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Abstract--High field superconducting dipole magnets were manufactured in industry or at CERN as model magnets for the future LHC particle accelerator and tested in superfluid helium. The pick-up coil method is now currently in use to precisely locate the origin of training quenches and to monitor the propagation of the transition. The improvements made on this diagnostic method in the past two years will be reviewed. This experience presently allows the location of the onset of the quenches both axially and in the cross section of the winding even for magnets equipped with a minimum of voltage taps on the winding. The location of training quenches are now understood to be related to the structure of the superconducting coil.

I. INTRODUCTION

CERN has launched in European industry the fabrication of several short and full length superconducting models of twin aperture dipole magnets for the LHC 7 Tev proton collider expected to work at the beginning of the next decade [1,2]. These magnets are designed to have their superconducting cable limits above 10 T, but suffer from training or premature quenches. The localization of these training quenches is a key requirement for improving the magnet design and fabrication.

The voltage taps technique is frequently used for this localization. It suffers from the high number of taps needed for precise resolution and from the difficulties of mounting them as well as the possible risk of short-circuits. This method cannot be used during the production phase of accelerator magnets where voltage taps are not allowed inside the coils.

Acoustic emission (e.g. [3]) does not interfere with magnet coils, but has limited accuracy and usually is used as a complementary method to determine quench origin [4].

The pick-up coil method developed at CERN [5] and successfully adapted for magnets of the former SSCL project [6] detects the magnetic field distortions induced by the quenching superconducting cable. These distortions are believed to be linked to current redistribution between the strands of the cable. They are detected by means of stationary pick-up coils assemblies (so-called quench localization coils or simply QLC) introduced into the magnet apertures. This paper summarizes the improvements made in the detector systems and data analysis of the pick-up coils technique.

II. DESCRIPTION OF THE DETECTORS

A. Geometry of the Quench Localization Coils

Figure 1 shows the arrangement of the QLC assemblies in the cross-section of LHC dipole coil. Two different coils designs are in use for short (see Fig. 1a) and long (see Fig. 1b) magnet models. For short (1 m long) models common coil assemblies both for magnetic measurements and quench localization are being used. The measuring shaft consists of 15 so-called harmonic coils grouped into 5 longitudinal sections of 3 coils each (see Fig. 2). In order to increase the longitudinal resolution of the quench localization in the magnet ends, two additional sections both of 3 coils have been added in each end (K1, K2 and K6, K7 in Fig. 2), parallel to the harmonic coils sections H12 and H67. For the purpose of the quench localization in the magnet cross-section, the measuring shaft is equipped with four dedicated tangential coils covering the entire length of the magnet.

Fig. 1. Cross-sectional arrangement of QLC: a) short models, b) long models.

Fig. 2. Longitudinal alignment of QLC.

For the 10m-long models a dedicated quench localization shaft is used. The cross-section consists of 4 radial coils shifted by 90° . This shaft is assembled with 10 longitudinal sections. Six 7 cm long sections are used to detect the quench start position in the magnet heads (3 sections for each end) and four 2m long sections to detect the quench in the magnet's straight part.

B. Data Acquisition

The acquisition system records signals both from voltage taps and quench localization coils. It is triggered by the quench detectors used for the magnets' protection. The signals of a pair of QLC are subtracted in order to cancel the noise coming from the power converter. The pairing is made between coils located at the same longitudinal position in both apertures. The maximum sampling frequency of the multi-channel transient recorder is 300 kHz. The transient recorder is capable of working in multi-event mode to record "spikes", the transient phenomena that occur during ramping the current up to quench.

III. FAST OSCILLATIONS AND "SPIKES"

A "Spike" is attributed to a sudden motion of a superconducting wire in the coil. The corresponding dislocation of a current I induces two electromagnetic effects. The first is a voltage pulse induced along the wire moving in the magnetic field B ,

$$V_1 = -B \frac{dA}{dt}, \quad (1)$$

where A is the surface marked off by the moving wire.

This voltage can be used for estimation of the energy released by the wire motion.

The second electromagnetic effect is a voltage pulse induced in the whole coil due to a transient flux change caused by a momentary dislocation of current,

$$V_2 = -\frac{d}{dt}(L \cdot I) - \frac{d}{dt}(M \cdot I), \quad (2)$$

where L is the self inductance of the coil and M is the mutual inductance between the moving wire and the rest of the coil.

The magnitude of voltage V_2 depends on the position of the wire where the movement appeared. The actual measured voltage V is the sum of V_1 and V_2 . The energy estimated according to

$$E = I \int V dt, \quad (3)$$

is therefore an upper limit. Moreover this voltage can partially be cancelled if voltage differences between two poles are measured (see Fig. 3).

A real spike provokes vibrations measured as oscillations on signals coming from both the QLC and the voltage taps.

Fig. 3. Partial cancelling of voltage induced by spike for different voltage taps.

The initial movement is usually localized i.e. the signals picked-up at the same time by the coils belonging to the same longitudinal section are graded. The initial spike or oscillation is followed by complicated, global mechanical vibrations of the magnet coil as well as other structure components. The set of different voltage tap signals presented in Fig. 4 shows that the vibration propagates in the magnet transverse section. At the same time longitudinal propagation is observed by means of pick-up coils (see Fig. 5). The typical longitudinal propagation velocity is measured to be in the range of 2000 m/s. A propagation from one aperture to the other was also observed.

Fig. 4. Propagation of the vibration in the magnet transverse section. Most upper curves show voltage difference between apertures.

Fig. 5. Longitudinal propagation of the vibration in the magnet detected by QLC (curves from H12 to H67). Most upper curves show voltage difference between apertures.

Fig. 6. The development of magnetic flux in a series of coils (H12 to H5) vs. time showing the longitudinal propagation of the normal zone detected by QLC.

Frequently the position of the spike is observed to be different from the one where the consecutive normal zone starts, indicating that the mechanical vibration dissipates frictional heating when propagating through the magnet structure.

IV. PROPAGATION AND AXIAL LOCALIZATION OF THE QUENCH

The quench propagation velocities are usually measured with the help of many voltage taps installed in the magnet (e.g.[7]). The pick-up coils technique can also be used. Observations of the voltage signals picked-up by QLC vs. time yield information from which a longitudinal quench velocity can be derived. Figure 6 shows magnetic flux calculated by integrating the induced voltages from a longitudinal series of coils. The time intervals at which the propagating normal zone reach subsequent coils can easily be measured.

Fig. 7. Turn-to-turn propagation measured by means of a) voltage taps, b) QLC. Two bumps refer to the rising of a resistive voltage in the two turns in which propagation appeared.

A quench starting in the straight part can be localized by ratios between these intervals. The quench velocity is derived from the longitudinal position of each coil. This velocity has to be assumed constant for a quench starting in the ends. The resolution is estimated to be better than 1 cm.

It is worth mentioning that a sharp transition is observed when the propagating normal zone leaves one coil and reaches the next one. The current redistribution associated with the propagating front is therefore localized.

Transverse propagation of the quench can also be studied with the help of QLC. Fig. 7b shows superimposed voltage signals induced in three coils of the same longitudinal section. The second bump corresponds to the inter-turn propagation detected by the voltage taps signals of Fig. 7a.

V. LOCALIZATION IN SOME LHC MODELS

The first experiences with this technique allowed the easy axial localization of the quenches, but it was difficult to localize them in the cross-section. It was feared that screening from the inner layer superconductors would disturb signals coming from transitions starting in the outer layer. The discrimination in which layer the quench starts became certain for magnets having an inner layer voltage tap. The different signatures coming from transitions starting in the inner or outer layers were understood. Improvements both in the 2D analysis tools and axial positioning increase the quench localization reliability.

The few cases studied in this section show that the tools described above have been able to discriminate between various weak points in the short and long model magnets tested:

- transition between different types of collar,
- first few turns of the outer layer due to the difficulties to correctly assemble the splice layer jump region,
- bending part of the first block of the outer layer,
- ramp-splice turn.

A. MTA1JS

The first trials of the quench localization were performed on this twin aperture short model, reaching 10T. 80 % of the quenches were located near to or in the ends, more in the return end. Without any possibilities to prove in which layer the quench was initiated, end problems were believed to be due to the bending of the stiff inner layer cable.

This magnet was modified to distribute more widely the forces applied by the iron yoke to the collars over the whole contact surface (line to line fit). Quenches at up to 9.6 T were detected in the smaller block of the outer layer, one at 9.2 T in the straight part, the other ten in the return end.

B. MSA1E

This single aperture model was equipped from the start with voltage taps between the layers. Most training quenches

were detected in the outer layer and bending part of the small block. Some were in the ramp-splice region on the turns external to the ramp-splice turn.

The magnet was modified to improve the transmission of the forces in the median plane for the whole length. Compared to the previous test, more quenches are seen in the transition region and less in the bending part.

C. MTA3CERN

This magnet has reached 10.5 T. The analysis indicates that the transition region between two different types of collars is a weak point inducing most quenches of the inner layer. Several quenches were also detected in the ramp-splice turns.

D. MTP1A1 and MTP1A2 10 m long models

Positioning of the training quenches brings similar results for both magnets. All of the quenches in MTP1A1 and 85 % of the quenches in MTP1A2 start in the outer layer. No quenches were found in the magnet straight parts. They originated mainly in the first turns of the outer layer in the length of the ramp-splice. Transitions between different types of collar are main weak points. These measurements bring the important result that the training behaviours of full length magnets and 1 m long models are similar.

CONCLUSIONS

The complexity of the spike phenomenon attributed to a sudden motion of the superconductor carrying current has been discussed. The interpretation of frequently observed different starting positions of spikes and normal zones for so-called spike-provoked quenches was proposed.

The power of the pick-up coils technique to investigate longitudinal and transversal quench propagation is demonstrated. It is a very useful tool to detect weak points responsible for premature quenches in superconducting magnets.

REFERENCES

- [1] The LHC Study Group, "LHC, The Large Hadron Collider Accelerator Project," CERN/AC/93-03(LHC), 8 Nov. 1993.
- [2] D. Leroy, J. Krzywinski, L. Oberli, R. Perin, F. Rodriguez-Mateos, A. Verweij, and L. Walckiers, "Test results on 10 T LHC superconducting one meter long dipole models," *IEEE Trans. of Appl. Sup.* Vol. 3, No 1, p. 614, March 1993.
- [3] O. O. Ige, A. D. McInturf and Y. Iwasa, "Acoustic emission monitoring results from Fermi dipole," *Cryogenics*, Vol.26, pp. 141-151, March 1986.
- [4] A.Devred, "Quench origins," SSCL-225, March 1990.
- [5] D. Leroy, J. Krzywinski, V. Remondino, L. Walckiers, R. Wolf, "Quench observation in LHC superconducting one meter long dipole models by field perturbation measurements," *IEEE Trans. Appl. Sup.*, Vol. 3, pp. 781-784, 1993.
- [6] T. Ogitsu et al. "Quench antenna for superconducting particle accelerator magnets," *IEEE Trans. on Magn.*, Vol. 30, No 4, pp. 2273-2276, 1993.
- [7] D. Bonmann, K. -H. Mess, U. Otterphohl, P. Schmuser, M. Schweiger, "Investigations on heater induced quenches in a superconducting test dipole for the HERA proton accelerator," DESY HERA 87 - 13, June 1987.