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First magnetic measurements of fast-ramping dipole DHPTB102 of BTF upgraded beam-lines

Valente, Paolo (INFN Roma) *et al*

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First magnetic measurements of fast-ramping dipole DHPTB102 of BTF upgraded beam-lines

G. Armenti, B. Bolli, A. Casamatta, E. Di Pasquale, F. Iungo, S. Lauciani, S. Martelli, M. Paris, L. Pellegrino, R. Ricci, L. Sabbatini, F. Sardone, A. Vannozzi – INFN LNF

P. Valente – INFN Roma

Abstract

In the framework of the BTF upgrade, aimed at realizing two beam-lines serving two distinct experimental areas, the splitting of the beam coming from the Linac is realized by a dipole, labelled DPTB102, with a bending angle of 15° and a fast ramping (<100 ms) in order to optimize the duty-cycle. This note reports on the first dimensional checks and magnetic measurements, performed in DC, intended for verifying the basic parameters of the magnet, like the excitation curve, the maximum field, and field quality.

1. Introduction

The Beam Test Facility (BTF) is part of the DAΦNE accelerators system, of INFN Frascati National Laboratory (LNF). It is a transfer-line optimized for selection, attenuation and manipulation of electrons and positrons extracted from the DAΦNE Linac. The BTF is characterized by a high versatility in terms of beam energy, intensity, dimensions and position [1].

The present configuration allows to split the 50 electron or positron pulses per second from the Linac in three different lines: the first one leads to the storage rings (if the beam is not bent). The second one bends the beam by a 6° angle by means a pulsed dipole (DHPTS01), leading to a magnetic spectrometer (60° bending dipole followed by a segmented detector) for an energy measurement at the end of the Linac. The third one is dedicated to the BTF, through a pulsed 3° dipole (DHPTB101). The energy beam selection is carried out by a DC dipole with a bending angle of 42° (DHSTB01) and by a collimator system, followed by a focusing quadrupoles doublet. Furthermore, in the present configuration, in the BTF line there is a DC dipole with a bending angle of 45° (DHSTB02) that lead the beam along the main axes the experimental hall (see Fig. 1).

In 2016 an upgrade of the facility has been approved, with a two-fold objective [2]:

- Doubling the existing beam-line, realizing a new experimental hall, replacing the former BTF control room;
- Consolidating the Linac, in order to improve the performance in terms of efficiency and reliability.

The layout, optimized with the aim of getting a good beam quality in both the new beam-lines [3], is shown in Fig. 1. The maximum energy reached in the transfer lines is 800 MeV, but a further upgrade proposal foresees a Linac energy increasing of about 200 MeV, adding four accelerating structures, fed by further RF sources.

For splitting the beam coming from the Linac, the crucial element of this new configuration is a dipole, labelled DPTB102 in the general layout shown in Fig. 1, driving the beam alternatively in one of the two lines (BTF-1 and BTF-2), with a bending angle of at least 15° in order to have a suitable space to place all the elements of the new beam line.

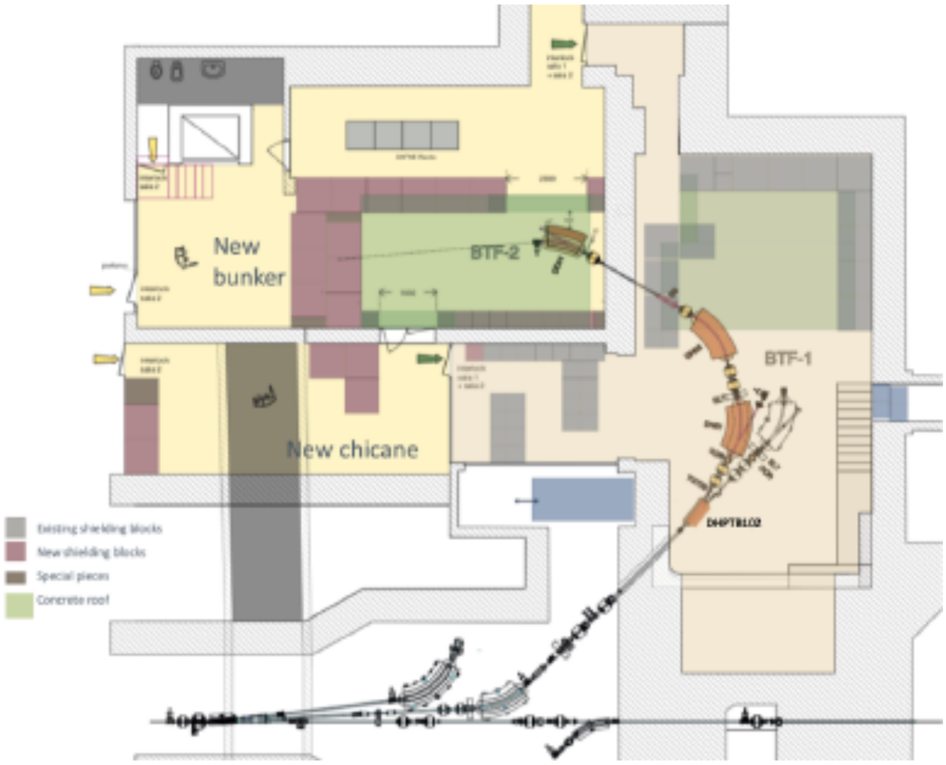

Figure 1 - New BTF and transfer line layout, showing the two new lines (BTF-1 and BTF-2) and the relative experimental halls.

Moreover, the dipole switching time must be short enough to allow the change from a beam line to the other one, with the minimum dead-time (within 100 ms). For this reason, the magnet has to be realized with packed iron lamination plates, 0.35 mm thick. A summary of the DHPTB102 dipole are summarized in the following Tab. 1. The magnet has been completely designed and optimized by LNF staff [4].

Table 1 – Parameters of DHPTB102, 15° fast-ramping dipole.

Parameter	Value
Magnetic field	1.11 T
Yoke length	756 mm
Yoke width	277 mm
Yoke height	359 mm
Gap	25.0 mm
Nominal current	316 A
Number of turns	72
Conductor section	7×7 mm^2 bore 4 mm
Resistance	78 mΩ
Inductance	29 mH
Nominal voltage	122 V
Nominal power	7.8 kW
Iron weight	510 kg
Copper weight	60 kg
Cooling water ΔT	15 °C
Cooling water flow	0.117 l/s
Cooling water speed	1.5 m/s
Cooling water ΔP	3 bar

All the other magnets of the new transfer line (BTF-2) are dipoles and quadrupoles operating in DC current, so they have constructive requirements and features completely different, i.e. can be in realized with full iron yoke [5].
The tender for the construction of the DPTB102 dipole has been assigned to ORMET S.r.l. and the construction has been performed from July 2017 to June 2018. A sample of pictures during the production of the yoke and coils of the dipole is shown in Fig. 2.

Figure 2 -The DHPTB102 dipole during different construction phases at ORMET S.r.l.

2. Setup

The DHPTB102 magnet has been positioned in the magnetic measurement hall (MEA) at LNF. All needed connections to the water cooling have been performed, as well as the connection to the available DC power supply of the lab. Indeed the pulsed power supply dedicated to DHPTB102 is still under construction, so that all measurements have been performed in DC.

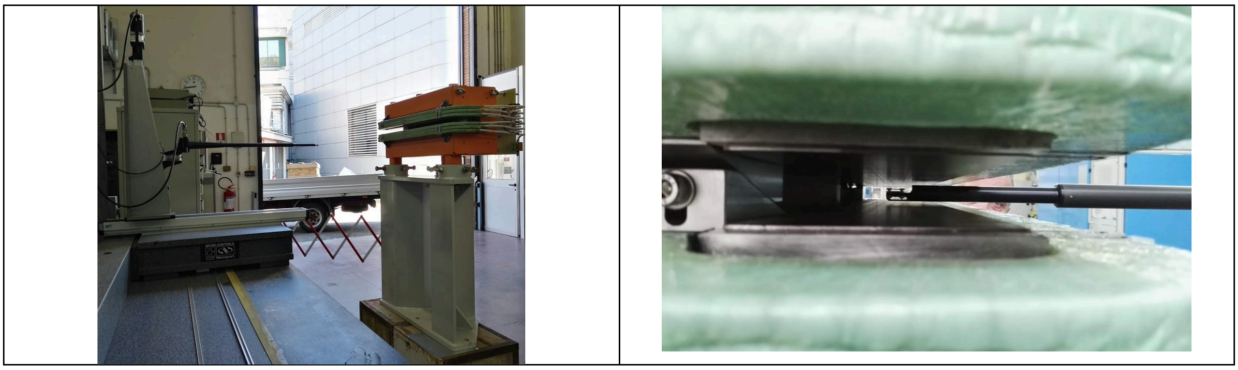

Figure 3 -The DHPTB102 dipole during magnetic measurements.

The magnet has been positioned on its support, custom designed, and aligned and measured with respect with the measuring device using the laser tracker (see Fig. 3).
The measuring device of MEA allows measuring the vertical compenent of the magnetic induction (B%) by means of a Hall probe, with an accuracy of 0.01% of the readout value ±0.006% of the full range.

The temperature of the MEA lab has been monitored during the measurement sessions and was 26 °C (within 0.5 °C). During the sessions the following measurements have been performed:

1. Mechanical dimensions
2. Excitation curve
3. B field longitudinal scans
4. B field radial scans
5. Electrical measurements

The magnetic field scans have been performed at the nominal current set of & '316 A, with the correction plates installed on both sides of the magnetic yoke and on both pole expansions. The coordinate reference system is shown in Fig. 4.

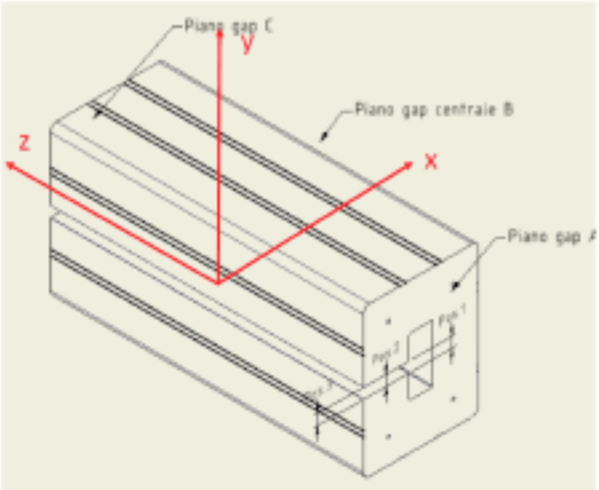

Figure 4 – Coordinate reference system for the measurements.

3. Mechanical measurements

The dimensional measurements were aimed at checking the mechanical tolerances after the packing of the iron lamination and the machining of the assembled yoke; these measurements have been performed by means of plane-parallel gauge blocks with the pass/no pass method. The precision of this method is ±0.01 mm.

The measurements have been performed on the three planes along *z* and for three different positions along the *x* axis, as shown in Fig. 4 (Pos. 3 to Pos. 1 from left to right). The results, summarized in Tab. 2, clearly show a deviation on the gap between the two polar expansions of about 0.3 mm on the *x* axis (see testing report "Verbale di Collaudo n°. 22227-C=-01-2" by the manufacturing company ORMET S.r.l.) and about 0.06 mm on the *z* axis..

Table 2 – Dimension of the gap.

Position	Plane A	Plane B	Plane C
Pos. 1 (inner)	26.04	26.04	26.03
Pos. 2 (central)	26.20	26.20	26.20
Pos. 3 (outer)	26.40	26.35	26.34

4. Excitation curve

The excitation curve, shown in Fig. 5, has been obtained by positioning the Hall probe at the geometric center of the gap, and by powering the magnet with a current variable in the range 0 to 330 A, in steps of 20 A (except the last two value, at the nominal and maximum current).
The maximum current is the maximum current specified for the fast power supply (100 ms ramp) specifically designed for this magnet. The linear fit of the obtained points shows a deviation from linearity below 1% at the nominal working current (I =316 A).

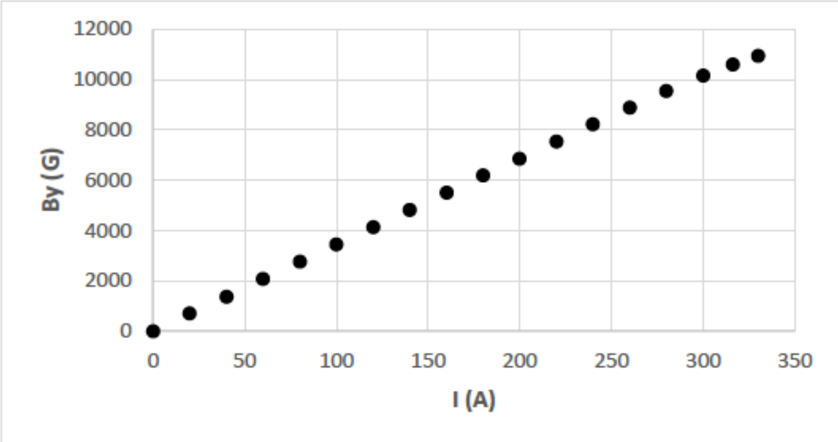

Figure 5 – Measured excitation curve.

5. Longitudinal scans for By field

In order to check the magnetic field uniformity in the required good field region, x = ±15mm, seven longitudinal scans have been performed: along the axis at x =0 mm, at x =±5 mm, at x =±10 mm, and at x =±15 mm.
These scans have been performed from z =-800 mm to z =+800 mm in order to have a full measurement also in the fringe field region, at the center of the gap in the vertical coordinate y =0 mm, and at the nominal current of I =316 A.
The scan along the magnetic axis is shown in Fig. 6.

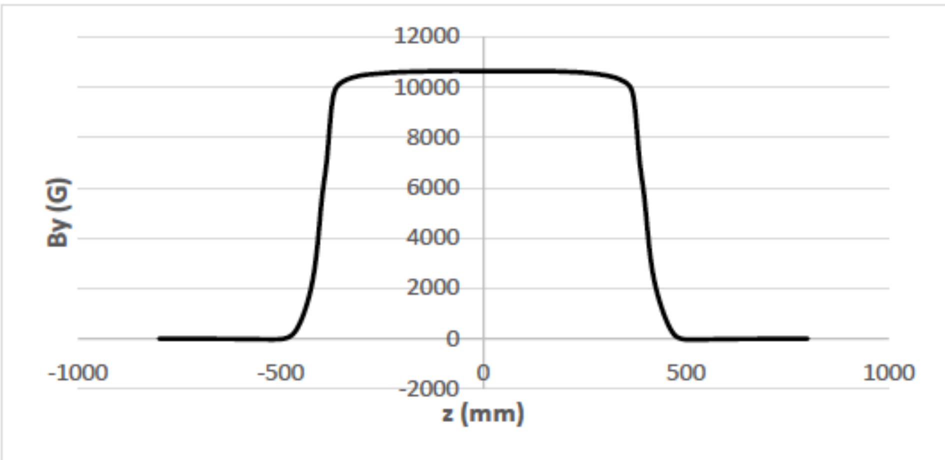

Figure 6 – Longitudinal scan of B_y at x =0.

The measured vertical component of the magnetic field at the center is B_y (0,0,0)=1.06 T, i.e. slightly lower than the nominal value 1.11 T required in the technical specifications. This value is however compatible with expectations, when taking into account the increased width of the gap between the polar expansion, measured to be 26.2 mm with respect with the design value of 25.0 mm.

The corresponding field integral along the magnetic axis (x =0mm) is thus 849 T mm, slightly lower than the nominal value of 872 T mm. In terms of the benging power, this translates in a maximum momentum of 972 MeV/c for the nominal deflection angle of 15°. The resulting magnetic length is 798 mm: the deviation from the design value (786 mm) is very small in this case due to the fact that correction plates have been installed.

Finally, the field uniformity in the good field region is 2.2 10^{-3}, i.e. at the limit of the required value.

However, the longitudinal scans clearly confim the deviation from parallelism of the polar expansions indicated by the dimensional measurements, both in the x axis (0.3 mm deviation) and z axis (0.06 mm on the external part). The latter is not relevant, both for the amount of the discrepancy and for final use of the magnet, while the x axis deviation has to be taken into account properly and possibly corrected for. The effect along the x axis can be better estimated by the radial scans.

6. Radial scans for $\boldsymbol{B}_y$ field

The vertical component of the magnetic field has been measured in five radial scans at the positions along the longitudinal axis of z =0 mm, z =±135 mm, z =±270 mm. These positions have been chosen in order to cover the "flat top" region of the longitudinal profile, taking as a reference the rule of thumb of five times the value of the gap: 5 × 26 = 130 mm, and a region well beyond this value but still below the half-length of the poles of 400 mm.

Radial scans have been performed in a transverse coordinate range from x =-40 mm to x =40 mm in order to measure the greatest part of the pole length and not only the good field region. Scans were performed at the center of the gap in the vertical coordinate, y =0 mm, and at the nominal current of
I =316 A. The scan at z =0 mm is shown in Fig. 7.

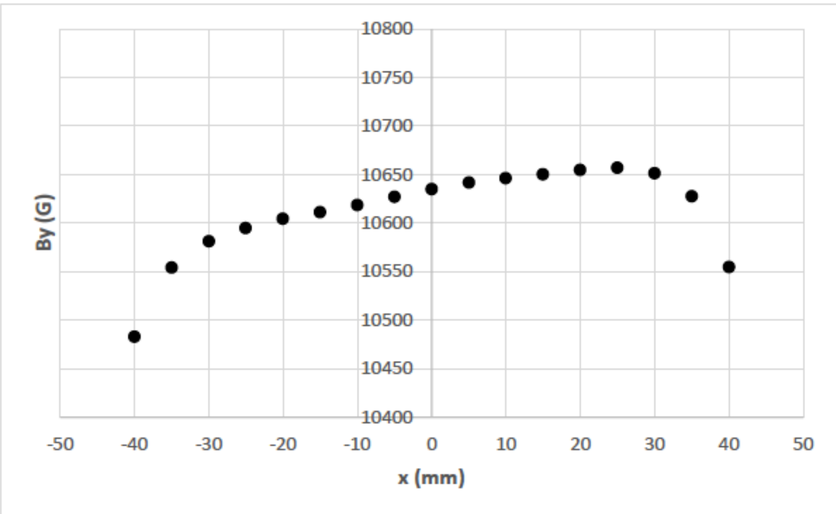

Figure 7 – Radial scan at z=0.

From the measurements we can conclude that a gradient of 0.1 T/m is present in the good field region, due to the deviation from parallelism along the x direction. A smaller deviation from parallelism of the pole surfaces is also present along the z axis, and is observable as a (relatively small) asymmetry in the field at opposite z coordinates These deviations from the expected shape of the magnetic field are indeed compatible with the measured deviation from the design geometry indicated by the dimensional measurements.

7. Electrical measurements

Electrical measurements have been performed, by using a LCR meter. In particular the inductance and the resistance of the magnet as a function of the excitation frequency have been measured. The results of such measurements are reported in Fig. 8 and Fig. 9.

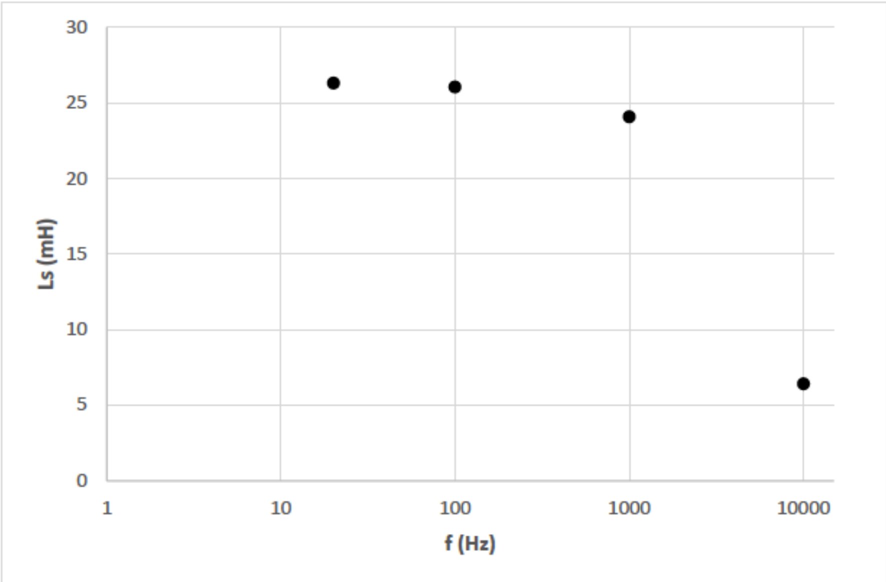

Figure 8 – Measured inductance as a function of the excitation frequency

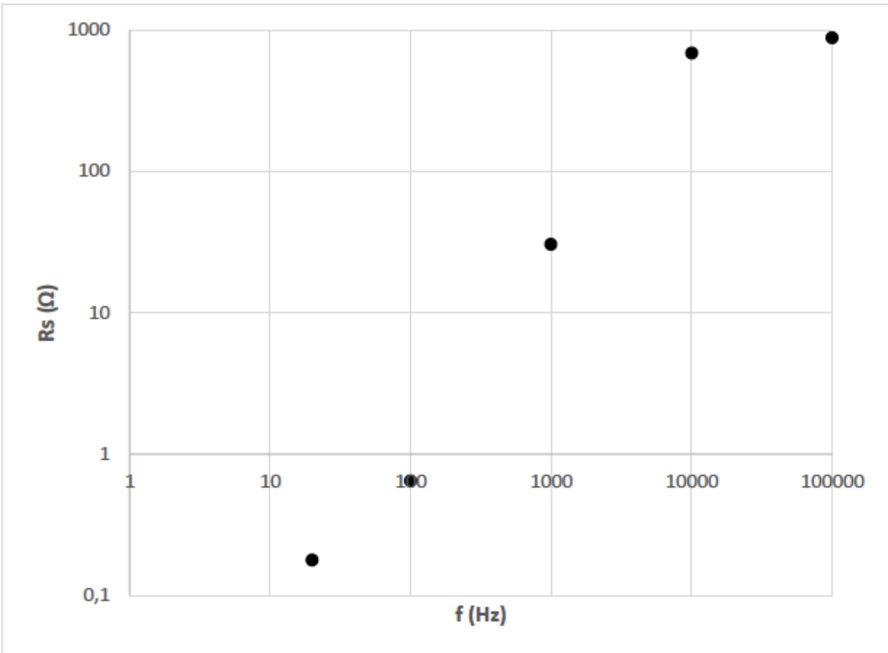

Figure 9 – Measured resistance as a function of the excitation frequency.

8. Conclusions

A first set of dimensional and magnetic measurements on the DHPTB102 magnet has been reported. The fast-ramping, 15Æ dipole is the crucial element for splitting the Linac beam among the two new beamlines of the upgraded BTF.
Since the pulsed power supply dedicated to DHPTB102 is still under construction, all measurements have been performed in DC.
The mechanical, magnetic, and electrical measurements show some deviation from the nominal parameters. However, the functions and the use of the magnet make these discrepancies tolerable, in particular the not-negligible field gradient due to the deviation from parallelism of the pole faces can be compensated by the optics of upstream transfer -line.

9. Acknowledgements

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