INITIAL 2D INVESTIGATIONS INTO THE DESIGN AND PARAMETERS OF AN EM QUADRUPOLE FOR FETS

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Abstract

The Medium Energy Beam Transport (MEBT) line for the Front End Test Stand (FETS) at Rutherford Appleton Laboratory (RAL) consists of a number of quadrupoles, re-bunching cavities and a fast-slow chopping system with dedicated beam dumps, as well as diagnostics. The type and design of the quadrupoles to be used merits special attention. Due to space restrictions, a hybrid quadrupole solution has been proposed in the past [1]. However, because of the limited range of field adjustability achievable, this approach is not ideal. In this paper, a very preliminary investigation of an electromagnetic quadrupole (EMQ) design is presented. Magnetic simulations results performed with a 2D simulation code will be discussed including magnet optimisation details.

INTRODUCTION

The interest for High Power Proton Accelerators (HPPAs) has grown significantly in the last few years due to their many applications: drivers for neutrino factories, neutron sources, transmuters for long-lived nuclear waste products and energy amplifiers.

The Front End Test Stand (FETS) project at Rutherford Appleton Laboratory (RAL) is the main HPPA R&D project in the UK [2]. It represents the national commitment to the development of a next generation high power, high intensity proton accelerator and at the same time prepares the way for a future upgrade for the ISIS Spallation Source.

When completed, FETS will consist of an H^- ion source, a Low Energy Beam Transport Line (LEBT), an RFQ and a Medium Energy Beam Transport line (MEBT). The ion source will generate a 65 keV, 60 mA, 2ms, 50 pps H- beam which will be focused and matched into an RFQ by a three-solenoid LEBT. The 4 m long, 324 MHz RFQ will bunch and accelerate the beam up to 3 MeV. The RFQ will be followed by the MEBT line which houses a two stage chopper with dedicated beam dumps. The MEBT will transport the beam through a comprehensive set of diagnostics and into a dedicated target area. The FETS layout can be seen in Figure 1.

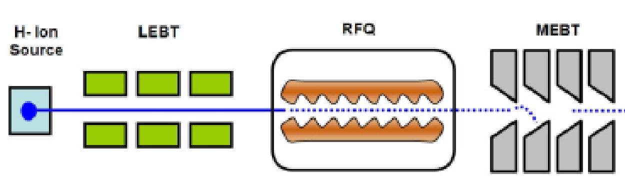

Figure 1: The Front End Test Stand.

EMQ DESIGN CONSIDERATIONS

One of the main components of FETS is the MEBT line [3]. The current MEBT scheme consists of 11 quadrupoles, 4 re-bunching cavities, a fast-slow beam chopping system with two electrostatic choppers and dedicated beam dumps and a diagnostics beam line, as it can be seen in Figure 2.

Electromagnetic quadrupoles have been used in linear accelerators worldwide for a long time. They are capable of producing high magnetic fields that can be adjusted by varying the current flow in the conductors in order to achieve the desirable magnetic field magnitude. More recently, a number of linac projects have adopted permanent magnet quadrupoles (PMQs) as focussing structures. PMQs are based on rare earth materials and they offer a compact design with very high field gradients, but on the other hand, the magnetic fields cannot be adjusted once they have been installed in the linac. The FETS MEBT line however, needs quadrupoles capable of dealing with different beam regimes for which adjustability is essential. Therefore, it has been decided that EMQs are a more suitable choice for this project.

The main quadrupole requirements have been specified by the MEBT beam dynamics design. An aperture of 30 mm is necessary and magnetic field gradients of up to 25 T/m. In this preliminary design investigation, we have taken the following guidelines into consideration:

- Magnetic design: The EMQs should meet the imposed design specification in terms of field gradient, field homogeneity, etc.
- Mechanical design: the EMQs have to fit inside the physical limits imposed by the MEBT optical design.
- Manufacturing: the optimised EMQ geometry should take into account the available cooling options, tolerances and generally ease of manufacture.

MODEL DETAILS

In order to analyse the achievable field gradients, a 2D model has been created using the ANSOFT MAXWELL software [4]. The model consists of a 4 pole magnetic bearing of silicon steel M400.

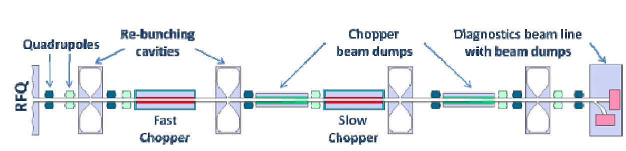

Figure 2: Schematic drawing of the FETS MEBT line.

This material has been chosen for its good magnetic and mechanical properties. Its magnetisation curve can be seen in Figure 3. To achieve the design field gradients, current densities of up to 5 A/mm^2 will be needed. This high current density requires a cooling system which will have to be integrated in the design. The most evident choice is using copper wire with cooling channels.

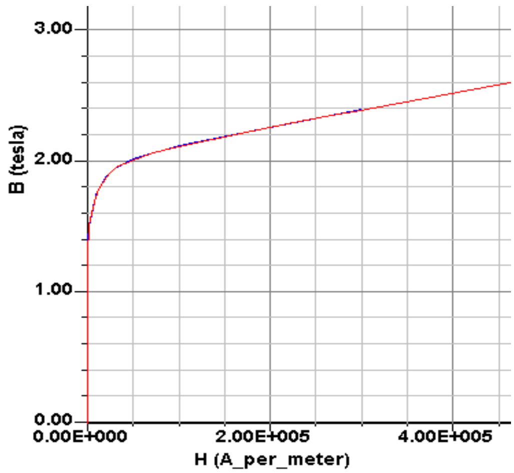

Figure 3: B-H curve for silicon steel M400.

Optimisation Procedure

To facilitate the optimal choice of parameters in this multidimensional simulation space, ANSOFT MAXWELL allows multiple simulations to be performed automatically choosing the starting, final and step values for each variable. Each parameter was thus simulated and its effects independently studied. An example of an optimisation study can be seen in Table 1.

Table 1: Parameter Values Considered for Simulations

	Size	Step
Magnet aperture radius (mm)	15	-
Winding radius (mm)	40-80	10
Yoke outer radius (mm)	100-150	10
Winding angle (º)	65-75	5
Current Density (A/mm^2)	0-5	0.5

A brief description of the above parameters is below. The quadrupole configuration can be seen in Figure 4.

- The magnet aperture radius corresponds to the beam pipe of the MEBT line and is fixed.
- The winding radius is the distance between the centre of the quadrupole and the outermost part of the coil.
- The yoke outer radius is the outer quadrupole radius.
- The winding angle is the angle between the abscissa and the opposite side of the winding.

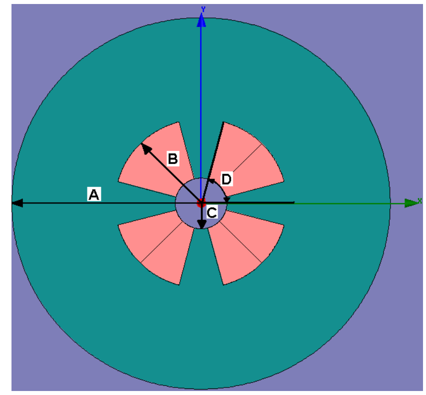

Figure 4: Quadrupole configuration: A) Yoke Outer radius; B) Winding radius; C) Aperture radius; D) Winding angle.

DESIGN RESULTS

After performing the optimisation, various parameters can be chosen based on the simulation results. Additional constraints like manufacturing feasibility and mechanical limitations have to be taken into account. For example, the difficulty of the winding increases with the increase of the winding radius (B), and as a result the lowest radius that satisfies the gradient requirements is preferred. An example of a possible set of parameters can be seen in Table 2.

Table 2: A Possible Set of Practical EMQ Parameters

	Size
Magnet aperture radius (mm)	15
Winding radius (mm)	50
Yoke outer radius (mm)	100
Winding angle (º)	75
Max. Current Density (A/mm^2)	5
Max. Gradient (T/m)	26.88
EMQ length (mm)	70

As expected, as shown in Figures 5 and 6, the winding radius and angle have a direct influence on the magnetic field gradient. As these two parameters increase, so does the gradient. This is clearly due to the fact that as the coil cross section area increases, more current flows through.

Simulations have also shown that the yoke outer radius influence on gradient is minimal above a certain value, as seen in Figure 7. The slight gradient variations are just simulation noise caused by mesh density differences between the various designs.

The gradient dependency on the applied current density can be seen in Figure 8, while Figure 9 shows a typical ANSOFT MAXWELL output of the magnetic field.

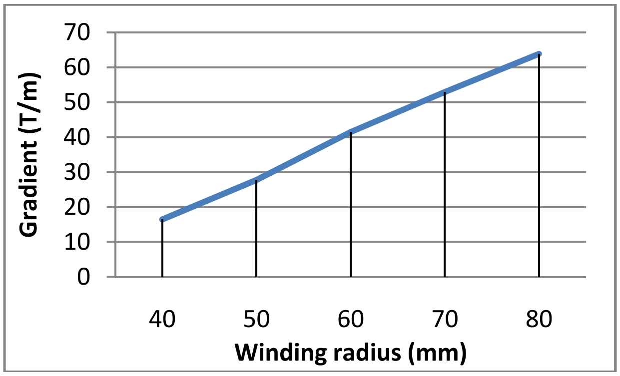

Figure 5: Magnetic field gradient with Winding radius (Current density = 5 A/mm^2, Yoke Outer radius = 100 mm, Angle = 75º).

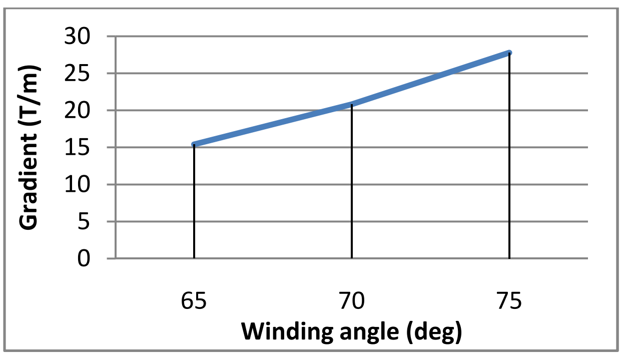

Figure 6: Magnetic field gradient with Winding angle (Current density = 5 A/mm^2, Yoke Outer radius = 100 mm, Winding radius = 50 mm).

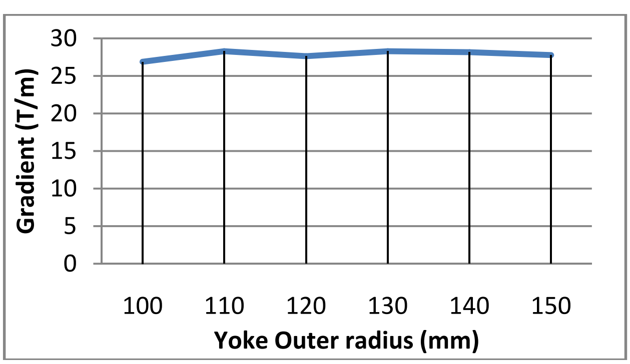

Figure 7: Magnetic field gradient with Yoke Outer radius (Current density = 5 A/mm^2, Winding radius = 50 mm, Angle = 75º).

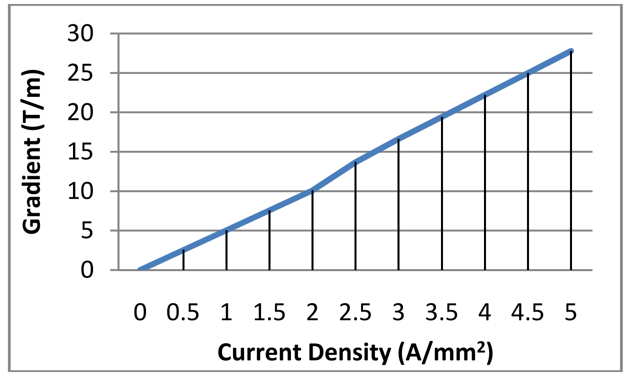

Figure 8: Magnetic field gradient with Current Density (Winding radius = 50 mm, Yoke Outer radius = 100 mm, Angle = 75º).

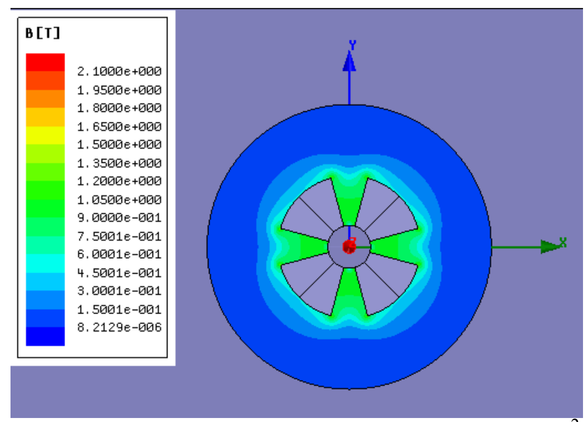

Figure 9: Magnetic field map of the EMQ at 5 A/mm^2.

CONCLUSIONS

A very preliminary study has been started in order to find a suitable EMQ design for the FETS project at RAL. Initial simulation results indicate that in order to achieve the design parameters, care has to be taken when optimising the quadrupole geometry. However, this is only an initial step in the overall design process. More work is further needed to optimise the quadrupole geometry as to improve the field homogeneity, while considering cooling, manufacturing, mechanical and cost aspects of the design. A 3D model is currently under development.

REFERENCES

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