ROOM TEMPERATURE MAGNETIC MEASUREMENTS OF SUPERCONDUCTING MAGNETS

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Abstract

In the frame of a contractual collaboration with IHEP for the UNK project, three test stands have been built and delivered to measure the magnetic field of the superconducting elements (dipoles and quadrupoles) at room temperature. This paper will describe the different parts of the apparatus which enables in particular to measure a 6 m long dipole in only one measurement, the qualification tests and the results of the first magnets measured in USSR.

Emphasis will be put on the mechanical measurements made on the measuring tubes and on the very high accuracy and reproducibility of the devices.

Introduction

In a superconducting magnet, the field quality is mainly determined by the conductor position ; that means that, as soon as the coils which make up the magnet have been wound and assembled, one can get a correct estimation of the final field quality, which also involved coil positionning, iron saturation and remanent field effects

That is of particular importance in the case of a mass production, where a large number of magnets can be produced before a defect can be detected. So, this kind of measurement has already been routinely done during the Energy Saver. Doubler project at FNAL [1] and the HERA project at DESY [2].

The three systems built to make the room temperature magnetic measurements of the UNK magnets (two for the dipoles and one for the quadrupole) are inspired by these two previous apparatus. One of its main improvement is the measuring tube which makes it possible to measure the field integral of a 6 m long dipole in only one measurement. A close study of the software and of the data presentation has also been made.

Measuring process

The principle of the measurement is the following : the magnet is excited with an alternating current (peak value ≈10A, frequency : 11 Hz). The flux variation due to the change in the B_θ field component is induced in a set of measuring coils and measured at different angles in the magnet aperture, using a lock-in amplifier. The signal is then Fourier analyzed to deduce the fundamental and the harmonics of the magnetic field.

The whole measurement consists of two phases :

- main field analysis, using only an external measuring coil ;
- harmonic analysis using a predetermined coil combination, such as to cancel the main field (and the dipole component in case of a quadrupole measurement).

Once the operator has chosen which part of the magnet must be measured (either the central part, or one end or the total length), the course of the measurement is fully automatic, and the parameters (coil combination, lock-in amplifier sensitivity...) are automatically set.

The measured points are displayed on line during the measurements. The data treatment is also done on line after each phase and the results of the magnetic field analysis are displayed in a numerical as well as in a graphic way. In the case of a quadrupole magnet, the final results take into account the calculated off-centering of the measuring tube in the magnet.

Main parameters of the magnets

The UNK magnet parameters which are important for this kind of measurement are the following :

- for the dipoles :

. coil aperture diameter	80 mm
. total length	5900 mm
. transfert ratio	≈ 10 G/A
. inductance	≈ 50 mH
. resistance at 300 K	≈ 4 Ω

- for the quadrupoles :

. coil aperture diameter	80 mm
. total length	3400 mm
. transfert ratio	≈ 2 G/cm/A
. inductance	≈ 12 mH
. resistance at 300 K	≈ 1 Ω

Description of the apparatus

Each of the three systems consists of a measuring tube which holds the measuring coils, a test stand, an electronic cabinet and a microcomputer with its line printer.

Measuring tubes

Made with fiber glass, they contain the measuring coils :

- for the dipole : three similar sets of two radial coils. Each coil mandrel is 2 m long and the coil is wound with 100 turns of a 100 μ diameter copper wire. The three sets are positioned along the tube which has a total length of about 6.2 m.

All the coils have been calibrated in a reference magnet ; they have an average area of 4.40 m². Thanks to the reproducibility of the construction, the coils can be combined without adding any resistance to get a good bucking ratio.

- for the quadrupole : three similar sets of three radial coils. Each coil mandrel is 1.08 m long and is wound with :
  . 50 turns of a 150 μ diameter copper wire for the external and the internal coils,
  . 100 turns of a 100 μ diameter copper wire for the central coil.

The three sets are positioned along the tube which has a total length of about 3.5 m.

These coils have also been calibrated (mean area : 1.32m² for the 100 turn coils, 0.66 m² for the 50 turn coils) and are also combined without any additional resistance to get a good bucking ratio.

A cross section of the radial coils for each case is shown on the Fig. 1.

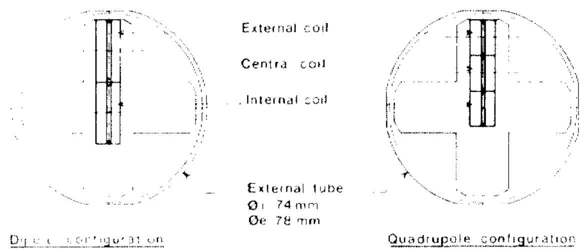

Fig. 1 : cross section of the radial coils

Test stand

It consists of a wooden support with a stepping motor at one end (SLO SYN MO 92 FC 08) with a reduction of 100 and an encoder at the other end (CODECHAMP COA 50089 A, with a resolution of 15 bits).

Electronic cabinet

It contains :

- the bipolar power amplifier (BOP 50-8 KEPCO for the dipoles, BOP 36-12 KEPCO for the quadrupoles), supplying a maximum current of 8A for the dipoles and of 12A for the quadrupoles.
- the lock-in amplifier (PAR 5210)
- a CAMAC crate with a crate controller, a digital input board, a digital output board, a coil switch module and a current swich module.

The measuring coil driving system is installed in a smaller cabinet, located near the test stand.

Computer

A Bull Micral 60 with a 60 Mo hard disk is used to monitor the installation and to make data acquisition and treatment. A graphic terminal enables to get copies of the results.

Figure 2 is a block diagram of the system.

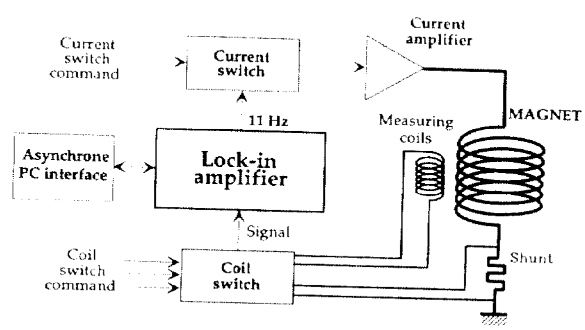

Fig. 2 : Block diagram of the system

Software

As previously mentioned, a close study of the software has been done so as to make its use as easy as possible and to present the results in a very usable way.

The same program is used for both dipole and quadrupole measurements.

After the initialization, wher among other things both the magnet type and the measuring tube are defined, the operator has the choice between :

- a standard measurement (integral measurement on the whole length of the magnet) with the three sets of coils put in series),
- a non standard measurement (measurement on one third of the magnet with only one selected set of coil).

Once this choice has been done, the whole measurement is fully automatic : a control of the hardware is done, the different apparatus are set at their inital value and the measuring tube is put at the zero position.

After a current measurement, a measurement of the fundamental is done, using only the external coil : the data are taken at 40 angular positions on 360° and displayed on line. Once this measurement is finished, a control of the current is done and the measuring tube is rotated back to its original position.

The fundamental term and its phase are calculated. In case of a quadrupole measurement, the misplacement of the measuring tube in the magnet is also calculated from the ratio between the dipolar and the quadrupolar terms which have been measured.

The harmonic measurement is then started in the same way but using bucking coils. The bucked signal is now measured at 100 angular positions on 360°. The data are also displayed on line.

Once the measurements are done, the data are treated and different results are calculated :

- raw results, which derive from the Fourier analysis,
- final results, which are normalized to the fundamental modulus and angular position, and which are recalculated in a system centered on the magnet axis in the case of a quadrupole.

The results are displayed in a numerical as well as in a graphic way ; in this last case, the tolerances are also displayed and the operator can immediately notice if the results are within the tolerances.

When the measurement cycle is done, the data are automatically transferred as a file on the hard disk. The stored files, which contain all the data from the initialization to the final results, can be visualized by the operatof at his request.

Preliminary tests of the systems

Before their expedition and installation in USSR, the systems have been tested at Saclay where two main kinds of tests were performed.

Mechanical tests

One of the most serious problem which could happen would be a twist between the three sets of measuring coils specially in the case of the 6 m long dipole tube.

After the mechanical assembly of the three sets, it is no longer possible to measure the twist of one set referring to the other, but the overall value of the twist can be measured, using the encoder put at the opposite end of the tube, with regard to the stepping motor.

For measurements at 100 angular positions on 360 d°, the results are very reproducible (some hundredths of a d°). A preliminary measurement, without the tube, gives the accuracy of the stepping motor precision measured by the encoder. The results are the following :

- for the 100 angular positions, maximum deviation from the theoretical value :

. without tube	0.04	d°
. with dipole tube n° 1	0.20	d°
. with dipole tube n° 2	0.48	d°
. with dipole tube n° 3	0.44	d°

- déviation from the theoretical value of 360° after one turn :

. without tube	0.02	d°
. with dipole tube n° 1	0.1	d°
. with dipole tube n° 2	0.4	d°
. with dipole tube n° 3	0.2	d°

Magnetic tests

Magnetic tests have been made at Saclay in the magnetic measurement laboratory, using two conventional reference magnets from CERN.

- An ISR dipole about 2 m long (cf Fig. 3.) This magnet is of the combined function type : it has shaped iron poles which generate a high quadrupolar component. Its magnetic caracteristics are :
  . dipole field : 1.14 T for I = 3000 A
  . field indice : n/ρ = 3.018 m^{-1}

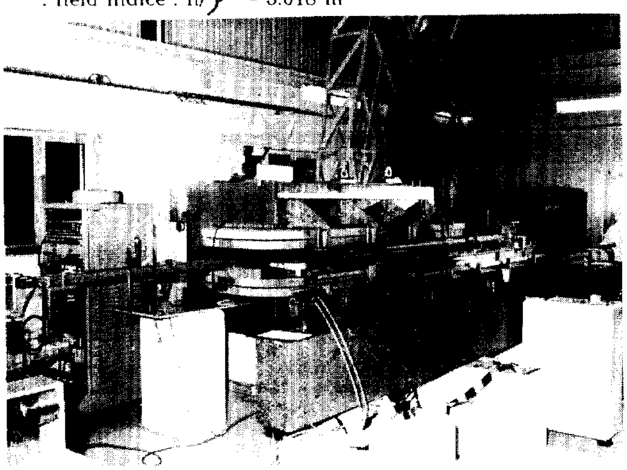

Fig. 3 : Preliminary tests in a reference dipole

- an ISR skew quadrupole, about 50 cm long, which generates a gradient of 1.03 T/m for a current of 55 A, in a 15 cm useful diameter.

The tests which were made with the reference dipole are :

- comparison between DC and AC measurement at 8 A : the DC measurements are made with a standard system, the AC measurements are made with the system described in this paper.

The difference in the quadrupole term (few %) is mainly due to the remanent field in the iron and the eddy currents. The sextupole term measurements agree within 1 %.

- reproducibility of the measurements : a statistic done with the central set of coil on six measurements (peak A.C. current = 7.55 A) shows that the reproducibility of the harmonic measurement is of a few 10^{-5} of the main field.

Installation and preliminary tests at IPHE

The three test stands have been now installed at IPHE and put in operation.

Some preliminary measurements have been made, using short models and final UNK magnets.

More results could be obtained with these magnets for which the apparatus were designed :

- taking into account the theoretical angular position of the measuring coil or the mean value between the theoretical value and the value read on the encoder changes only the harmonic of some 10^{-5} at 35 mm, on a 6 m long dipole.
- when measuring a long dipole with two different tubes, the results agree within 2 10^{-4} up to n = 5 and within 4 10^{-4} up to n = 10.
- when measuring a short quadrupole (1 m long), the reproducibility of the measurement is better than 2 10^{-5} up to n = 10.

More statistical measurements are now underway but these preliminary results already show that the systems are operational.

Conclusions

Three test stands have been built and put in operation to make the room temperature measurements of the UNK magnets (dipoles and quadrupoles).

Compared to previous ones, the main improvement of these systems is the possibility to measure 6 m long dipoles in only one measurement.

The most impressive point of the systems is the reproducibility of the harmonic analysis : the use of a lock-in amplifier enables a reproducibility on the harmonic measurement of some 10^{-5} of the main field, the value of which is around 100 G.

Once the results are correlated with cold measurements, this kind of measurements will provide an early and quick control of the harmonic content of the magnet.

Acknowledgements

Thanks are due to Messrs C. AUERBACH, J. FABRE, M. HUMEAU and J.M. LOCATELLI, who have made most of the construction and tests of these systems.

Our soviet colleagues from IPHE and especially Messrs K. GUERTSEV, S. TROFIMOV and V. PROKOVSKI, have been quite involved in this project, especially during the installation and preliminary tests of the systems.

References

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