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FAST RAMPED DIPOLE AND DC QUADRUPOLES DESIGN FOR THE BEAM TEST FACILITY UPGRADE

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Abstract

The Beam Test Facility (BTF) is part of the DAΦNE accelerators system of INFN Frascati National Laboratory. It is a transfer-line optimized for electrons and positrons extracted from the DAΦNE LINAC. An upgrade of the line is planned in order to reach a beam energy of 920 MeV (with respect to the present 750 MeV), adding a new branch to the present transfer line.

The design of the magnets for this new layout has been completely performed at INFN, including electromagnetic, mechanical, thermal and hydraulic aspects. This effort lead to a complete set of detailed CAD drawings that can be used by Industrial partners to build the magnets. The manufacturing processes have been studied in detail: the goal is to boost the manufacturing of prototypes and small series from Small and Medium Enterprises. Magnetic measurements will be performed at our Institute.

In this report we describe two types of magnets for this project. The first magnet is a C-shape fast ramped dipole, designed for a beam deflection of 15 degrees; the rise time is 100 ms, the gap is 25 mm with a magnetic field of 1.11 T. The second is a family of seven quadrupoles with a gradient of 20 T/m and a bore of 45 mm.

INTRODUCTION

The BTF 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.

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. The second one bends the beam by a 6 degrees angle by means of a pulsed dipole, leading to a magnetic spectrometer (60 degrees 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 degrees dipole. The energy beam selection is carried out by a DC dipole with a bending angle of 42 degrees 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 degrees that leads the beam along the main axes of the experimental hall.

The maximum energy reached in the transfer lines for the electron beam is 750 MeV, but the new project (BTF2) foresees a LINAC energy increase to about 920 MeV, adding four accelerating structures, fed by further RF sources.

The BTF2 project [1, 2] also foresees a new branch of the present BTF transfer line, in order to have two different beam lines into two separate experimental halls. Therefore, it will be possible to split the beam towards two different test apparata. The layout of the BTF2 is shown in Figure 1.

A crucial element of this new configuration is a dipole driving the beam alternatively in one of the two lines (labelled as BTF-1 and BTF-2), with a bending angle of 15 degrees. The dipole switching time must be short enough to allow the change from a beam line to the other one, with a minimum dead-time (ideally, the switching time should be within 20 ms corresponding to the time from two subsequent pulses of the LINAC). The BTF2 will also need few quadrupoles in order to focus the beam along the machine lattice. The other new magnets of the BTF2 are three sector dipoles operating in DC current, with a full iron yoke, designed to bend the beam of further 125 degrees. These magnets are presented on another poster at this Conference [3].

Figure 1: New configuration of the Transfer Line, the two BTF lines and the experimental hall.

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WORK PERFORMED

The main goal of this work is to perform the complete design of the magnets for the BTF upgrade within the INFN, taking advantage of the long term expertise of Physicists and Engineers of the Accelerator Division and Technical Division of the Frascati National Laboratory (LNF).

This activity will boost the involvement of local Small and Medium Enterprises in the manufacturing of prototypes and small series of magnets, giving them the occasion of acquiring specific experience in magnet technology.

Electromagnetic Design

The general parameters of the magnets have been set by the study of the beam dynamics. Electromagnetic FEA simulations have been performed both with 2D and 3D software (using Poisson Superfish and OPERA respectively). The electromagnetic study allows the optimization of pole profile and mechanical length in order to comply with the requirements of magnetic field or gradient and its quality. Error analysis both on transversal and longitudinal directions has been performed to fix the required manufacturing tolerances.

Thermo-hydraulic Design

The cooling system of the magnets must be compliant with the present BTF plant. Hence the dimensioning of the hydraulic systems has been performed in order to have a 3.5 bar pressure drop. The details of the cooling have been fixed.

Mechanical Design

The result of the full design of the magnets is a complete set of CAD drawings. They describe in detail all the features of the magnets, including the yoke, the coils, the electrical and hydraulic connections. All the materials and tolerances have been defined. This work also aims to transfer our specific knowledge in magnet technology to the companies participating to the bids for the construction.

Magnetic Measurements

Magnetic measurements will be performed at INFN-LNF. The magnetic measurements laboratory is equipped with a Hall digital teslameter with a 5 axes movement device mounted on a granite bench, a rotating coil, a nuclear magnetic resonance teslameter. Several other magnetic instruments, such as gaussmeters, digital and analogic integrators, are available. The laboratory is also equipped with high precision electrical instruments in order to perform measurements on the power supplies.

FAST RAMPED DIPOLE

The crucial element of the new BTF configuration is a dipole driving the beam alternatively in one of the two lines, with a bending angle of 15 degrees. Due to the geometrical constraints of the pre-existing hall, the preferred shape is a straight C-dipole. This so-called DP01 dipole is designed to deflect an electron or positron beam up to 1 GeV. The required integrated field needed is about 0.87 T m; the geometrical constraints impose to keep an overall length of the magnet at approximately 1 m, while the required gap is fixed at 25 mm in order to host the beam pipe; this lead to a choice of B_0 of 1.11 T. The integrated field quality is required to be about 2 10^{-3} over a good field region of ±15 mm.

The magnet must be compliant with the pre-existing timing of the DAFNE accelerator. For that reason, and in order to minimize the dead time, the rise time must be of 100 ms. Hence the yoke will be realized with laminations; their thickness has been studied in detail, taking into account the electrical power loss and the skin depth. The yoke has been designed with about 2140 laminations of 350 µm thickness of M270-35A, with a minimum required packing factor of 96%. The insulation and bonding between laminations has been designed to be obtained with Stabolit 70. In order to reduce the production time and cost, the laminations have been laser cut, and the main mechanical tolerances have been measured with CMM to verify their compliance with specifications. End plates of a-magnetic material have been added in order to reduce eddy currents and contribute to mechanical stiffness. Packing method has been studied in detail, taking into accounts the tolerances of the single sheet and the requirements for the assembled yoke.

Small plates of magnetic material could be added at the end of the poles in order to adjust the magnetic length when the measurements will be performed on the finished object.

The excitation coil is a racetrack coil of 36 turns per pole. The conductor is 7x7 mm^2 copper conductor with a cooling hole of 4 mm diameter. The current needed to sustain the magnetic field is 316 A.

The final required parameters for this magnet are reported in Table 1, while a general view of the saturation on the yoke is shown in Figure 2.

Table 1: Main Design Parameters of Fast Ramped Dipole

Beam energy (GeV)	1
Magnetic field (T)	1.11
Bending angle (°)	15
Gap (mm)	25
Pole width (mm)	110
Magnetic length (mm)	786
Yoke material	M270-35A
Integrated field quality (over ±15mm)	2 10^{-3}
Conductor dimensions (mm^2)	7x7 / bore 4 mm
Turns per pole	36
Pressure drop (bar)	3
Nominal current (A)	316
Magnet resistance (mΩ)	78
Magnet Inductance (mH)	29
Nominal voltage (V)	122
Power (kW)	7.8

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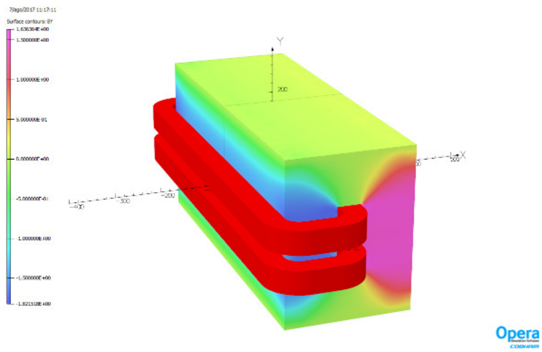

Figure 2: Schematic view of the DP01 magnet showing the saturation level.

QUADRUPOLES

The geometrical constraints related to the proximity of the two new beam lines impose an octagonal configuration for the quadrupoles. The required gradient of 20 T/m on a bore of 45 mm in diameter will be achieved with 45 windings of the 5x5 mm^2 copper conductor, powered with a nominal current of 93 A. The yoke will be realized in full AME iron. The pole width and its facetted hyperbolic profile have been designed to obtain the required field quality, that is 5 10^{-3} on a radius of 15 mm. The electromagnetic design includes also the analysis of harmonic content and its optimization. In particular, detailed study of the chamfering needed to reduce the 12-pole term has been performed. Removable end blocks have been designed for the poles, to be eventually machined in order to adjust the harmonic content after measurements. A view of the magnetic design is reported in Figure 3, while Table 2 resumes the main parameters.

Table 2: Main Design Parameters of the Quadrupoles

Gradient (T/m)	20
Bore (mm)	45
Magnetic length (mm)	200
Pole width (mm)	45
Integrated quality (r=15mm)	5 10^{-3}
Conductor dimensions (mm^2)	5x5 / bore 3 mm
Turns per pole	45
Pressure drop (bar)	3.5
Current (A)	93
Magnet resistance (mΩ)	116
Magnet inductance (mH)	22
Nominal voltage (V)	11
Power (kW)	1.02

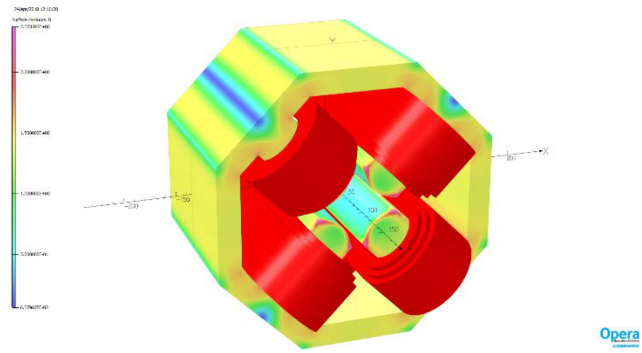

Figure 3: Schematic view of the quadrupole showing the saturation level.

CONCLUSIONS

The design of the magnets has been completely performed at INFN, including electromagnetic, mechanical, thermal and hydraulic aspects. A complete set of detailed CAD drawings has been produced.

The manufacturing processes have been studied in detail in order to reduce the fabrication costs.

Magnetic measurements and characterization will be performed at INFN-LNF.

The production of the dipole is in an advanced phase: the yoke and coils have been already built; their assembly, electrical and hydraulic tests will be performed in the next few months. Installation and commissioning are planned in Fall 2018.

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