DEVELOPMENTS AND MEASUREMENTS DONE AT ALBA MAGNETIC MEASUREMENTS LABORATORY ALONG 2016

J. Marcos, V. Massana, L. García, J. Campmany
ALBA-CELLS, Barcelona, Catalonia, Spain

Abstract

Along 2016 ALBA magnetic measurements laboratory has measured magnets for a number of facilities that are being built over the world. Their measurement has been a challenge in terms of improving the methodologies of fiducialization and data analysis, since we have to accommodate to different sets of magnets characteristics and specifications. Especially relevant has been the measurement of closed structures using a conventional Hall probe bench, making the measurement in two steps and relying on alignment accuracy to merge both measurements. In this paper we enumerate the different projects in which ALBA has collaborated, and we remark the new method developed for aligning the quadrupoles to the rotating coil, as well as the methodology used to measure closed magnets in two steps with the conventional Hall probe bench.

INTRODUCTION

The characteristics of the magnetic measurements laboratory at ALBA have been described elsewhere [1]. Along 2016 a series of measurement campaigns for other facilities have been carried out, namely: (i) all the bending magnets and the quadrupoles of ThomX facility, (ii) two corrector magnets for CNAO facility, (iii) four dipole magnets for CLARA linear accelerator. In order to carry out some of these measurements we have developed some improvements in our experimental techniques.

EXPERIMENTAL IMPROVEMENTS

Merging of Hall Probe Field Maps

One of the addressed challenges has been the measurement of magnetic field maps in structures without lateral access (H-shaped dipoles or window-frame magnets). With this purpose we have developed a special L-shaped Hall probe holder with an arm length of 340 mm, shown in Figure 1. Holder is made of tin, and contains the same electrical 3D Hall assembly used in the ALBA laboratory and described elsewhere [1].

By entering from one side of the aperture such a probe was able to reach the central region of all measured magnets, which had a physical length of 430 mm in the worst case. However, it does not allow covering the full length of the magnets including the fringe field regions, which is necessary in order to determine the integrated field strength. In summary, the range to be measured is ~500 mm.

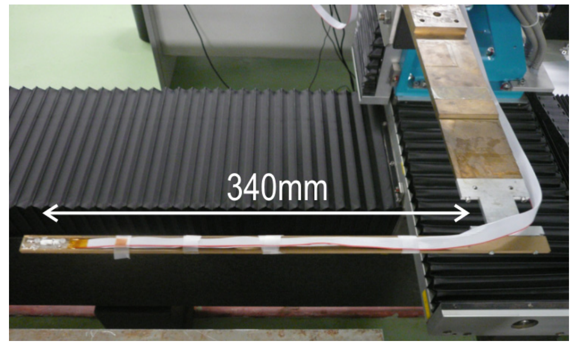

Figure 1: Image of long Hall probe for the measurement of magnets without lateral access.

In order to overcome this limitation magnets have been measured from two opposite sides, and the obtained magnetic field maps have been combined into a single one. In order to merge the coordinates of the two field maps we have relied on our alignment procedure based on laser tracker measurements and ancillary reference magnets, as described in [1]. The agreement of the measured field components in the overlapping region around the center of the magnet provides an estimation of the overall accuracy of the used procedure.

As an example, in Fig. 2 we show a comparison for all three components of the magnetic field between the two field maps measured on one of the CNAO correctors. In this particular case, the difference between the two measurements was well within ±40 μT, with a *rms* value of ~10 μT for all three field components, comparable to the intrinsic accuracy of the used field sensor.

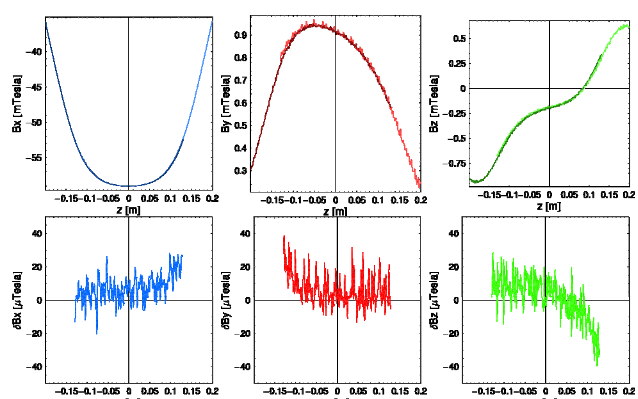

Figure 2: Magnetic field (*top*) and difference (*bottom*) in the overlapping region between the field maps measured from both sides for one of CNAO magnets with its vertical corrector powered at 140 A.

Alignment of Rotating Coil

In rotating coil measurements one of the difficulties consists in determining the axis of rotation of the coil with respect to which we will obtain the magnetic axis deviation of the measured magnet. In the past we have used as a reference the profile of the cylindrical pieces supporting both ends of the coil determined from laser tracker measurements. However, any eccentricity of those pieces with respect to the real rotation axis will lead to systematic errors in the determination of the magnetic axis. For this reason it has been decided to modify the rotating coil alignment scheme.

In the new scheme, instead of determining the profile of the supporting pieces, we determine the profile of the cylindrical body of the coil itself. Given that the coil's assembly procedure does not guarantee a centering of the body of the coil with respect to its ball bearings better than 0.1 mm, the center of the surface profile for a given orientation of the coil does not provide a reliable estimation of its rotation axis.

However, if we measure the surface profile of the coil at different rotation positions, and for each profile we obtain the center of a best fitting cylinder, the set of obtained centers will define a circumference centered at the rotation axis of the coil and with a radius equal to the eccentricity of the coil's body with respect to the ball bearings.

In practice, the following procedure has been defined, as illustrated in Figure 3:

(i) the surface of each end of the rotating coil is scanned using the laser tracker for 4 orientations of the rotating coil at 90º intervals; (ii) from the analysis of the obtained data, a set of 4 centers is obtained for each end of the coil; (iii) the rotation axis position at each end of the coil is identified with the average of the 4 obtained centers.

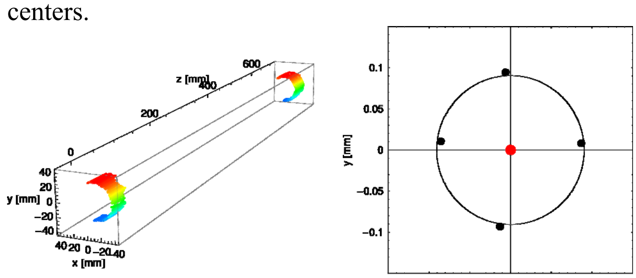

Figure 3: Procedure to determine the rotation axis of the coil. *Left:* Scan with the laser tracker of the surface of both ends of the coil. *Right:* Determined center of the coil at 4 different orientations (*black dots*) and reconstructed center of rotation (*red dot*).

In order to test the accuracy of the method, we have determined the magnetic axis deviation for a given quadrupole using three coil shafts with different radii. The obtained results were reproducible within ±20 μm in both planes, so the methodology is reliable enough within the usual accuracies requested in accelerator technologies.

MEASUREMENT CAMPAIGNS

ThomX Magnets

All dipoles and quadrupoles for the accelerators (transfer/extraction lines and storage ring) of ThomX Compton Backscattering Source being built in LAL-Orsay [2] were measured between February and July of 2016. All magnets had been manufactured by Sigmaphi. Figure 4 shows a picture of a dipole and a quadrupole at ALBA magnetic measurements laboratory.

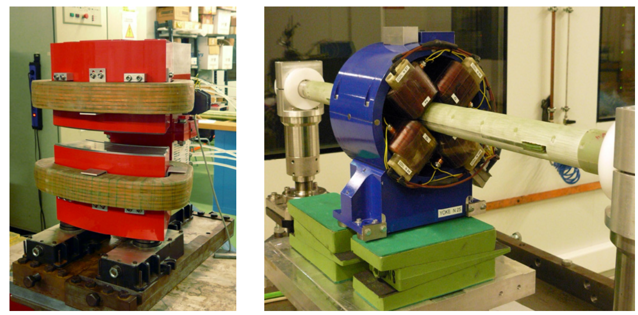

Figure 4: Image of ThomX dipoles (*left*) and quadrupoles (*right*).

In the case of dipoles, they consisted of 15 identical C-shaped bending magnets (8 for the storage ring, 6 for the transfer/extraction lines, plus 1 spare), each one of them providing a 45º deflection to the electron beam. They had an iron length of 276 mm and generated a magnetic field of 0.63 T at a nominal current of 263 A.

The aim of the measurements was to characterize the magnetic field distribution at different excitation currents (100 A, 200 A and 275 A). For this purpose we measured magnetic field maps in the midplane of the magnet with our Hall probe bench using the same methodologies described in [3]. From the obtained field maps the multipolar content of the magnetic field along the electron beam trajectory and the corresponding integrated values were obtained.

As for the dipoles, a total of 34 identical magnets (24 for the storage ring, 10 for the transfer/extraction lines) were measured. Quadrupoles had an aperture diameter of 41 mm and an iron yoke length of 150 mm, generating a gradient of 5 T/m at a nominal current of 10 A.

The aim of the measurements was determining the magnetic axis deviation, the roll angle, the integrated quadrupolar strength and the harmonic content for different excitation currents between 0 and 12 A. Measurements were carried out using a PCB-based rotating coil developed in-house with a diameter of 40 mm, providing a bucking ratio for the quadrupolar term close to 800.

In order to improve the accuracy in the determination of the roll angle of the quadrupoles, they were measured two times, before and after rotating them by 180º around the vertical axis. The comparison of the data for the two orientations also provided a check for the accuracy in the determination of the magnetic axis deviation.

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CNAO Correctors

Two corrector magnets for the extraction to the new beamline dedicated to research (XPR) being built at CNAO in collaboration with INFN [4] were measured on April 2016. The magnets had been manufactured by ANTEC SA. Figure 5 shows a picture of one of the corrector magnets at the measuring bench.

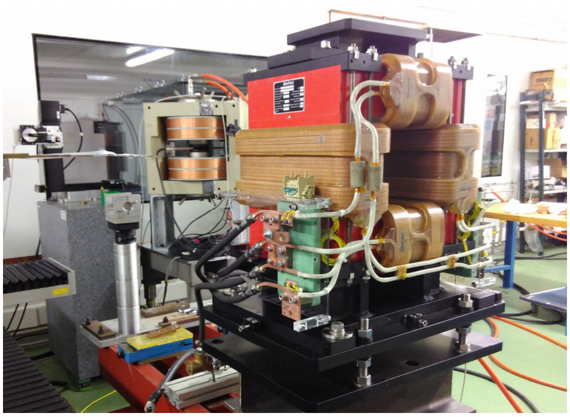

Figure 5: CNAO corrector on Hall probe bench at ALBA magnetic measurements laboratory.

The magnets were two identical window-frame dipoles, with an iron length of 300 mm, providing correction in both planes, with a nominal field of 60 mT at a current of 140 A. The aim of the measurements was to determine the magnetic center, the transfer function at the magnet center, the effective length, and the integrated field quality at different currents. The magnetic center for each corrector was determined by powering the corresponding pair of coils with opposite polarity (Quadrupole Configured Dipole method). As for the determination of the effective length and the integrated field quality, fieldmaps using the described merging technique were measured within an aperture of ±30mm in both horizontal and vertical directions. The requested accuracy for the integrated field values was $2\cdot10^{-3}$.

CLARA Dipoles

The four dipole magnets of the Variable Bunch Compressor (VBC) of CLARA linear accelerator being built at Daresbury Laboratory [5] were measured on September-October 2016. All four magnets had been manufactured by ANTEC SA. Figure 6 shows some pictures of the dipoles during the measurement procedure.

The magnets were four identical H-shape dipoles, with an iron length of 200 mm, generating a nominal field of 0.5 T at a current of 150 A. The magnets were also equipped with trim coils in order to tune the field level by a ±1.5%. The aim of the measurements was to determine the field linearity (transfer function at the magnet's center), the integrated magnetic strength, the integrated field quality, and the residual field level.

The specification for these magnets established that the maximum integrated field variation within the good field region shall be smaller than $1\cdot10^{-4}$. Therefore an accuracy better than $1\cdot10^{-4}$ in the determination of the integrated field values was required, which is beyond what can be attained by integration of Hall probe data (typically between $0.5\cdot10^{-3}$ and $1\cdot10^{-3}$). For that reason, it was decided to complement Hall probe measurements with rotating coil measurements. A 40 mm-diameter coil fitting the 44 mm pole gap of the magnet was used, and it was scanned transversally through the window of the magnet (-50 mm $\le x \le +50$ mm) to get information about its whole good field region. The integrated field data from rotating coil measurement was taken as a reference, and the Hall probe data was corrected accordingly.

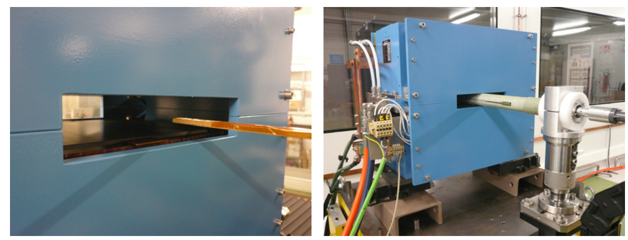

Figure 6: CLARA dipole magnet being measured with Hall probe (*left*) and rotating coil (*right*).

CONCLUSIONS

The presented methodological improvements introduced along 2016 at ALBA magnetic measurements laboratory have allowed to conduct a series of measurement campaigns for different sets of magnets to the satisfaction of the final customers.

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