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INFN –LNF Magnetic Measurement Laboratory Status and Upgrade

Abstract—Magnetic Measurements Laboratory at the Frascati National Laboratories (LNF) of INFN played a crucial role for magnets characterization of the whole LNF accelerators apparatus (DAFNE [1], SPARC_LAB [2], BTF [3]) and also for external user (i.e. CNAO [4]) leading to an extensive expertise acquisition in the recent past. In the last years, a revamping phase of the instrumentation was necessary to continue the measurements avoiding an expertise loss. This upgrade [5] has been started thanks to several co-funding projects such as LATINO [6], IRIS [7] also with the INFN internal funding support. The revamping was oriented both towards the update of the old instrumentation, i.e. a Hall probe measurement bench, and towards the purchase of new equipment like a new rotating coil, a Single Stretched Wire Bench, a Pulsed Wire bench, a probe calibration system, and 3D Hall probe mole system. Moreover, several infrastructure works are planned to improve the organization of laboratory spaces. All these interventions are oriented to guarantee a high flexibility of the measurements requirements covering a wide range of magnets type for external user and for the future projects at LNF like EuPRAXIA [8].
Keywords—Hall Probe, Rotating Coil, Single Stretched Wire, Calibration System, Magnetic Laboratory Facility

I. INTRODUCTION (HEADING 1)

The Frascati National Laboratories (LNF) of INFN have extensive experience in measuring magnets for particle accelerators. They have conducted tests, with deep magnetic characterization for various projects including the DAΦNE collider, the Beam Test Facility and the SPARC_LAB linear accelerator of LNF, CNAO, and other experiments.

Aiming to face new projects and to keep the laboratory up to date with current technologies in the magnetic measurement scenario, a consistent instrumentation and infrastructure upgrade has been started in the last years. This has been possible also thanks to co-funded projects such as the LATINO project, supported by Regione Lazio under the POR-FESR 2014-2020 program. In this framework, a rotating coil system and a stretched wire bench were purchased, and civil and plant engineering works were executed. The goal of the project was to establish a magnetic measurements laboratory as part of an open research infrastructure aimed to support industries and the scientific community.

Another very important pillar of this upgrade is the IRIS project who has the goal to create a distributed infrastructure for applied superconductivity. The INFN-LNF pole is in charge to provide magnetic measurement laboratory specifically devoted to testing superconducting coils and magnets at room temperature. The project allows to purchase a 3D hall probe mole system, a pulsed wire bench, several DC power converters of various power sizes, a probe calibration system and to upgrade the linear stages of the current Hall probe stage. Moreover, a mezzanine will be realized inside the laboratory aiming to allocate all the power converters, the electronic boards and power electronic components spare parts separately from the instruments and the workbenches.

The requirements of all the instrumentations have been defined in order to have a high flexibility in terms of magnets specifications that could be measured aiming to raise up INFN-LNF laboratory as a key provider magnetic measurement for the whole INFN and, in general, for the scientific community. Moreover, several instrumentation requirements have been based on the preliminary design of EuPRAXIA linac.

II. INFRASTRUCTURE

The magnetic measurements laboratory of LNF is hosted in a 200 m2 building and is operated by the Electrotechnical Engineering Group, that is currently composed of seven technicians and three technologists.

A maximum electrical power of 430 kVA is available to feed power converters of various range and a demineralised water-cooling system is available with a dedicated dry-cooler. An overhead crane is installed for the lifting and handling of the equipment with a maxim weight of 20T. In the framework of IRIS project, the construction of a mezzanine is foreseen within the end of next year.

III. EQUIPMENT

A. Hall Probe Bench

The current Hall probe bench is composed of two linear stages that allow the vertical (z-axis) and longitudinal (y-axis) translations of a Hall probe holder. These two stages are installed over a 3 m long granite bench, with the x-axis operating on planar air bearings. The longitudinal and vertical shift ranges are 1m and 300 mm respectively. Also a manual rotation around x, y and z axis is available.

Several aluminum Hall probe holders have been designed internally by LNF staff with 30 and 25 mm outer diameter. A new probe holder is under design with an internal diameter of 20 mm and it will be realized in carbon fiber.

All the stages are connected to a NewPort XPS control unit while the data acquisition and the control relies on a LabView VI. For this bench, currently, only 1D Hall probes are

available. All probes were provided by Group 3 Company because of their high compatibility with the current LabView VI. The purchasing of new Hall probes is ongoing including new 3D hall probe.

The revamping of the bench foresees also the replacement of the current movement systems with new motorized linear and rotational stages as well as upgrading the controller system. With these enhancements, the positioning accuracy will be better than 10 µm for linear stages and better than 10 mrad for angular stages.

The main measurements performed in the last year with the current system include: 3D field mapping of all the magnets of the new transfer line of the BTF facility, the measurements on several magnets of the SPARC_LAB photoinjector [9] , of the new SABINA transfer line [10] , measurements for the STAR facility [11] and for the FOOT experiment [12].

B. Rotating Coil

A rotating-coil measurement system has been specifically designed for the field characterization of small-bore multipole magnets, within the collaboration agreement KR4708/TE between INFN and CERN. The current system [13] is based on a PCB magnetometer with 256 turns for each of the five coils, inserted on a carbon fiber tube, with an external diameter of 26 mm and a total length of 620 mm.

Different configurations of PCB and shaft may be designed in the future to meet specific needs. All connecting components are 3D-printed. The system is equipped with a commercial DC brush-less motor, a high resolution incremental encoder, a through-hole slip-ring, a data acquisition system, a software application for the operations based on LabView and a post processing analysis based on Mathlab.

The system can achieve an absolute accuracy of the main integrated gradient of 50 ppm, with a repeatability of 10 ppm, while the accuracy of high-order compensated harmonics is 100 ppm with a repeatability of 10 ppm. The specifications have been based on the preliminary specifications of the quadrupoles for the new EuPRAXIA linac.

C. Single Stretched Wire Bench

The single stretched wire (SSW) was originally designed and built by ESRF [14]. The system is composed of two pairs of vertical and horizontal linear stages that lie on a 3m long granite bench. They could shift on dedicated rails adjusting the distance between them, depending on the magnet size. They are controlled by a NewPort XPS controller, while the voltage induced on the titanium wire (diameter of 100 µm), is measured by a Keitley 2182 nanovoltmeter.

All the DAQ and stages movements are managed by a dedicated software based on IGOR [15]. The accuracy of the multiple is of the order of few 10-4 while the magnetic center accuracy is about 2 µm and the pitch, roll and yaw angles can be determined with a precision of 0.1 mrad. The precision of the integrated gradient is typically 0.2 Gm.

The main measurements performed in the last years with SSW are the quadrupoles of the new BTF transfer line, several small bore permanent magnet quadrupoles for SPARC_LAB plasma acceleration experiments [16] and also for CECOM company [17].

D. Pulsed Wire Bench

A pulsed wire bench is currently being designed, based on the one described in [18]. The bench is designed with two separate granite pillars to accommodate magnets in a wide range of mechanical lengths. One of the pillars is equipped with pivoting wheels for easy movement. Each pillar has two stages, horizontal and vertical, to support and move wire tensioned along the magnetic axis of the magnet.

These linear stages are identical to those used in the previously described SSW, ensuring compatibility and ease of maintenance. The bench will be equipped with Keysight electronics (pulse generator, voltage analyzer), as well as optical elements for wire position transduction. The technical specifications document is almost completed, while the purchasing phase will start by the end of 2024.

E. Hall Probe Mole System

A Hall probe mole measuring system is currently under design for field mapping of small gap magnets. The goal is to have a travelling probe sliding inside the magnet aperture, in particular for insertion devices measurements. The system will be integrated into the existing Hall probe bench, adding a compact 3-axis Hall probe, mounted on a thin mechanical support, the related Keysight digital multimeter, a mechanical interface between the current linear stages and the probe holder and a dedicated DAQ and data analysis software. Considering the unique and long experience with such systems, this bench is under development with Kyma S.p.A. [19] who has already realized a similar system for measuring undulators and insertion devices, also gaining experience in the development of measurements procedures.

F. Probe Calibration System

The laboratory will be equipped also with a reference system to calibrate probes and validate measurements. The design and manufacturing of the system has been awarded to Caylar S.a.S [20]. Delivery is expected in February 2025. The system is composed of a 2 T dipole, with a 30 mm gap and a 0,02% field homogeneity over a volume of 15x15x15 mm3. Also included in the system are the 4-quadrant power supply with 10ppm stability, 3 NMR probes to cover the range from 20 mT to 1.8 T and the related gaussmeters for readout. A future upgrade of the system involves the availability of a thermal chamber to guarantee probes calibration with thermal stability at different temperatures.

G. Search Coil for Pulsed Measurements

In the framework of the SIGRUM project [21], LNF is in charge for the characterization of the FeCo material [22] [23]: a serious candidate for the realization of the yoke of scanning magnets part of a superconducting gantry designed for hadrontherapy applications.

A dipole with FeCo yoke, is currently at LNF for testing the eddy current effects in terms of the flux density responses in pulsed current regime. A measurement setup is realized with a search coil provided by CERN, a high-resolution 16-bit DAQ board, a control system based on LabView and a data analysis software based on Mathlab internally designed at LNF.

IV. CONCLUSIONS

The Magnetic Measurement Laboratory at LNF is under a deep revamping phase aiming to face new projects and to keep the laboratory up to date with current technologies. This process involves both the laboratory infrastructure and the equipment. An overview of all these upgrades is given together with a summary of the main measurements performed in the last years. When all the upgrades will be completed, the laboratory aims to perform a wide range of magnetic measurements to support both INFN internal projects and to fulfill a wide range of requirements of possible external users.

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