MAIN MAGNETS DESIGN STUDIES FOR THE NON-SCALING FIXED FIELD ALTERNATING GRADIENT ACCELERATOR FOR A FINAL ACCELERATION STAGE OF THE NEUTRINO FACTORY*

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Abstract

The International Design Study of the Neutrino Factory (IDS-NF) aims to design the next generation facility for the precision neutrino oscillation searches. The non scaling Fixed Field Alternating Gradient Accelerator was proposed for the final muon beam acceleration in order to reduce the cost of the final acceleration. A superconducting magnet design based on the independent multipole coils approach using the ROXIE code is presented. The feasibility of the magnet construction together with the quench limitations is discussed.

INTRODUCTION

The neutrino oscillations are currently the only confirmed physics beyond the Standard Model and the Neutrino Factory (NF) is the proposed future facility aiming for the precision measurement of this phenomenon including the verification of an existence of the CP violation in the leptonic sector. The International Design Study (IDS-NF) [1] is currently performing detailed conceptual design for the NF. The Interim Design Report was accomplished this year [2] and the Reference Design Report is expected to be accomplished by the IDS-NF collaboration in 2013. The neutrino beam from the Neutrino Factory is generated in the decay of muons circulating in the storage ring, thus the facility requires the muon accelerator, which needs to boost the muon beam energy from ~150 MeV at the capture downstream the pion production target, up to 25 GeV at injection to the storage ring. The main constrains, which dictate the design are the large required normalised acceptance of 3 π.cm.rad and the short muon life-time (2.2 μs at rest). According to the current IDS-NF baseline, the acceleration from 12.6 GeV to 25 GeV is foreseen in the Non-Scaling Fixed Field Alternating Gradient (NS-FFAG) machine. The FFAG lattice consists of an identical and relatively short FDF triplet cells. The strong focusing needed to obtain a very small orbit excursion is performed in the combined function superconducting magnets. The momentum compaction is adjusted in order to create the quasi-isochronous optics, which is required in order to allow for the acceleration with high and fixed frequency RF cavities. The main parameters of the NS-FFAG, which corresponds to the magnet design presented in this paper are listed in Table 1 and it should be noted that they differ from the current ones [3], as the machine definitions were updated.

Table 1: Parameters of NS-FFAG Based on Triplet

Number of cells	64
Circumference	667 m
RF voltage	1.213 GV
Max field in F magnet	4.3 T
Max field in D magnet	6.1 T
F magnet radius	16.3 cm
D magnet radius	13.7 cm
Muon decay	6.7 %
Injection energy	12.6 GeV
Extraction energy	25 GeV

MAGNET DESIGN

The preliminary design of the main superconducting combined-function magnets for the linear non-scaling FFAG has been performed using the CERN ROXIE code [4]. As the design of the focusing (F) magnet is more advanced, we present only this element. The design uses the well-established technology of Ni-Ti superconducting magnets fabricated with Rutherford cable. In order to simplify the geometry and allow for flexible beam optics tuning, the magnet design is based on separate coils for dipole and quadrupole field components, which are assembled according to the conventional "cos θ" geometry [5]. The inner layer creates a dipole field using 3 conductor blocks, and the outer layer creates a quadrupole field with 2 conductor blocks. For the needs of the actual design the dipole and quadrupole cables have been generated in ROXIE based on the standard Large Hadron Collider (LHC) main dipole inner cable [6] at CERN. The cables consist of 28 strands and have a trapezoidal geometry. They would be constructed using the same filaments as the LHC magnet. An iron yoke made of soft magnetic steel is placed beyond the quadrupole layer. The magnet is closed with a clamp in order to limit field leakage in the long straight section, where it could affect hardware components like superconducting RF cavities or kickers. The geometry of coils and yoke for half of the F magnet is shown in Fig. 1. The dipole field and gradient on axis have been reproduced according to the lattice design specifications with an accuracy of ~ 10^{-4}. However the field off axis still needs to be improved.

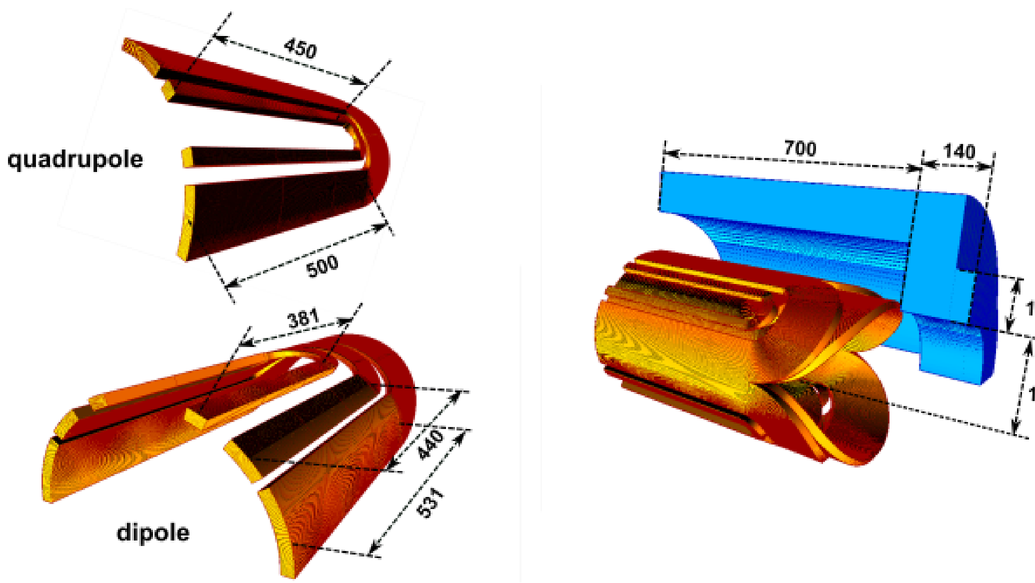

Figure1: Geometry of the main focusing (F) magnet for the NS-FFAG for the Neutrino Factory. The dipole, quadrupole coils are shown together with the magnet yoke.

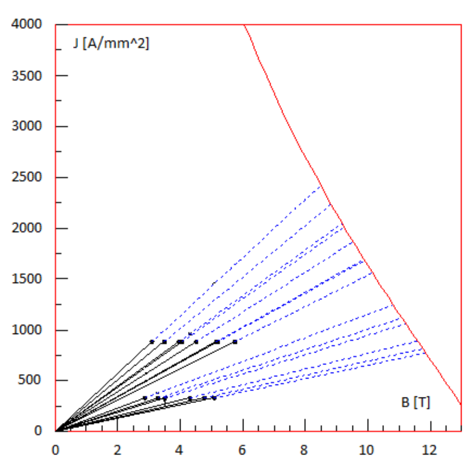

Figure 2: Quench analysis in the focusing superconducting F magnet for the Neutrino Factory. The individual dots represent the conductor block for dipole and quadrupole layers.

The main parameters of the focusing (F) FFAG magnet are collected in table 2. A quench analysis has been performed using ROXIE, and calculations of the temperature margins suggest stable magnet operation. The Fig. 2 shows, the results of the quench analysis for each magnet block both for dipole and quadrupole layers. The position of each block is located within sufficient margins with respect to the critical surface at 1.9 K., but the operation at 4.2K could also be possible. The vertical field component on the median plane of the F magnet is shown in Fig. 3.

Table 2: Parameters of NS FFAG Focusing Magnet

Parameter	value
Strand diameter	1.065 mm
Number of strands/cable	28
Cable height(dipole and quadrupole)	15 mm
Dipole cable inner/outer width	1.58/1.75 mm
Quadrupole cable inner/outer width	1.83/1.98 mm
Number of conductors in dipole blocks	52,25,13
Number of conductors in quadrupole blocks	41, 10
Inner radius of dipole blocks	163 mm
Inner radius of quadrupole blocks	179 mm
Inner radius of the yoke	300 mm
Yoke thickness	100 mm
Half of the yoke length(with clamp)	840 mm
Dipole current	3190 A
Quadrupole current	8490 A
Peak field in the conductors	5.75 T
Minimal temperature margin to quench at 2.2 K	3.84 K

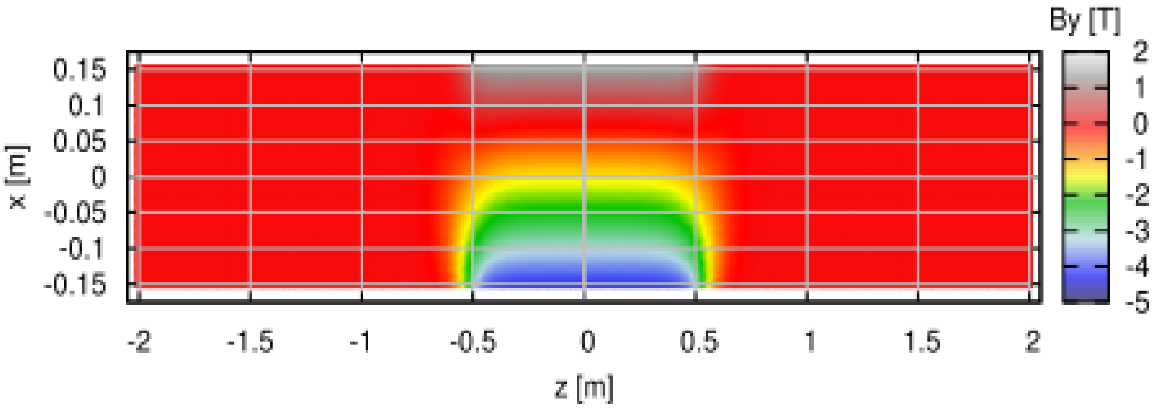

Figure 3: Median plane field map for the main focusing superconducting magnet for the NS-FFAG for the Neutrino Factory. The figure shows the vertical component of the magnetic field.

SUMMARY AND FUTURE PLANS

The focusing main superconducting magnet for the NS-FFAG accelerator for the final stage of muon acceleration in the Neutrino Factory has been designed using the CERN ROXIE code. The assumed standard "cos θ" geometry with individual dipole and quadrupole layers turned out to be sufficient to produce the desired field pattern. Quench simulations suggest the stable magnet operation at 1.9 K, but large margins with respect to the critical surface may allow for the operation at higher temperature. The field quality off-axis still needs to be improved, which will require an update of the magnet geometry. The effect of magnetic field imperfections still needs to be assessed in the tracking studies. Future studies will address the field quality, the possible addition of higher multipoles (mainly sextupole, but octupole may also be considered) for chromaticity correction. It was also proposed to compare this kind of conventional magnet design with the more advanced coil geometries for combined function superconducting magnets [7, 8] with respect to the field quality, quench margins and the cost. The cryogenic analysis for this design has been recently initiated [3], but more insight into the engineering aspects is required in the future.

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