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A NEW BENCH CONCEPT FOR MEASURING MAGNETIC FIELDS OF BIG CLOSED STRUCTURES

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Abstract

The measurement of big closed magnetic structures is becoming a challenge of great interest. The main reason is the tendency towards building accelerators with high magnetic fields produced by small gap magnets, as well as the development of cryogenic or superconducting narrow-gap insertion devices. The usual approach, based on side-measurements made with a Hall probe mounted on the tip of a motorized arm mounted on a long granite bench is no more applicable to such closed structures. So, new concepts and approaches have been developed, mainly relying on complex devices that insert a Hall probe inside the magnetic structure maintaining the desired position by closed-loop controls. The main problem of these devices is that they are not general-purpose oriented: they need a special vacuum chamber, require a specific geometry of the magnetic structure, or do not provide 3D field-map measurements. We present in this paper a new bench that has been built at ALBA synchrotron that is simple, multi-purpose and can be a general solution for measuring big closed structures.

INTRODUCTION

The conceptual approach to design this new bench has been presented elsewhere [1],[2]. Basically, it consists in placing a very light Hall probe in the middle of a flexible belt that can be easily introduced inside a magnetic system. The edges of this belt are then attached to an external mechanical bench to position the Hall probe with a high degree of accuracy. Magnetic fieldmaps are recorded operating in on-the-fly mode: that is, acquiring the magnetic field values at the same time the Hall probe is moving along a path. The path is a set of straight lines oriented along the longitudinal direction (Z) that can be independently defined to scan any desired region.

For CELLS standardization reasons, we used step motors controlled via the Icepap motion driver system [3], developed by a collaboration participated by CELLS.

The main challenges that, if not solved, could have jeopardized the feasibility of this concept were:

- Vibrations of the flexible belt.
- Positioning Accuracy of the Hall probe.
- Synchronization between movement and acquisition.
- Alignment of Hall probe with respect to gravity.

The first challenge is related to the vibrational eigenvalues of the mechanical structure; the second to the straightness, linearity and flatness of the bench; the third to the real time control system; and the latter to the methodology used for measurements.

REQUIREMENTS

A general view of the bench is shown in Figure 1.

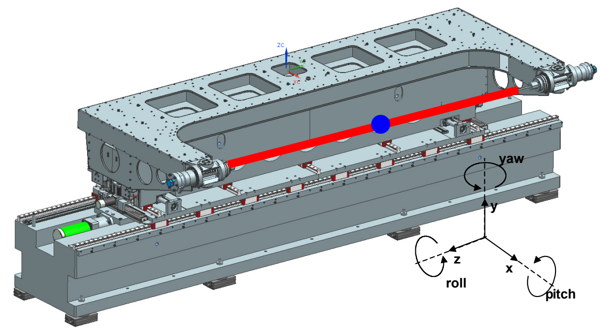

Figure 1: General view of the new Hall probe bench and reference system. Stretched belt is painted red, and Hall probe position is marked with a blue dot.

The specifications of the bench are shown in Table 1.

Table 1: Main Specifications

Magnitudes on top of Hall probe	**Values**
X positioning tolerance	$\pm 25\cdot 10^{-6}$ m
X stroke	0.2 m
Y positioning tolerance	$\pm 25\cdot 10^{-6}$ m
Y stroke	0.1 m
Z positioning tolerance	$\pm 10\cdot 10^{-6}$ m
Z stroke	1.2 m
Z positioning resolution	$10\cdot 10^{-6}$ m
Pith angle tolerance	$\pm 50\cdot 10^{-6}$ rad
Yaw angle tolerance	$\pm 100\cdot 10^{-6}$ rad
Roll angle tolerance	$\pm 50\cdot 10^{-6}$ rad
Eigenfrequency (Z direction)	> 50 Hz
On-the-fly velocity	$\sim 15\cdot 10^{-3}$ m/s

In order to fulfil the positioning and angular tolerances, the material for the bench basis is granite, and the linear guides and mechanical chain have been designed according to the usual high precision mechanics concepts.

Regarding vibrations, the key point is the fact that the Hall probe is placed on a stretched string, and therefore

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affected by standing waves in the string. Their eigenfrequencies depend on belt density and tension, and can be displaced to high frequencies by tightening the belt. The material selected for the belt is carbon fibre with a cross section of 16 mm x 1.6 mm, and the stretching force applied in the operation regime has been 5000 N.

Finally, in order to perform on-the-fly measurements, we have implemented a new feature developed for Icepap, consisting in the trigger generation according to the encoder reading. This feature existed for servomotor controllers as PMAC, but so far it was not yet implemented in Icepap. Therefore, tests have been made in order to ensure the right agreement between the real position of the Hall probe and the read position of the encoders during on-the-fly motion.

MECHANICAL PERFORMANCE

Main issues to solve were: (a) the very narrow cross section (5 mm x 25 mm) and long stroke to be measured (~1.2 m); (b) the closed structure, typically a vacuum chamber only accessible through edge flanges; and (c) the vacuum itself. To this end, we proposed a new concept based on a stretched carbon fibre with a Hall probe fixed on top [1]. The system is compact and can be inserted through narrow cross sections, allowing the installation of an antivacuum pipe along the magnetic axis of measured device, leaving an air aperture for Hall probe motion.

In order to support the stretched belt, we designed a «C» shape allowing a tension up to 20000 N to shift up the natural frequencies fibre carbon belt. In this way, mechanics can be placed outside, avoiding exotic tailor-made solutions for closed devices and allowing classical high precision mechanics solutions. Details were presented elsewhere [2].

Table 2 summarizes the measured values for several magnitudes, including those specified in Table 1 above.

Measurements have been done using a laser interferometer Renishaw ML10. Resolution of this equipment is 10^{-9} m linear, $41\cdot10^{-9}$ rad angular, 5 kHz of sampling ratio, and ~$0.1\cdot10^{-9}$ m RMS noise level. Linear accuracy is ±0.7 ppm and angular linearity $\pm0.5\cdot10^{-6}$ rad.

With this setup we have tested the displacements along the X and Y axis and pitch and yaw angles [3].

Table 2: Summary of Measured Performances. Errors are Expressed in Terms of Peak Values (2.6σ)

Magnitudes on top of Hall probe	Values
X stroke	0.233 m
Y stroke	0.092 m
Z stroke	1.282 m
X positioning error (wrt encoder)	$7\cdot10^{-6}$ m
Y positioning error (wrt encoder)	$5.41\cdot10^{-6}$ m
Z positioning error (wrt encoder)	$10\cdot10^{-6}$ m
Z positioning resolution	$10\cdot10^{-6}$ m
Pitch angle error	$25\cdot10^{-6}$ rad
Flatness	$6.7\cdot10^{-6}$ m
Yaw angle error	$20\cdot10^{-6}$ rad
Straightness error	$7.8\cdot10^{-6}$ m
Roll angle error	$35\cdot10^{-6}$ m
Eigenfrequency in Z direction	90 Hz
Amplitudes in Z direction	$10\cdot10^{-9}$ m
Eigenfrequency in Y direction	43.5 Hz
Amplitudes in Y direction	$150\cdot10^{-9}$ m
Eigenfrequency for torsion (roll)	23.6 Hz
Amplitudes of torsion	$3\cdot10^{-6}$ rad
On-the-fly velocity	$13\cdot10^{-3}$ m/s

Some results are shown in Figures 2 and 3 below. All are well within the specifications given in Table 1.

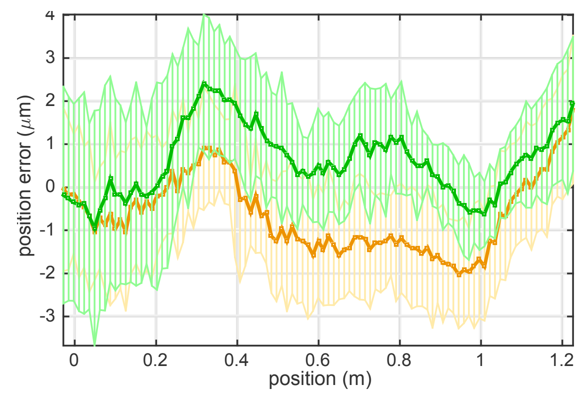

Figure 2: Longitudinal position error (real with respect to encoder reading), forward (orange) and backwards (green). Thick lines link mean values, light lines the associated dispersion.

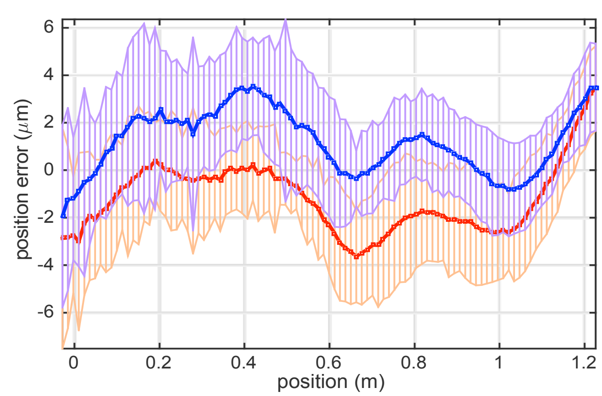

Figure 3: Straightness (horizontal error) along z axis forward (red) and backwards (blue). Thick and light lines have same meaning as above.

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MAGNETIC PROBE

To measure magnetic fieldmaps of narrow gap devices, we developed a very thin (13 mm wide, 2 mm high, 25 mm long) 3D Hall probe head, which is shown in Figure 4. It also has an integrated Pt100 to record the temperature during measurement, allowing a post-processing correction. The weight of the head is 0.75 g. The Hall sensors mounted on the probe are F.W.Bell GH700, and the determination of positions and angles of each individual probe has been carried out according to the procedure which is described elsewhere [4].

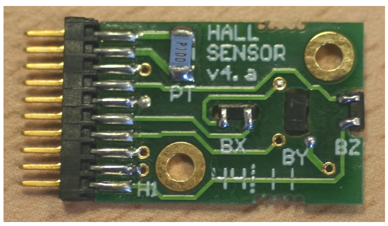

Figure 4: Hall probe head developed at CELLS.

The Control system structure has been described elsewere as well [5] and has been implemented in Tango [6]. The core concept is that multimeters (model Keithley 2001) measuring Hall voltages are triggered directly at hardware level by Icepap motor controller [7].

MEASUREMENT METHODOLOGY

To measure a device with this bench the first step is detach the belt and introduce it through the structure to be measured. After that operation, the belt is reattached and stretched at 5000 N.

This procedure yields the need of orienting the Hall probe for every new structure to be measured. To this end we have designed and built a reference dipolar magnet (Figure 5) powered by permanent magnetic blocks.

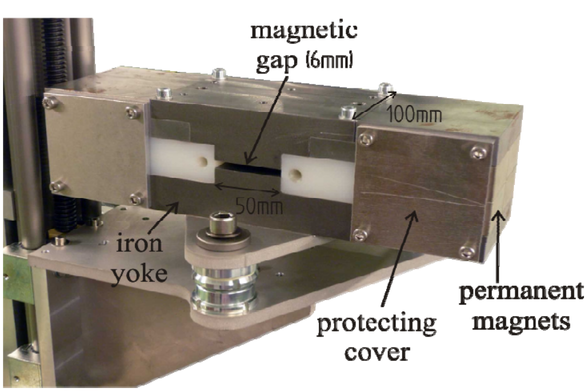

Figure 5: Reference dipole magnet made at CELLS.

This magnet produces a highly homogeneous vertical magnetic field in the central region that can be aligned with respect to the gravity with an accuracy in the range of $100 \cdot 10^{-6}$ rad.

Once the carbon fibre is reattached, the reference magnet is placed around the belt, that can be corrected in roll and pitch to position the BY Hall probe parallel with respect to gravity. After this operation, the reference magnet is taken out. The alignment procedure involves therefore opening and closing the reference magnet. The repeatability of this operation is $<150 \cdot 10^{-6}$ rad.

We have also manufactured a system of magnetic cones (Figure 6) to fiducialize the position of magnetic centre of the Hall probe, located by definition on BY Hall sensor.

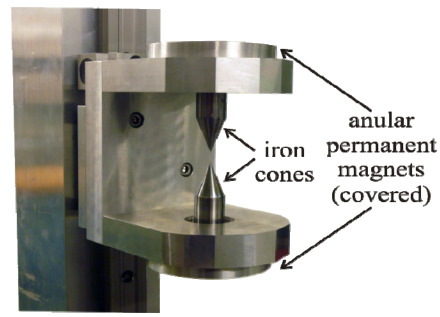

Figure 6: Cone system used to fiducialize Hall probe head.

CONCLUSION

We developed a high accurate magnetic measurement bench to measure magnetic fieldmaps of big closed magnetic structures adopting an original concept. The current prototype can scan a region of 1.282 x 0.233 x 0.092 mm^3, and we have proved that the mechanical solution invented and developed at CELLS is feasible, and performs according to the specifications.

ACKNOWLEDGMENT

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