Development of a Mutual Inductance Quench (MIQ) Detector for the new Superconducting Magnets of the FAIR Facility

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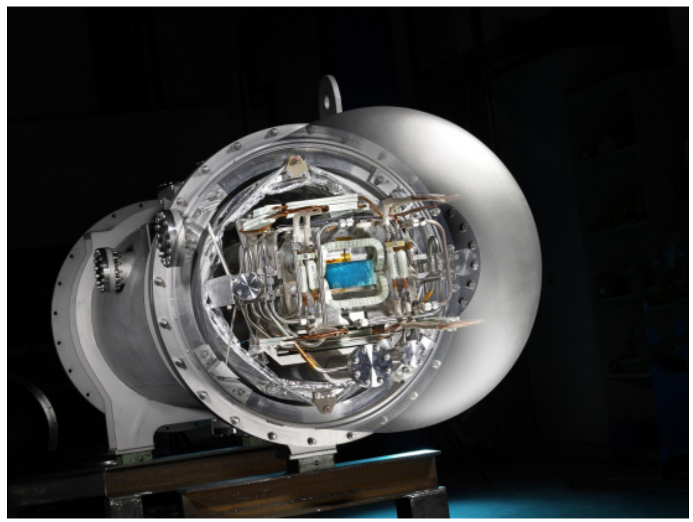

Facility for Antiproton and Ion Research in Europe GmbH

EE- Meeting

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What is a Magnet Quench?

Abnormal working conditions of magnet when the **superconducting material (coil) enters in resistive state**

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Heat generated by the increment of the resistance

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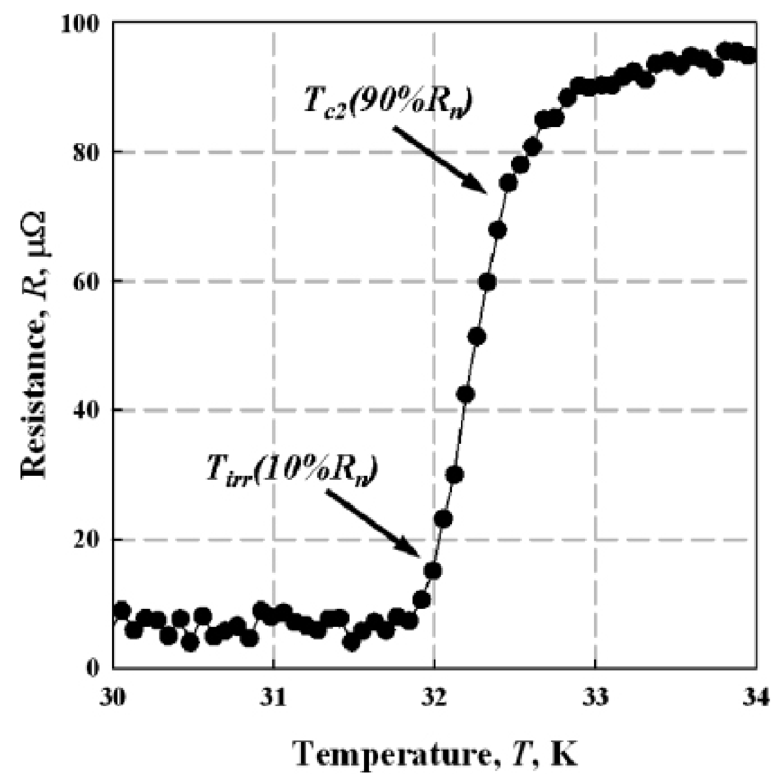
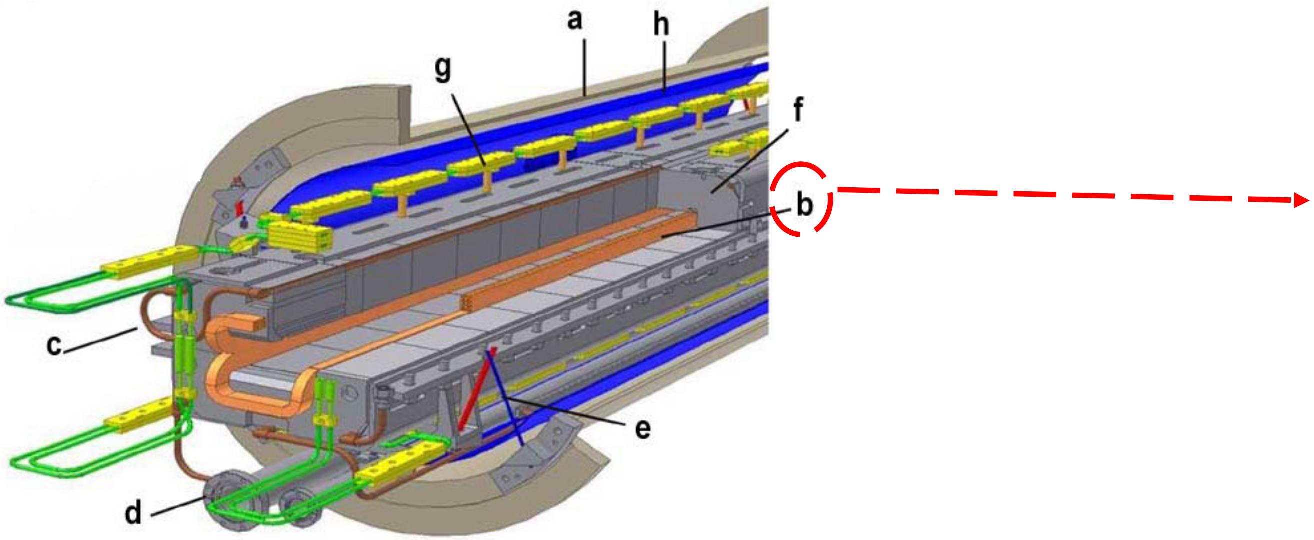
Coolant (Liquid He) evaporates and expands (1 to ~750 expansion ratio)

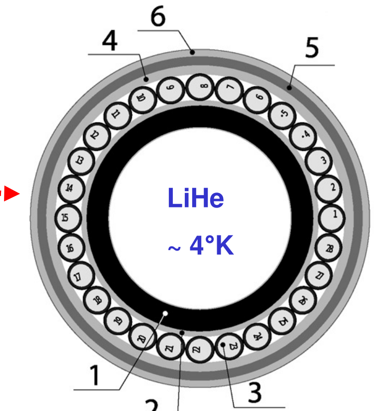
↓

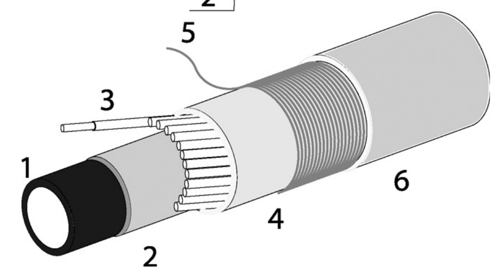
Explosion



Example SIS100 Dipole





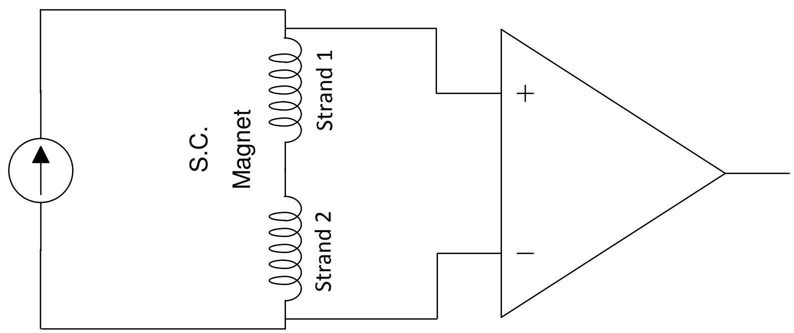


- SIS100 Dipole Design
  - a.- Cryostat Vessel
  - **<u>b.- Half Superconducting Coil</u>**
  - c.- Yoke and Cooling Pipes
  - d.- Liquid He Lines
  - e.- Suspension Rods
  - f.- Soft iron yoke
  - g.- Bus bars
  - h.- Thermal shield

- Nuclotron Cable
  - 1.- 4mm CuNi tube (Liquid He Flow)
  - 2.- Kapton Insulation Layer
  - 3.- Insulated Superconducting Strands (all in series, the number depends of magnet, from 10 to 28)
  - 4.- Kapton Insulation Layer
  - 5.- CrNi Wire for Fixation
  - 6.- Kapton Insulation Layer

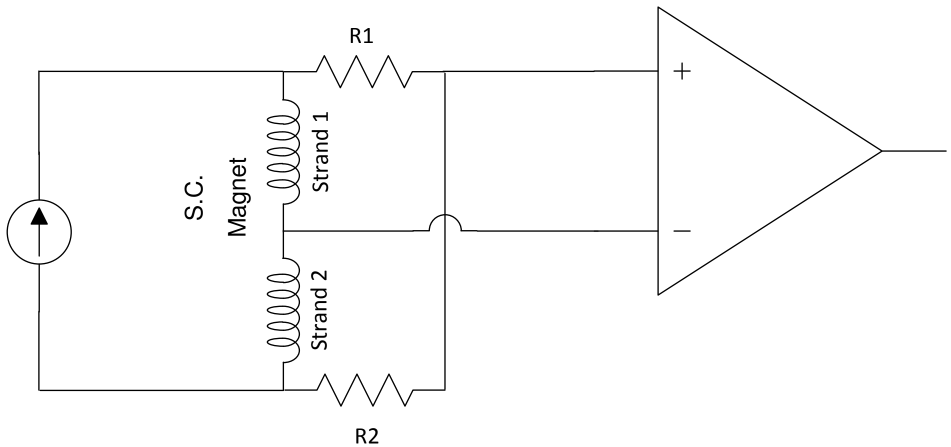
How do we do this?

A) Single?



No Quench detection when ramping, no protection for pulsed magnets…

B) Bridge?

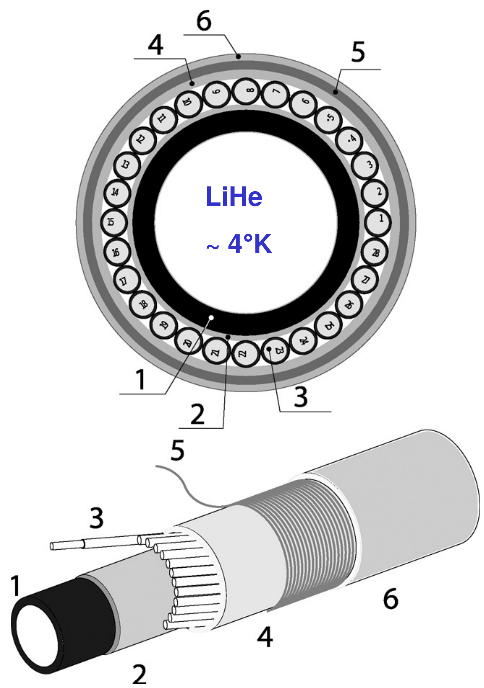


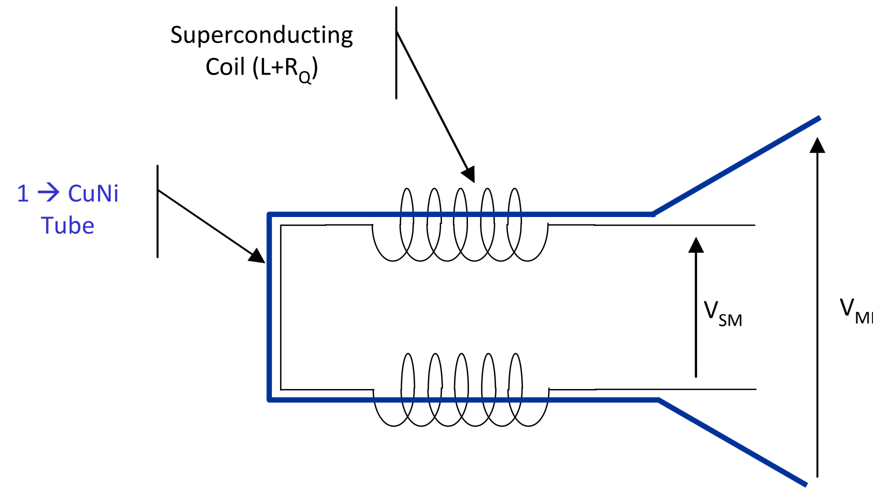
If R1 = R2 and Strand1 = Strand2 → Quench detector also when ramping and only one strand quenches…

Not able to detect symmetrical quenches…

Mutual Inductance Concept

Mutual Inductance Concept





QUENCH

$$V_{SM} = L \cdot \frac{di(t)}{dt} + R_Q \cdot I$$

V_{SM} = Voltage Single Magnet

L = Inductance of Magnet

R_Q = Quench resistance

$$V_{MI} = M \cdot \frac{di(t)}{dt} = \frac{L}{ns} \cdot \frac{di(t)}{dt}$$

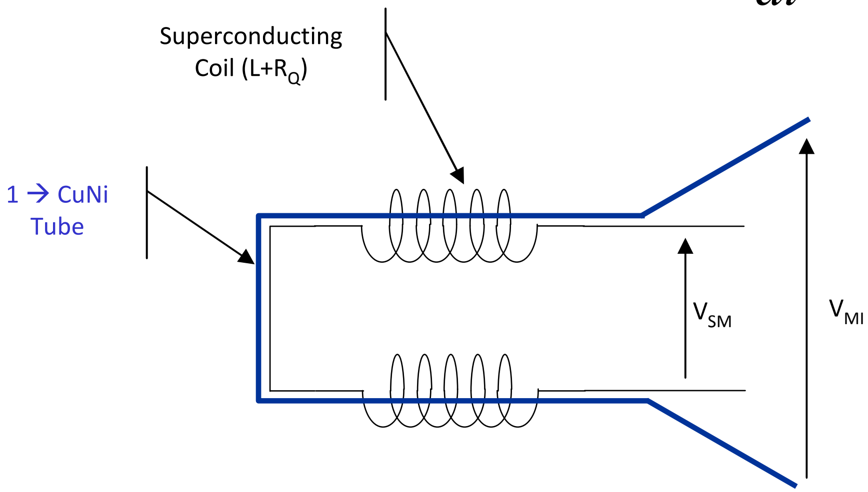
V_{MI} = Induced Voltage on the CuNi Tube due to Mutual inductance effect

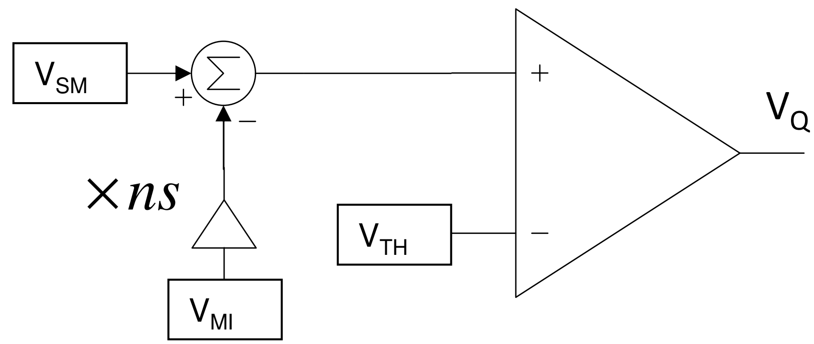
M = Mutual Inductance = L/ns

ns = Number of superconducting strands in series

Basic Idea of Mutual Inductance Quench Detector

$$V_Q = R_Q \cdot I_Q = V_{SM} - L \cdot \frac{di(t)}{dt} = V_{SM} - \frac{L}{M} \cdot V_{MI} = V_{SM} - ns \cdot V_{MI}$$





$$V_Q \leq V_{TH} \longrightarrow NoQuench$$

$$V_Q \geq V_{TH} \longrightarrow Quench$$

- Some Characteristics:

  - **High Voltage Protection and Insulation**: protect circuit against high voltage transients (Transient Voltage Suppressors, Gas Discharge Tubes, Zener Diode…) and insulate input from output (optical, galvanic…).

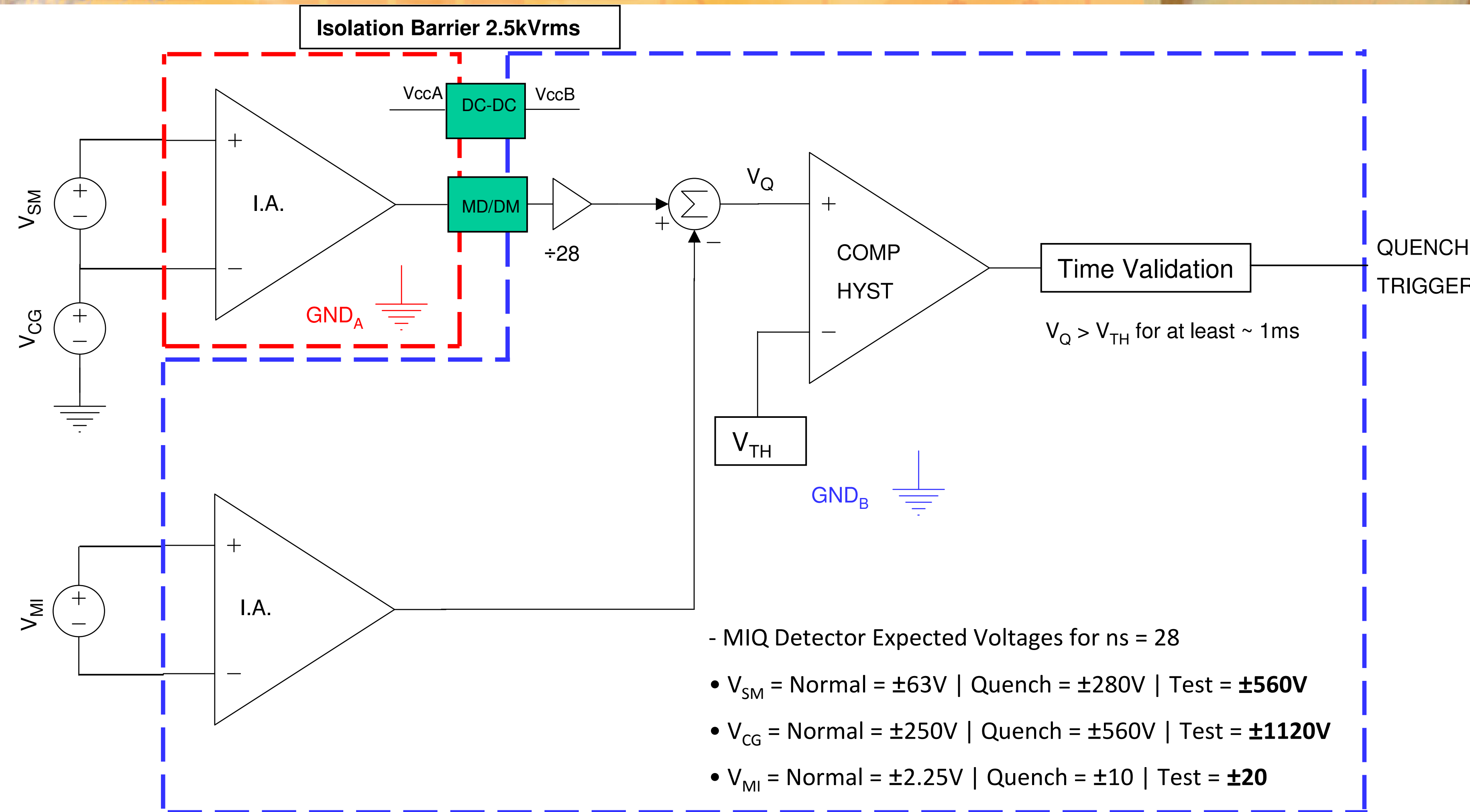
  - **Hysteresis**: prevent oscillations when comparing magnet voltages with V_{TH}

  - **Validation Time**: prevent “fake” quench due to noise/delay…

  - **Inverted TTL output logic**: ‘0’ is +5V and ‘1’ is 0V to be sure detector is working.

  - **All configurable**: first time mutual inductance is used for quench detection with ns > 1. Design only based on simulations!

Designed MIQ Detector



- MIQ Detector Expected Voltages for ns = 28

- V_{SM} = Normal = ±63V | Quench = ±280V | Test = **±560V**
- V_{CG} = Normal = ±250V | Quench = ±560V | Test = **±1120V**
- V_{MI} = Normal = ±2.25V | Quench = ±10 | Test = **±20**

GND_A = Floating at V_{CG}

GND_B = Normal Ground

Outlook

- Work to be done:
    - **Layout:** Under work
    - **Tests in Lab:** system performance, insulation, voltage withstand, leakages, response speed… Prototype ready Feb-2013
    - **Test with magnets:** Test with SIS100 Chromacity Sextupole in Dubna – Russia. Mar-2013

- If tests are successful, SIS100 + Super-FRS will need 250 MIQ-Detector… next generation must have:
    - **Digital isolation** instead of **analog isolation** to reduce costs due to “mass production” ($$$)
    - Include **FPGA/Microcontroller** to be able to monitor and configure remotely (System integration)
    - **CE** certificate + **RoHS (Lead Free?)**
    - … and much more…

Thank you!