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Development of Quench Antennas for Quench Detection in Nb_3Sn Magnets

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Abstract

Detailed localization of quench start in Nb3Sn accelerator magnets by voltage taps, which is less feasible in long prototype coils. Localization with quench antennas is a proven concept for longitudinal quench localization in full length accelerator magnets. Quench antennas are also excellent vibration detection tools, and can five important information on the cause of the quench. Dedicated quench antennas were produced using state of the art flexible printed circuit boards. They were installed Nb3Sn model magnets and measurements are expected to be taken later this year.

Quench Antenna Principle

In the event of a quench, current redistributions in superconductor leads to a magnetic field variation, which can be detected according to Farady's law of induction. Using a pair of coils (A-C) allows to be sensitive purely to **local field changes** and not to homogeneous as during the powering process of the magnet

$$U_{ind}(t) = -N_t \frac{d}{dt}\left[\int_a B_{1,a} \cdot dA + k_c \int_c B_{1,c} \cdot dA\right]$$

However, the greater the distance between pick-up coils and quench origin, the weaker the signal. Magnetic measurement shafts can be used as Quench Antennas but are installed inside.

Therefore its coils are far away from the windigs as the figure on the right side shows.

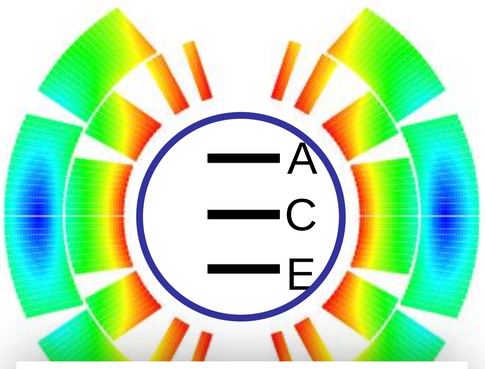
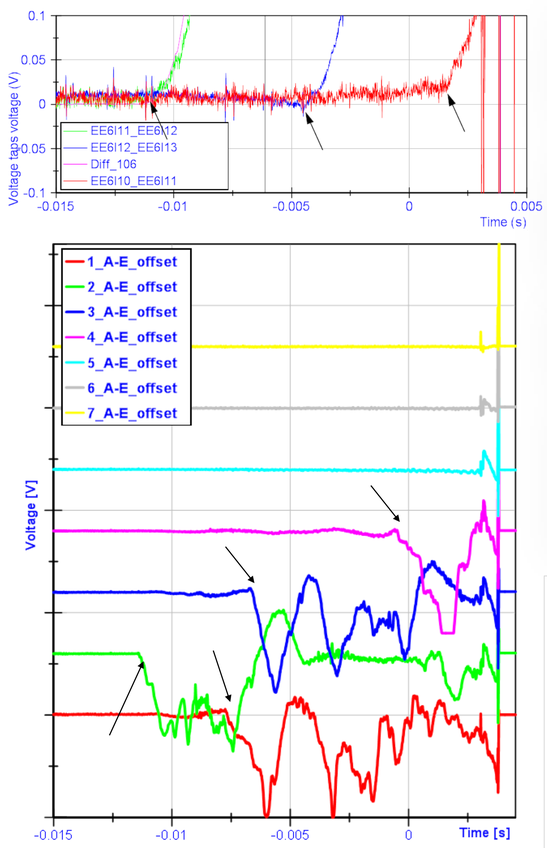


Fig. 1: Coils of a standard magnetic measurement shaft

Quench propagation in 11 T model with Quench Antennas

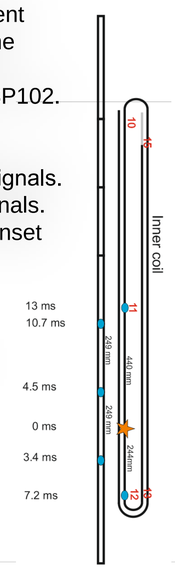


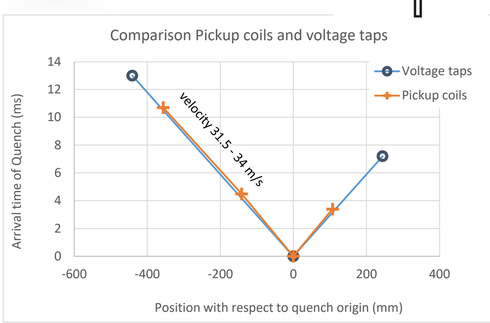
Using a magnetic measurement shaft as a quench antenna, the quench propagation could be clearly seen in a quench on SP102.

Left, top: differential voltage ("Diff_106") and voltage tap signals. Bottom: quench antennas signals. Note the sequential quench onset marked with arrows.

Right: the quench start (star), and different sensor's signal onset times

Bottom: quench propagation velocity calculated from voltage taps and quench antenna signals





Vibration Measurements

Quench Antennas are a valuable measurement tool to investigate the magnet behavior. Besides good longitudinal quench localization it allows also characterization of vibrations that are related to mechanical movements inside the magnet structure.

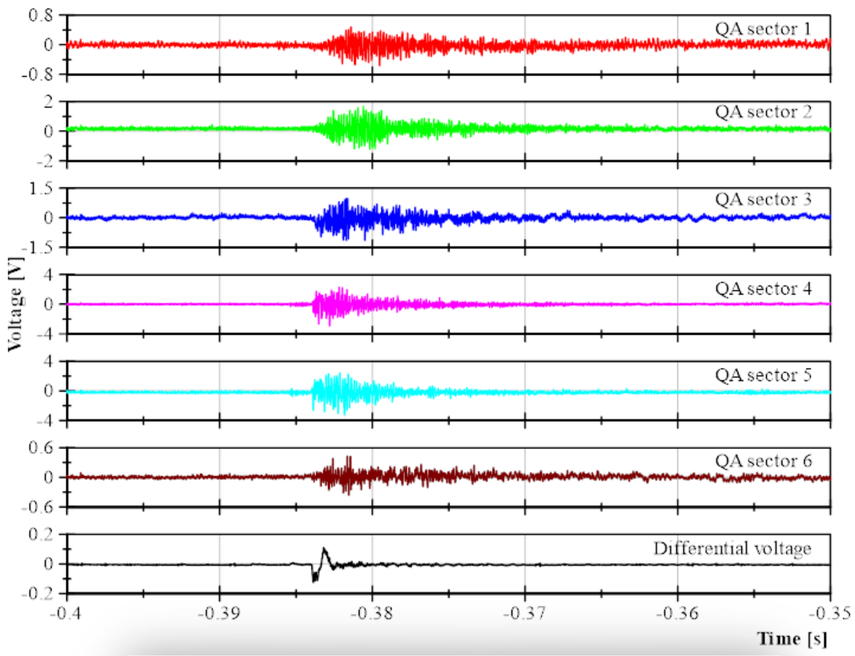


Fig. 3: Vibration measuement with a magnetic measurement shaft used as a QA

Acknowledgements

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Flexible Circuit Board Prototype

Idea:
In order to overcome the problem of the great distance between quench origin and coil, the gap of ≈ 2.5 mm between the magnet bore and the magent's windings can be used (see fig. 1). This brings the coils **closer to quench origin**. Thus, shape of coils follows the curvature of bore pipe and have to be very thin. Flexible circuit boards (FPCB) allow to achieve this.

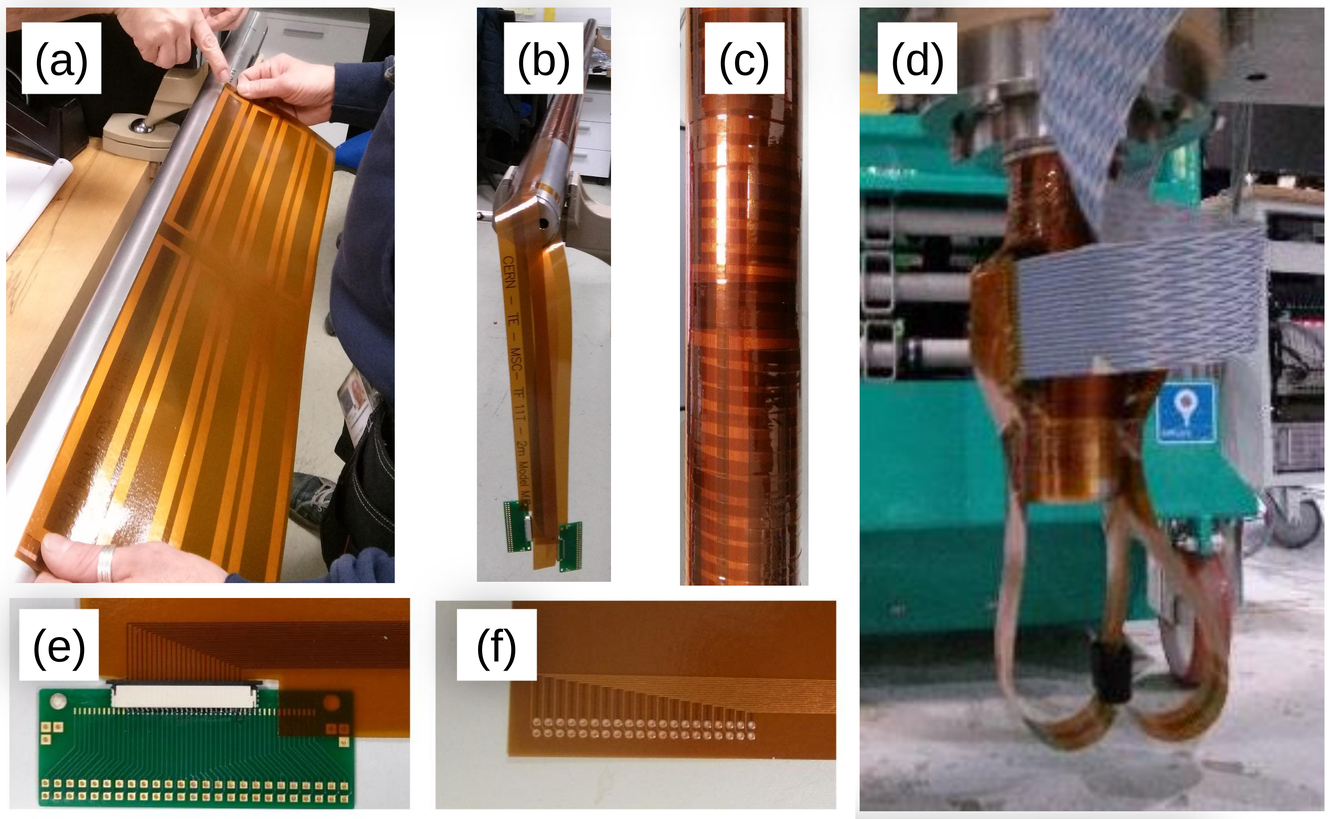


Fig. 2: Assembly of flexible Quench Antenna on beam pipe (a), (b). Several boards are connected by simply overlap the contact pads and apply pressure via Kapton that is wrapped around the antenna. The antenna is connected to the DAQ via flat cables. The connector was improved from the first prototype (e) to the new version (f).

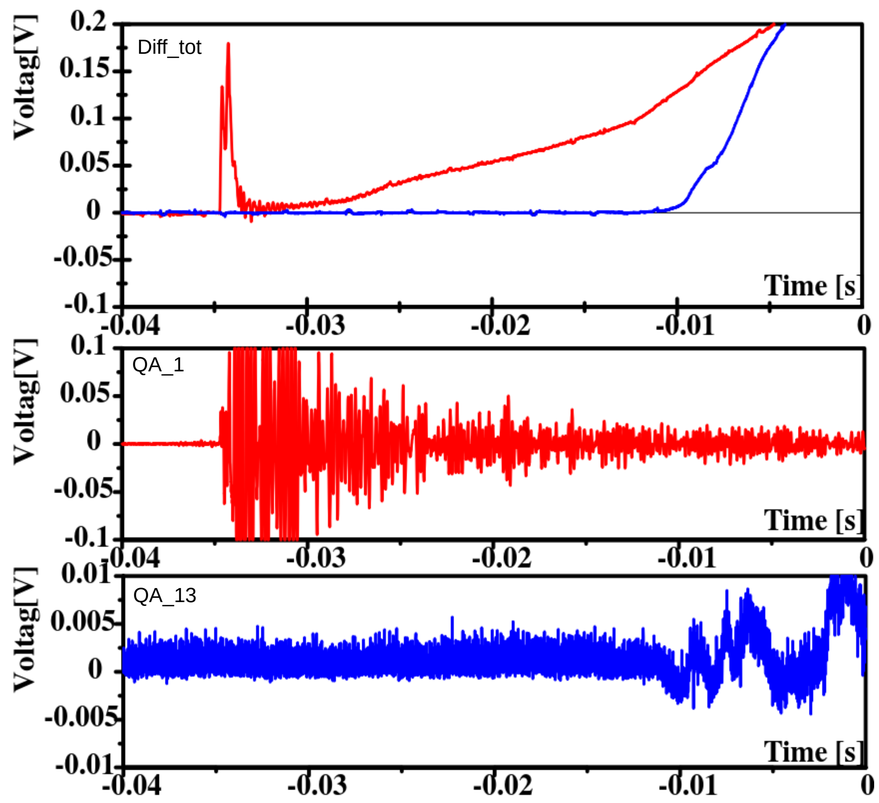
Quench precursor detection

Comparison of signals from a quench with precursor (red curves) and without precursor (in blue).

Top: differential voltage.
Middle: quench antenna segment 1
Bottom: quench antenna segment 13

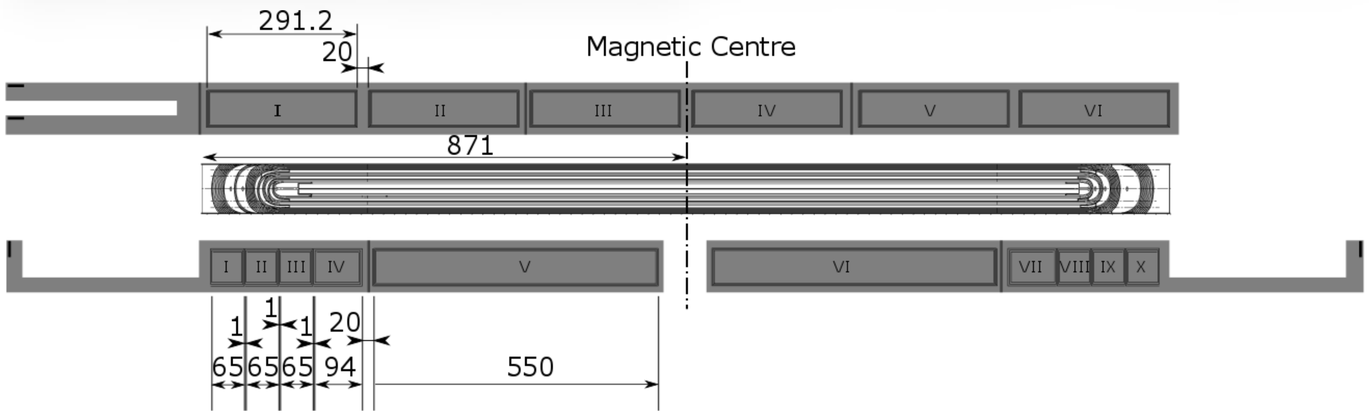
The quench antenna shows fast oscillations at the same time as the precursor whereas without a precursor a smooth low frequency signal is measured.

In absence of stick-slip movement during quench the measured signal will pickup changes in current distribution in the quenched turn. In case of slip-stick, the oscillation will create a strong dB/dt on the quench antenna and the current distribution signal cannot be identified anymore.



Antenna Setup for 11T-Magnet

The assembly of a first prototype was already tested. For the upcoming test of the 2 meter long Nb_3Sn 11 T double aperture model magnet two flexible Quench Antennas will be used in the two bores.



Conclusions

Quench antenna are a proven tool for localisation of quenches. With state of the art flexible Printed Circuit Board technology an additional quench antenna set is created, which is a dedicated system, optimized for surface and distance to the coil. The concept has proven to withstand a cooldown in a magnet. In October a first full test with these quench antennas is foreseen.