Current derivative sensor applied to the magnet protection system

Ernesto De Matteis
TE-MPE-EP

ATS KT Innovation Day 26.10.2018

Topics

- Current derivative sensors
  - IPQ and 600 A corrector magnet
- HEP and no HEP application?
- Who has been involved in its development?
- Next steps to take it further?
- Conclusions

Current derivative sensors

Why: Important part of the consolidation of the Quench Detection System (QDS) for the Individually Powered Quadrupole (IPQ) and 600 A corrector magnet circuits

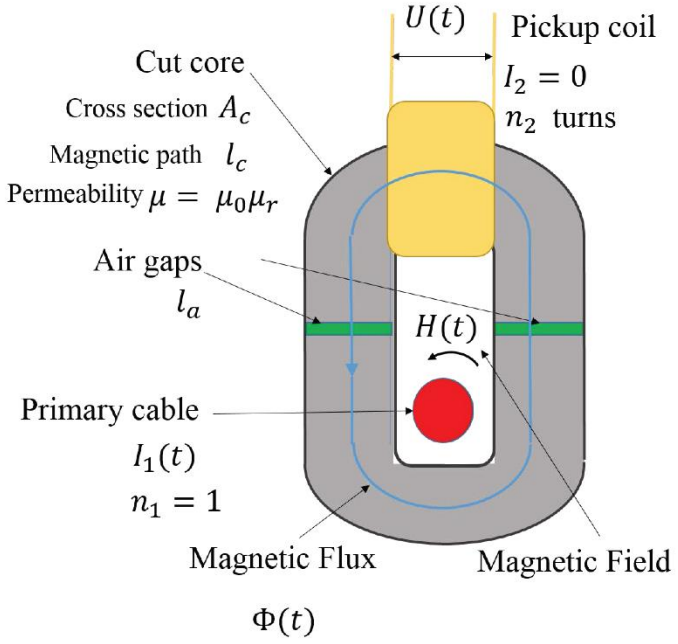
1) Developing a new type of quench detector providing a dedicated and independent means to symmetric quench detection for the IPQs;

2) removing the dependence of the 600A QDS from the numerical current derivative.

Proposed solution: current derivative sensors [1]

Transformer-based technology:

- Easy performance optimization using a cut-core configuration.
- Non invasive installation.
- Reliability improved due to the passive nature of the sensor.



Response voltage of the sensor U(t) proportional to the current derivative dI/dt

$$U(t) = \frac{\mu A_c n_2}{2(l_c + \mu_r l_a)} \frac{dI_1(t)}{dt}$$

Proof of principle:

6kA IPQ prototype (SM18)

600 A corrector prototype (EE rack – Bld 281)

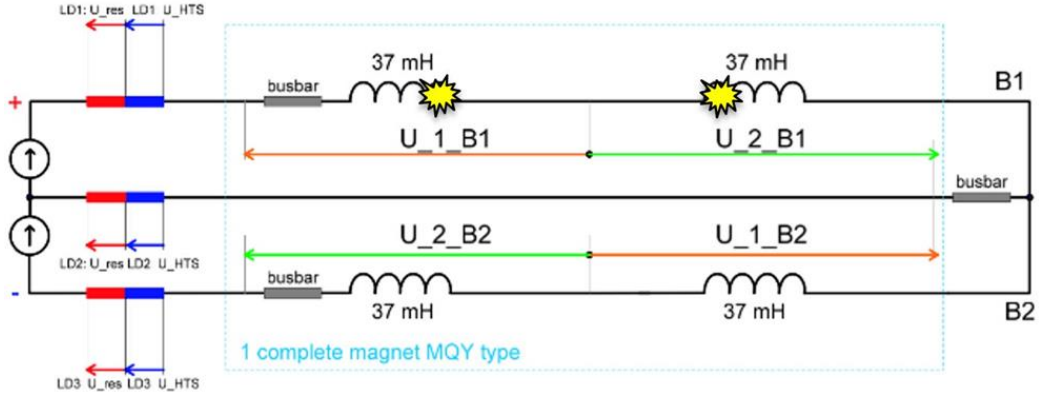
No similar solutions available on the market

[1]E. De Matteis, D. Calcoen, R. Denz, A. Siemko, J. Steckert and M. B. Storkensen, "New method for magnet protection systems based on a direct current derivative sensor", IEEE Trans. Applied to Superconductivity, Vol. 28, Issue: 3, April 2018.

6 kA didt sensor tests for the IPQ magnets

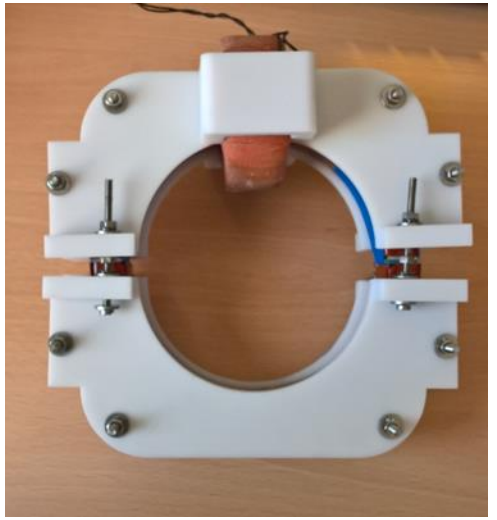
New detector for the symmetric quenches in the IPQ magnets:

- Measuring the high dI/dt during the quench using a measurement transformer $V_D \propto k\frac{di}{dt} > 100\ mV$

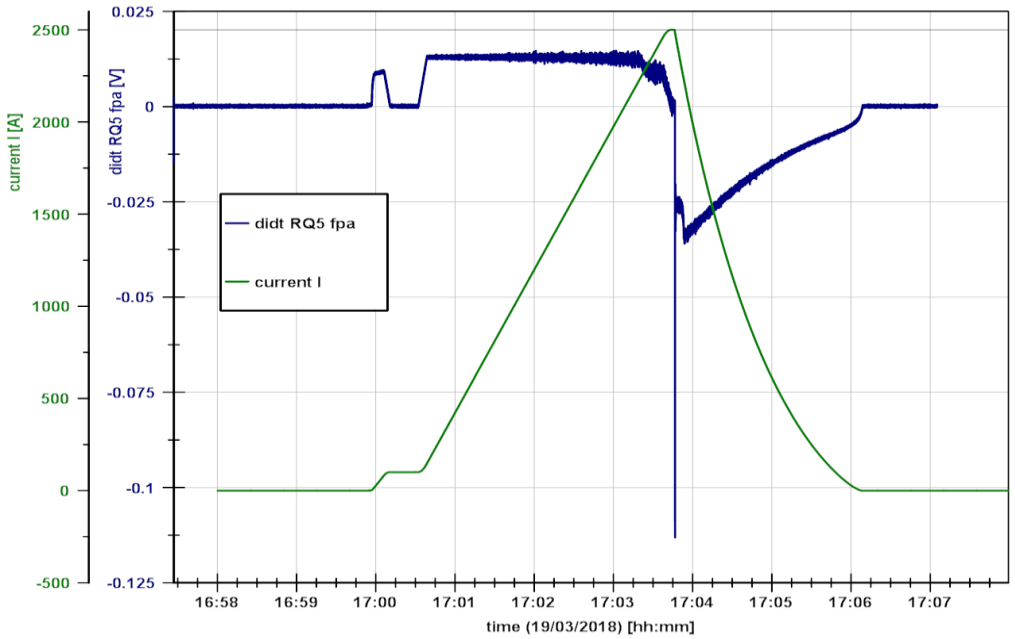


From LHC – UA27 RQ5 circuit

Sensor to be installed

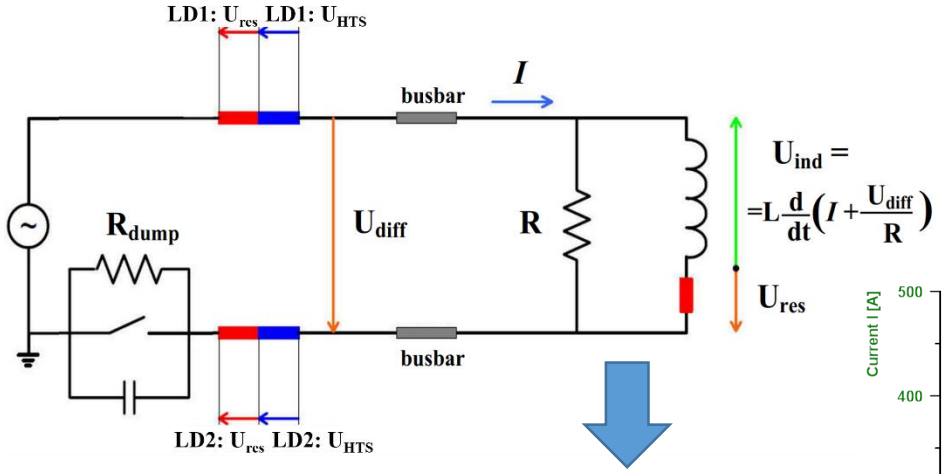


From SM18



600 A didt sensor tests for the corrector magnet circuit

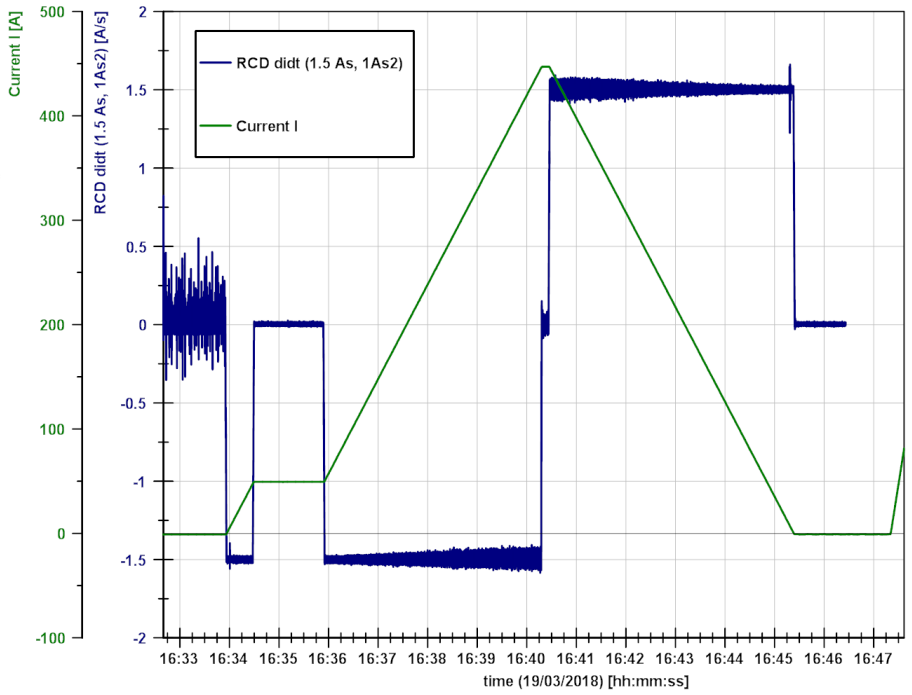
New sensor for measuring the derivative of the magnet current:



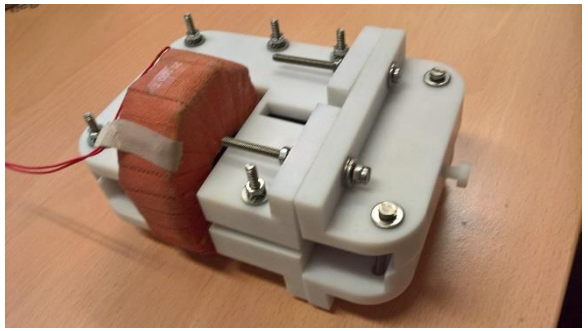
Quench detection scheme

$$U_{res} = U_{diff} + L(I)\frac{d}{dt}\left(I + \frac{U_{diff}}{R}\right)$$

- The numerical dI/dt is heavily filtered to make the calculation stable introducing a significant phase shift (for >>A/s^2) and restricting the operational range of circuit (A/s^2)
- Proposed mitigation is a direct measurement of the dI/dt;



Sensor to be installed



From Bld 281

From SM18

First Quench detected on Wednesday!!! CLIC Wiggler magnet in SM18

HEP application?

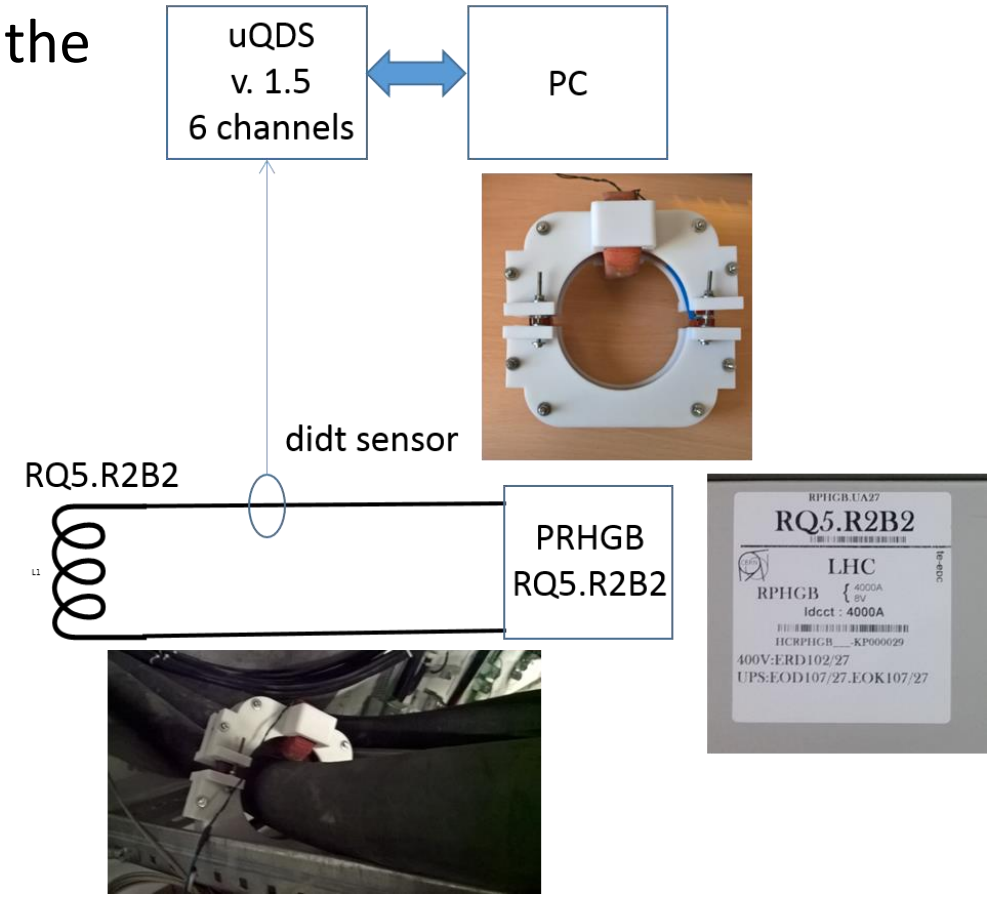
Sensor for measuring the derivative of the magnet current:

- Quench detection for superconducting magnet as the 600 A corrector magnet (two voltage taps)

New quench detector for superconducting magnets in HEP:

- Measuring the high dI/dt during the quench

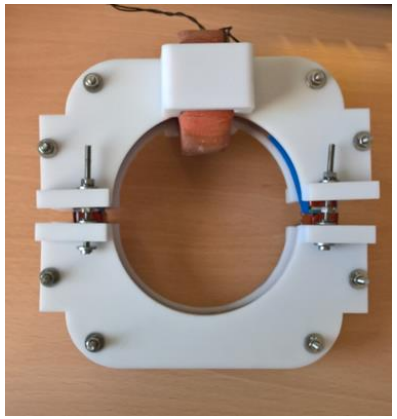
$$V_D \propto k\frac{di}{dt} > 100\ mV$$



No HEP application?

The potential applications of these sensors could be all the industrial or research activities/plants that need to measure current derivative:

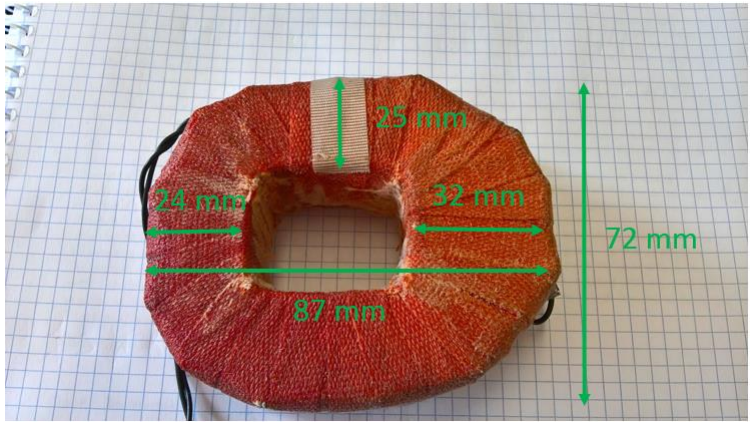
- AC motors (control)
- Automotive (e-cars market is growing up)
- Power converter (regulation)

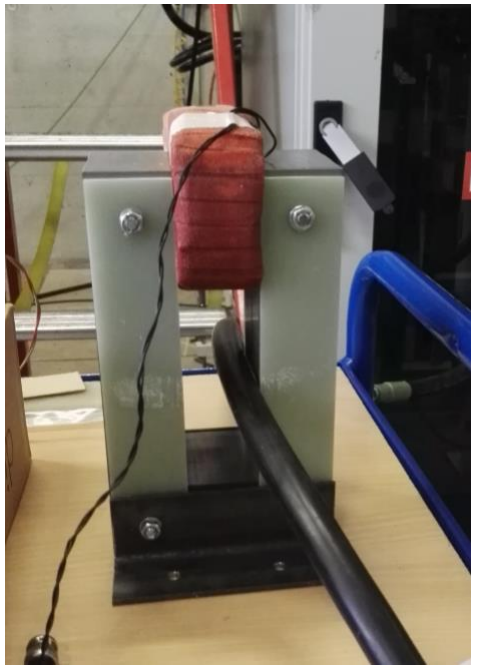


Who has been involved in its development?

External partner:

- LiLCo Ltd. – Broadband Measurement Transformer:
  - First prototypes in electrical grade steel
  - Consulting on the core material
  - Pickup coil supplier

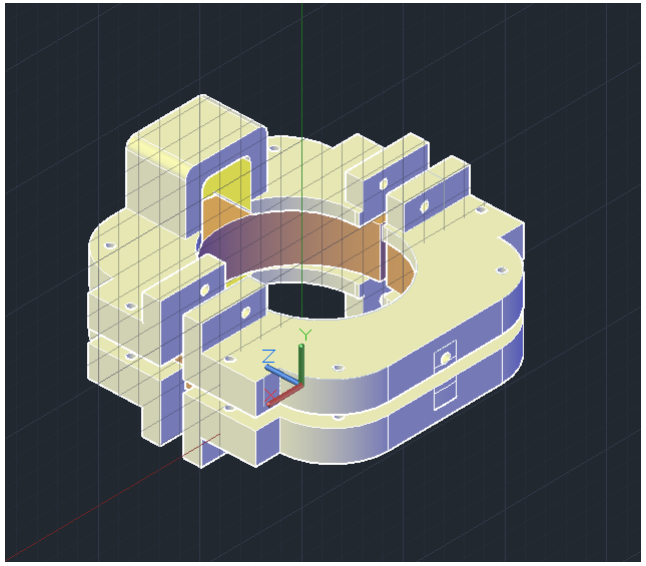


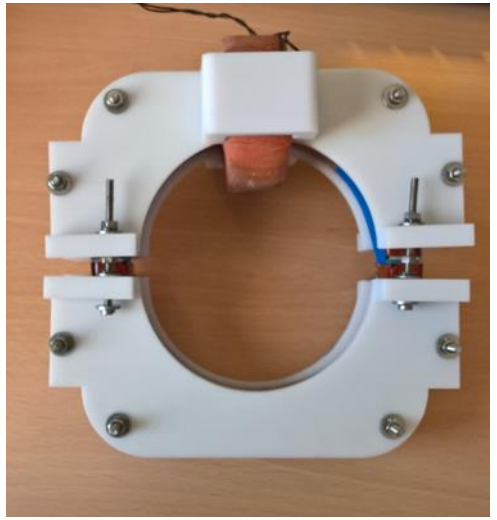


Who has been involved in its development?

CERN Services and resources:

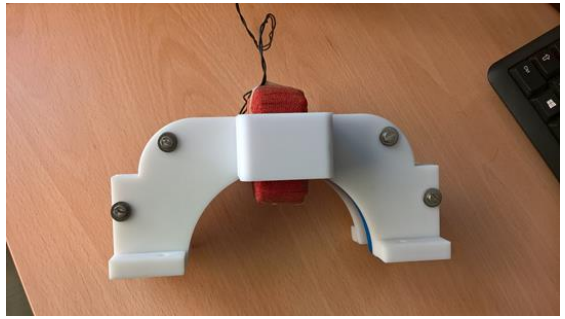
- Polymer Lab (3D printer)
  - Plastics Sensor Holder

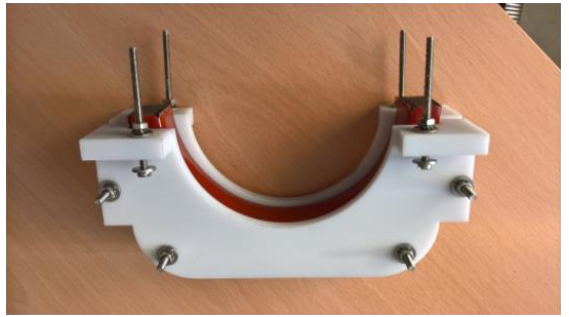




- Stores - Raw materials

Water jet cutting machine used to cut the toroidal core





Apart the precious help/collaboration of different CERN sections, groups, and departments… especially for the test campaigns (LHC, SM18)

Next steps to take it further?

- EM and mechanical dependence of the sensor performance with respect to the noise and to the environmental effects:
  - Improving the electromagnetic shielding of the sensors (if needed)
- Model optimization study
- Industrialization:
  - Repeatability/reproducibility of the sensor (different core)
  - Holder design for the LHC machine application (or others)

Conclusions

- The sensors have passed the proof of concept (scalability)
- Different prototypes were designed and tested on-field (SM18, LHC)
- Validation is ongoing -> First Quench detected
- Prototypes cost: 280 chf (coil + core) except the holder
- Next steps: Industrialization/Commercialization thanks to the help of KT… (?)

Thanks for your attention…