

UPGRADE OF THE ALBA MAGNETIC LABORATORY FOR MEASURING LIPAC HEBT QUADRUPOLES AND DIPOLE

J. Marcos, F. Becheri, J. Campmany, L. Garcia-Orta, V. Massana, R.A. Petrocelli, ALBA-CELLS, Barcelona, Catalonia, Spain, B. Brañas, J. Castellanos, CIEMAT, Madrid, Spain

Abstract

Along 2017 ALBA magnetic measurements facility has measured LIPac HEBT quadrupoles and dipole designed by CIEMAT and built by ELYTT Company. ALBA magnetic measurements laboratory has been improved through an upgrade program of its measurement benches to complete this set of measurements. One of the main aims of the upgrade has been the replacement of obsolete parts and the standardization of both hardware and software to ensure an easy maintenance of the systems. In parallel, new shafts for the rotating coil bench have been built and tested, with specific designs to improve the sensitivity and minimize the signal-to-noise ratio. In this contribution we detail the upgrades and the results of performance tests.

INTRODUCTION

CIEMAT is responsible for the design and construction of the High Energy Beam Transport (HEBT) of the LIPac linear accelerator being built in Japan [1]. The HEBT includes 9 magnets —8 quadrupoles and 1 dipole— as shown in **Figure 1**. The parameters of the different types of quadrupoles are reported in [2]. The magnets have been manufactured by ELYTT, and ALBA has taken care of characterizing them at its magnetic measurements laboratory.

The characteristics of the magnetic measurements laboratory at ALBA have been described elsewhere [3]. By the end of 2016 several of the available measurement systems were facing obsolescence issues, and it was decided to launch an upgrade program before undertaking the measurement of LIPac HEBT magnets.

MEASUREMENT BENCHES UPGRADE

Hall Probe Bench

The Hall probe bench at ALBA, used to map the magnetic field over 3D regions, was originally built in 1997 by Ramem Company [4]. Over the years the system had undergone several hardware and software upgrades in order to improve its performance. In particular, in 2005-2006 the control system was completely revised in order to migrate it from EPICS to TANGO and to implement the on-the-fly measurement mode, which allows acquiring data while the system is moving.

However, one of the critical hardware components, the motion driving system, a Delta Tau VME PMAC, had never been replaced and by the end of 2016 it had become obsolete, with no support or spares available anymore.

Therefore it was decided to replace the motion driving system by a state-of-the-art one providing equivalent capabilities and compatible with the DC motors of the bench. The selected system was a Delta Tau Power Brick AC unit, which integrates a Power PMAC controller. In parallel, it was also decided to develop a new version of the control system, having it up-to-date with ALBA standards. In this way we can take profit of the tools that have been developed during the last 10 years for the control of Beamline instrumentation at ALBA, and the future maintenance of the system will be made easier.

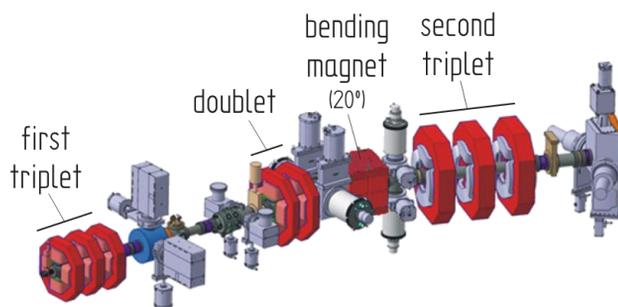


Figure 1: Drawing of LIPac HEBT, with the magnets indicated in red color.

The major hardware and software upgrades of the Hall probe bench are summarized in the diagram in Figure 2. The hardware replacement took place in Oct-Dec of 2016. Afterwards, between Dec 2016 and Feb 2017 the hardware was tuned and adjusted. Finally, in the period Feb-Apr 2017 the new control system was successfully commissioned and debugged.

Before the measurement of LIPac HEBT magnets, the Hall probe bench was used for the Factory Acceptance Test of an APPLEII undulator for ALBA in the period May-Jun 2017 [5]. Obtained results showed that the performance of the bench has been preserved after the upgrade.

Flipping Coil Bench

The flipping coil bench at ALBA, designed to determine low-value field integrals from small gap devices, was purchased as a turn-key system from ESRF on 2006. The system made use of linear and rotating stages based on DC motors, controlled by a 6-axis Newport MM4006 motion controller. The control system provided with the instrument consisted of a series of macros running on Igor Pro software.

In 2016 the motion controller unit broke down, and given that the system was not commercially available

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any more and that no technical support existed, it was neither possible to replace nor to repair it. Therefore it was decided to replace the motion controller by the standard solution used at ALBA, an IcePAP unit [6]. However, current version of IcePAP firmware only implements stepper motor control. As a consequence, it was necessary to send the linear/rotating stages to the manufacturer (Newport) in order to have their DC motors replaced by stepper ones.

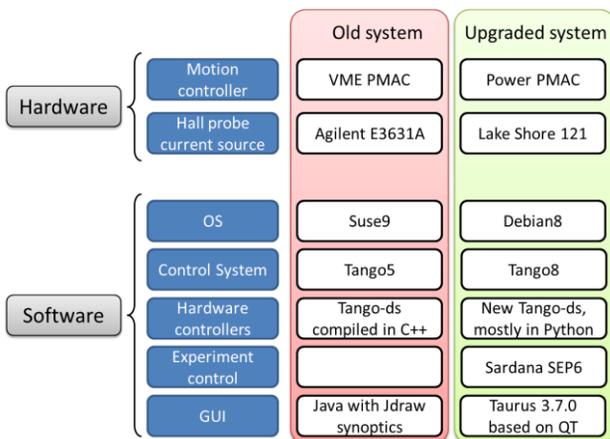


Figure 2: Hardware and Software upgrades of the Hall probe bench at ALBA.

The hardware refurbishment was complemented with the development of a new control system based on Tango that conforms to standards at ALBA. This new control system, in addition to allowing for an easier maintenance, will make it possible to combine in a straight forward way the operation of the Hall probe and the flipping coil benches, which is a particularly convenient feature in the case of measuring Insertion Devices.

The hardware upgrade was carried out on Feb-Apr of 2017; the system was reassembled on May 2017 and the control system was developed and commissioned on Jun-Jul 2017. The upgraded system, despite the replacement of DC motors by stepper ones, displays a performance similar to the original one, with a *rms* repeatability of the field integrals of $1 \times 10^{-6} \text{T}\cdot\text{m}$.

Rotating Coil Bench

The rotating coil bench at ALBA, used to determine the integrated field harmonics of accelerator magnets with lengths up to 0.5m, is a second-hand system purchased from CERN on 2008. The system rotation is driven by a DC motor controlled by a Maxon PCU2000 unit. The coil signal is acquired by means of VME integrators based on voltage-to-frequency converters developed at CERN, and the control system is based on LabVIEW running on a Sun Ultra workstation. Most of the system is obsolete and difficult to maintain both from a hardware and a software point of view. Therefore, a major upgrade of the system has been already planned. This upgrade will include the substitution of the DC motor by a stepper one and the installation of an IcePAP controller; the replacement of the outdated VME integrators by a state-of-the-art system

(either a Metrolab FDI2056 or a nanovoltmeter); and a new control system based on Tango. However, given the impossibility of combining the bench upgrade with the measurement of LIPac HEFT quadrupoles, it was decided to postpone the upgrade until the measurements have been completed.

In the case of this bench the upgrade activities relevant for this paper consisted in the manufacturing of two new measurement shafts adapted to the aperture diameter of the magnets that had to be characterized. LIPac HEFT quadrupoles have an aperture of 90mm (1st triplet) and 136mm (doublet and 2nd triplet), and field harmonics have to be determined at 75% of the aperture, i.e. at $R_{\text{ref}}=33.75\text{mm}$ and $R_{\text{ref}}=51\text{mm}$ [2]. At the time when the measurements were being planned, the largest available shaft at ALBA magnetic measurements laboratory had a diameter of 40mm, and hence it was not well suited for the task. Therefore it was decided to manufacture two new shafts with a diameter of 78mm and 130mm, respectively.

The coils for each shaft have been produced using the multilayered-PCB technology that has been previously employed at ALBA. For the two shafts we have used a different arrangement of the coils in order to obtain the desired dipole-quadrupole bucking. In the case of the 78mm-diameter shaft, we have used a 2-coil compensation scheme as the one described in [7]. In the case of the 130mm-diameter shaft we have used a CERN-type compensation scheme, with 4 identical radial coils centered at different radial positions, as described in [8]. The configuration schemes and some images of the two shafts are shown in Figure 3, and the corresponding geometrical parameters are listed in Table 1. We have experimentally checked that both shafts have a bucking ratio of the main harmonic (quadrupole) close to 1000.

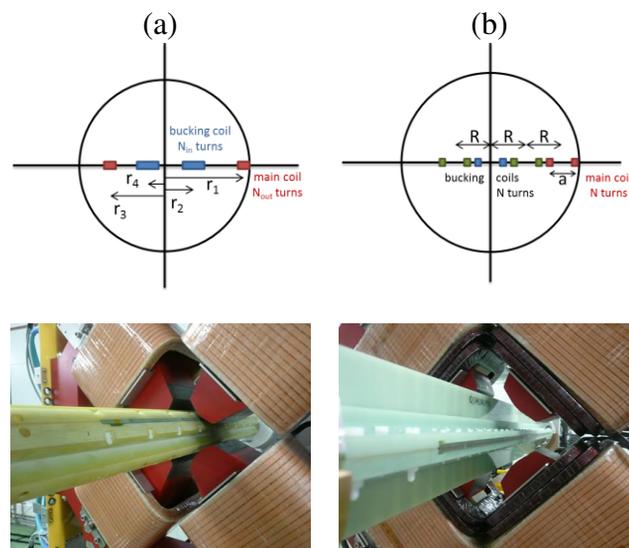


Figure 3: Configuration diagram and pictures of the shafts manufactured for measuring LIPac HEFT quadrupoles with an aperture diameter of (a) 90mm (\varnothing 78mm shaft) and (b) 136mm (\varnothing 130mm shaft).

Table 1: Parameters of the Two Shafts Manufactured for the Measurement of LIPAc HEBT Quadrupoles

Shaft diameter	Circuits position	Turns per layer	Layers	Length
78mm	$r_1=34.55\text{mm}$	$N_{\text{out}}=72$ $N_{\text{in}}=40$	48	550mm
	$r_2=22.65\text{mm}$			
	$r_3=19.0\text{mm}$			
	$r_4=7.1\text{mm}$			
130mm	$R=26\text{mm}$ $a=14.1\text{mm}$	$N=55$	48	644mm

MEASUREMENT OF LIPAC MAGNETS

LIPAc HEBT magnets have been manufactured in different batches, and have been delivered and measured at ALBA all along 2017.

The 8 quadrupoles (magnets HMA01 to HMA08) have been characterized using the rotating coil bench. In order to check the absolute sensitivity of the two new shafts, some of the quadrupoles were also measured with one of the previously existing shafts with a diameter of 40mm. In addition, one of the quadrupoles has also been measured using the Hall probe bench and the flipping coil bench in order to check the consistency of the integrated gradient values among the three different systems: the obtained values were in agreement within 0.1%.

Figure 4 shows the obtained transfer functions (integrated gradient vs excitation current) for all 8 quadrupoles. Results for each type of quadrupole get superimposed and cannot be distinguished.

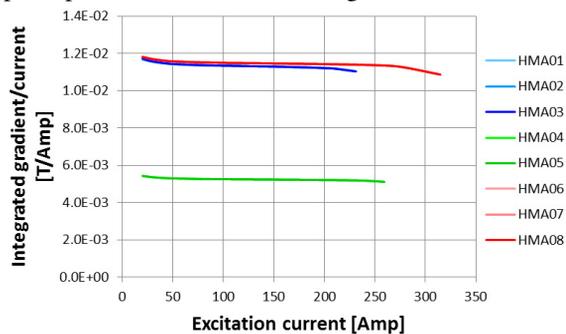


Figure 4: Integrated gradient normalized to the excitation current for the 8 quadrupoles of LIPAc HEBT.

LIPAc HEBT dipole (magnet HMA00) was measured using Hall probe bench on Jul 2017. Given that it is a H-shape magnet without lateral access, it was measured using a long L-shaped Hall probe with a free length of 340mm that can be inserted inside the magnet's aperture from one side, allowing to reach its center. A combination of data acquired from both sides of the magnet provided a complete map of the magnetic field along the trajectory of the particle beam. The longitudinal overlap of the two sets of data at the magnet center was 73mm.

The magnetic field has been measured within a rectangular grid of 1mm×5mm (longitudinal×horizontal) covering a transversal range of 51mm at both sides of the nominal trajectory. One example of a field map is shown in Figure 5.

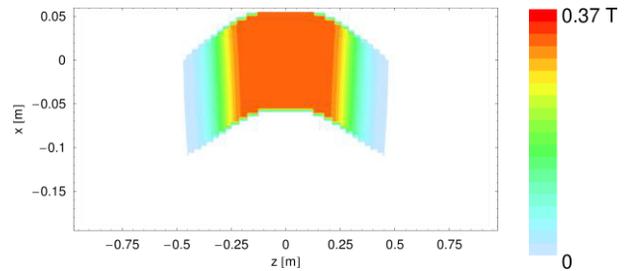


Figure 5: Vertical component of the magnetic field within the midplane of LIPAc HEBT dipole determined for an excitation current of $I=100\text{Amp}$.

CONCLUSIONS

The upgrade program undertaken at ALBA magnetic measurements laboratory, which is still under progress, is solving many of the obsolescence issues that were being faced by the available measurement systems.

The upgraded benches have been used for the magnetic characterization and successful validation of the magnets of LIPAc HEBT. The detailed results of these measurements will be presented elsewhere.

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