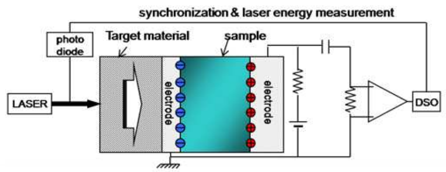
Focused Laser Intensity Modulation Method (FLIMM)



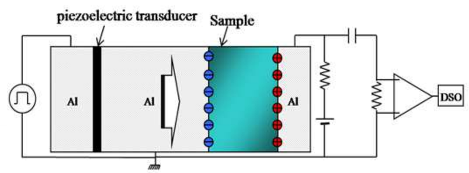
Pressure Pulse Methods

Principle:
An elastic wave is transmitted into the insulation to be tested;
It moves successively the plan of charges included in the material;
This motion induces an ***electrical response*** which is measurable from adjacent electrodes.

Laser-induced-pressure-pulse (LIPP)



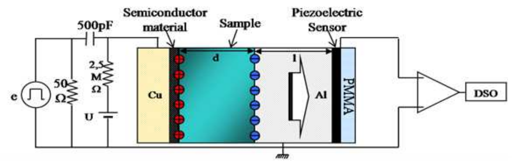
Piezoelectrically Induced Pressure Pulse (PIPP or PIPWP).



Pulsed Electro-Acoustic Method

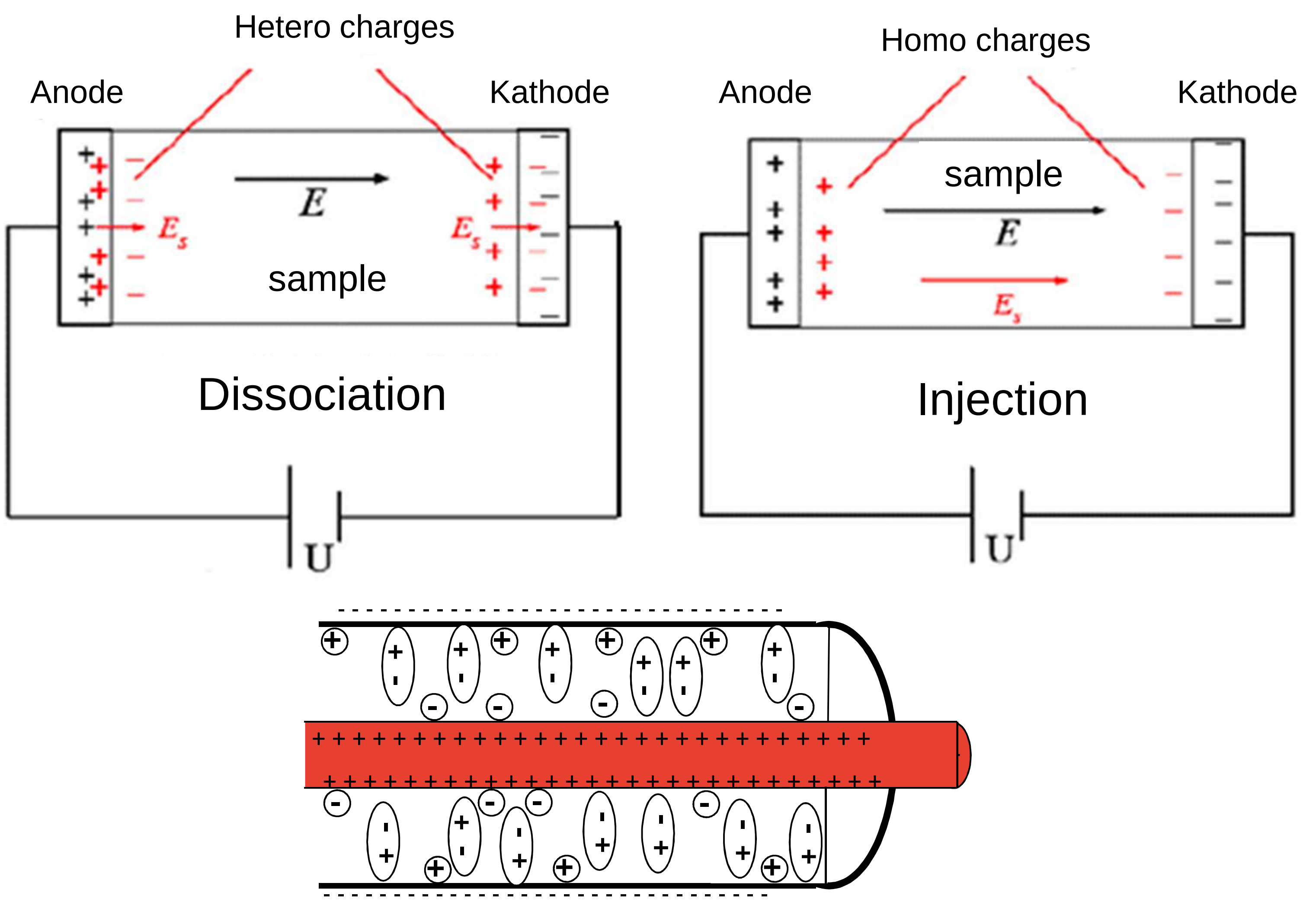
Principle:
The insulator is subjected to short voltage pulses.
This creates elastic waves propagating from the charges and proportional to their amplitude.
These ***elastic waves*** travel through the insulator and are measured by a transducer.

Pulsed electroacoustic method (PEA)



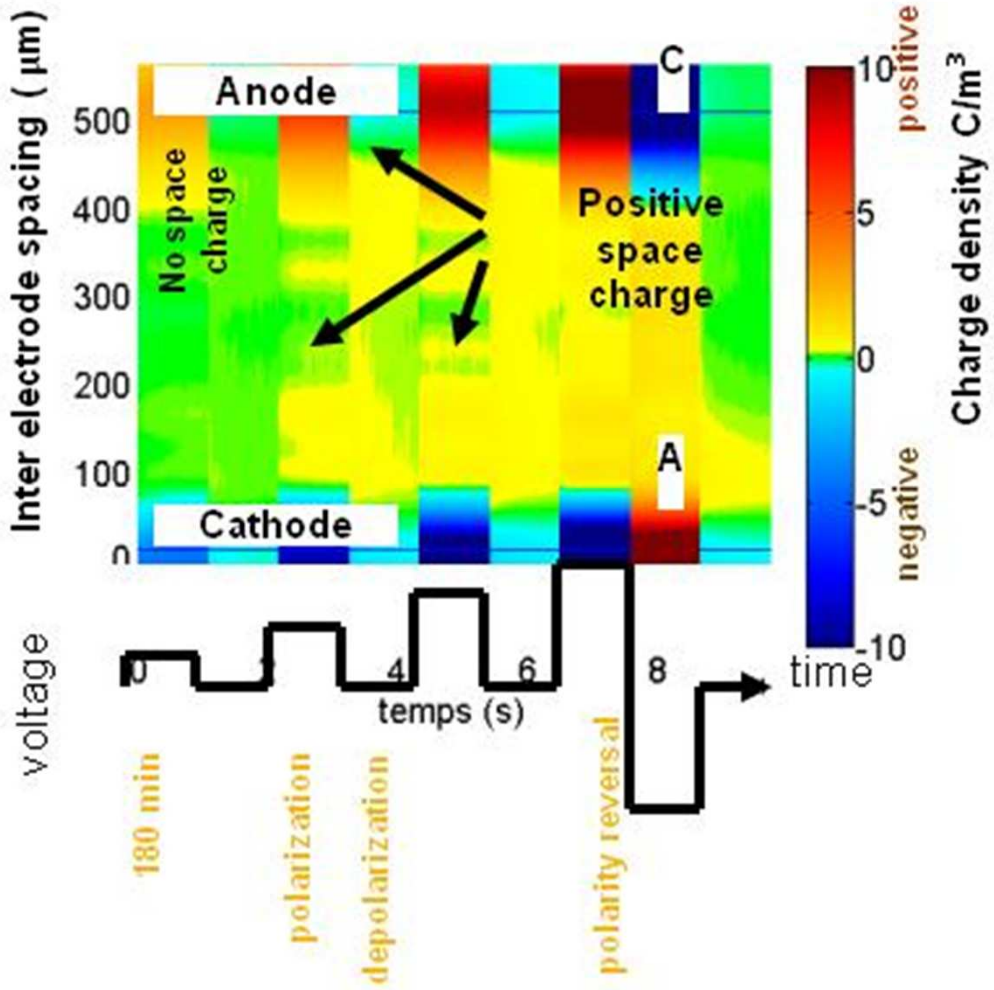
Specific attention has to be paid to **CALIBRATION** porcedure

Space charges behaviour



Close and Return

Example of space charge distribution evolution as a function of stress steps (PEA)



Ambient temperature – test object: 0,5mm film

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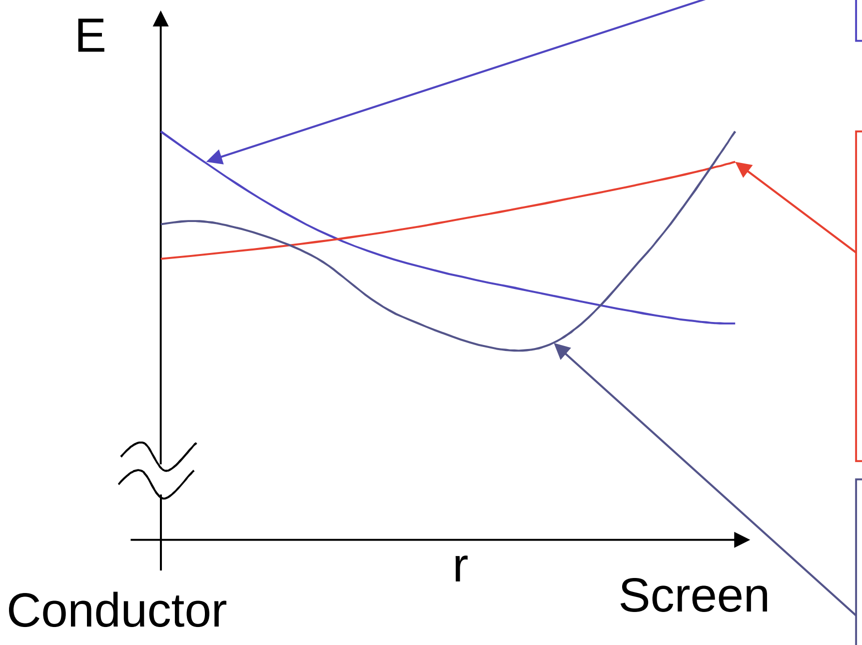
Close and Return

Field distortion under DC stress



Electrical field @ constant material properties

Field distortion taking XLPE conductivity dependence from temperature and electrical stress into account

Possible field distortion under temperature, stress and space charge accumulation

ANALYSIS OF THE ELECTRIC STRESS

Electric stress is usually analysed in terms :

- **The LAPLACE field:**

  The LAPLACE field is the electric field that is calculated when there are no charges in the insulation material.

- **The RESISTIVE field:**

  The resistive field is the electric field that is calculated taking into account the applied voltage, the temperature profile in the insulation and the dependence of resistivity as a function stress and temperature. When the LAPLACE field is distorted by the variation of resistivity, space charges are created according to the equation:

  A difference in resistivity (or permittivity) at an interface creates a layer of space charge that derives from the local change of electric field.

- **The FIELD ENHANCEMENT by space charges:**

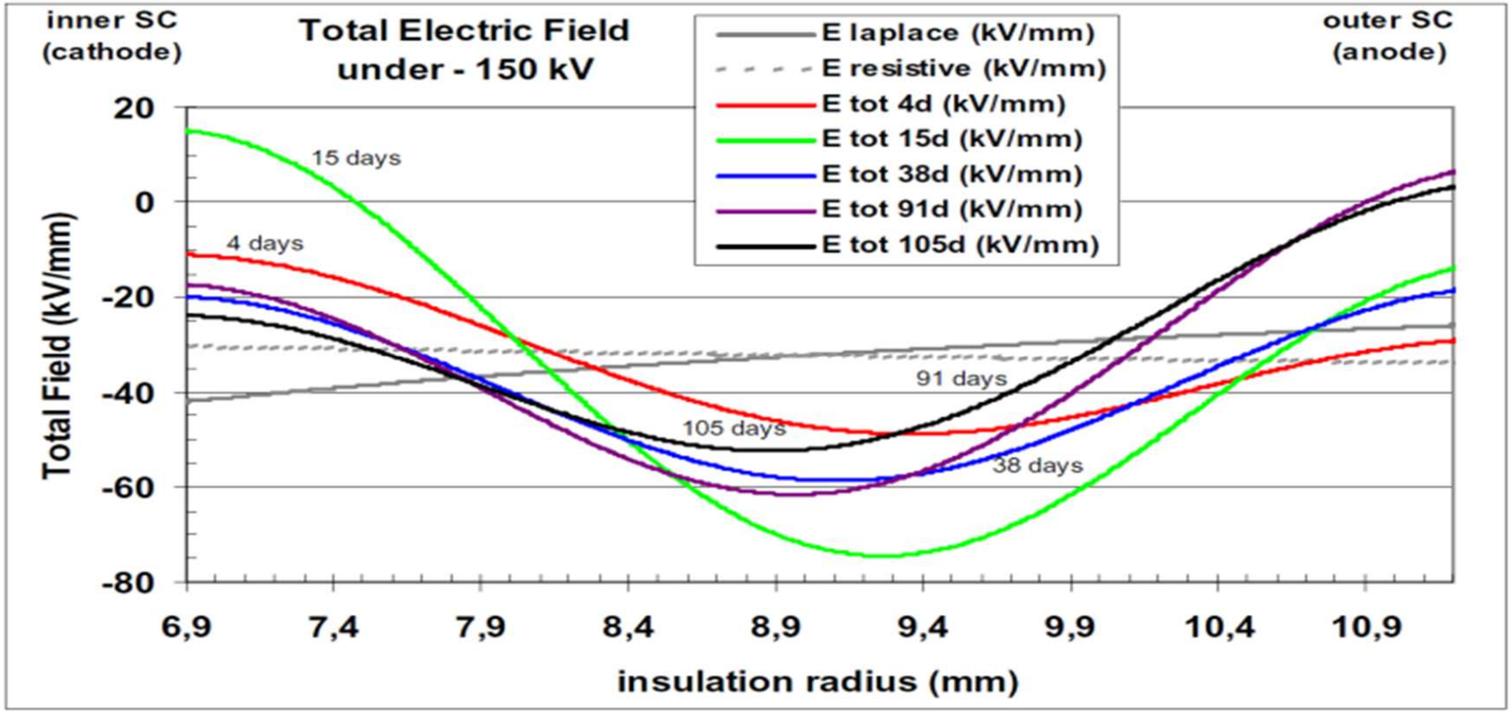
  The field enhancement by space charges is the difference between the measured electric field in the insulation and the resistive field. These charges originate from ionisation of salts of the insulation material (Onsager effect), or from injected charges.

ANALYSIS OF THE ELECTRIC STRESS

- **The FIELD ENHANCEMENT FACTOR (FEF)**
  is the ratio of the Total field measured / LAPLACE field at the same location.

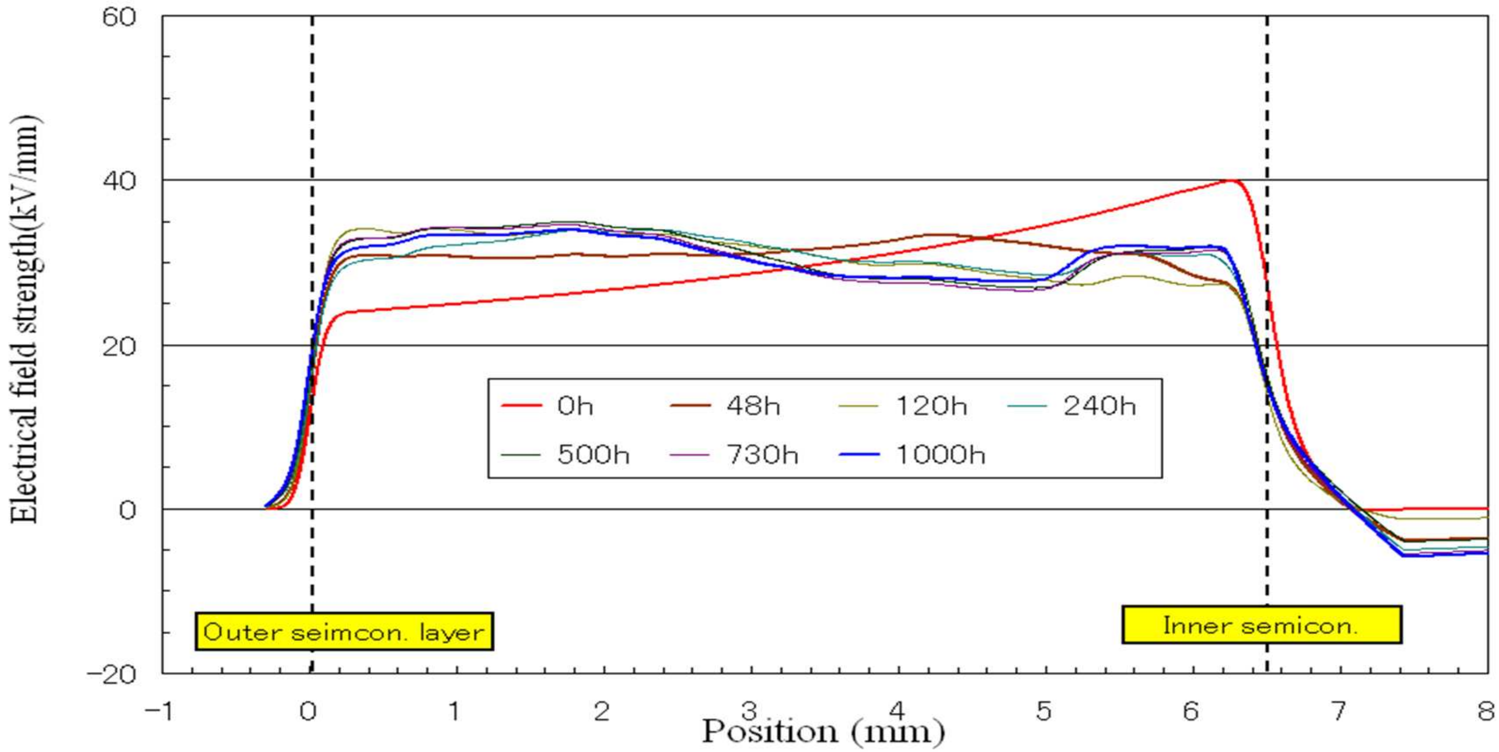
  The higher the FEF, the more critical is the material

Field distribution as a function of time under constant stress



80C – test object: 4mm thick model cable

Field distribution as a function of time under constant stress



Test object: 6,5mm model cable

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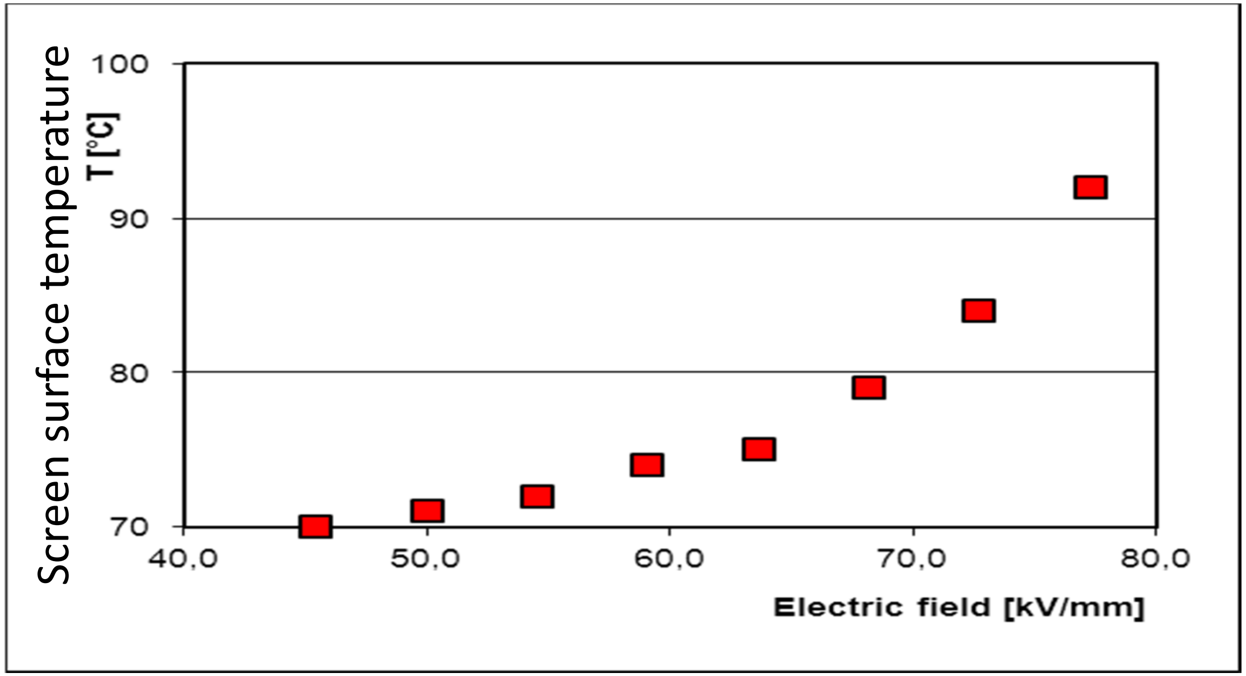
Long term stability assessment



example of thermal instability during a DC
breakdown test of a miniature cables
Conductor at 70C – voltage steps

Example of HVDC cable system loop.

The final step of the development of extruded cables for DC application is a Prequalification Test on a complete cable system according to CIGRE TB 496.

HVDC cable system during a Prequalification Test according to CIGRE TB 496

Close and Return

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Sensitivity to material and processes variations

HVDC insulation systems are very sensitive to small variation in the chemical composition of the materials. It is the know-how of the manufacturer to master it through a fine tuned material and process control

Conclusion

The HVDC extruded cable systems have a bright future,

first for underground transmission projects where there is a preference for HVDC extruded due to the efficiency of jointing and the reduced weight as compared with the MI cable.

Engineers have developed cables systems that comply with the CIGRE TB 496 qualification recommendation.

Through further development tests, operation feedback, academic and applied research, the questions about the long term behaviour will get an answer and the design rules will be improved consequently.