THE EMMA NON-SCALING FFAG

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Abstract

The Electron Model for Many Applications (EMMA) will be the World's first non-scaling FFAG and is under construction at the STFC Daresbury Laboratory in the UK. Construction is due for completion in Summer 2010 and will be followed by commissioning with beam and a detailed experimental programme to study the functioning of this type of accelerator. This paper will give an overview of the motivation for the project and describe the EMMA design and hardware. The first results from commissioning will be presented in a separate paper.

INTRODUCTION

Non-scaling FFAGs (NS-FFAGs) were invented at the end of the last decade [1], principally for the acceleration of muons in a Neutrino Factory [2]. More recently, due to their interesting properties, they have been studied for other applications, in particular for proton and carbon cancer therapy [3] and for driving sub-critical nuclear reactors using thorium as a fuel [4]. However, as originally conceived, they have a number of unique features, including

- the variation of tunes over a large range during acceleration, leading to many resonance crossings
- a very small momentum compaction
- acceleration outside of RF buckets.

These features have been studied in some detail for muon acceleration and none appear to prevent NS-FFAGs from working. However, before a machine can be built for this or any other application, it is essential to build at least one proof-of-principle NS-FFAG. This is necessary to study these and all other features of this type of machine and benchmark tracking codes to enable their use for other machine designs. This is the purpose of EMMA.

EMMA DESIGN

The EMMA machine is a linear, non-scaling FFAG that will accelerate electrons and the basic parameters are shown in Table 1. It is being built at the STFC Daresbury Laboratory in the UK and the electron beam will be provided by the existing ALICE accelerator there [5]. To do this, a dipole magnet has been installed in ALICE and new injection line built to transport the beam to the EMMA ring. The design of EMMA is shown schematically in Figure 1. It includes an extraction line, which will house the diagnostic devices that will perturb the beam too much to be mounted in the ring. Each of the main components of the machine is described in the following subsections.

Table 1: EMMA Parameters

Energy range	10 to 20 MeV
Cell	Doublet
Number of cells	42
RF	19 cavities; 1.3 GHz
Cell length	394.481 mm
Ring circumference	16.57 m

Magnets

The ring consists of 42 doublet cells mounted on 7 girders. An example is shown in figure 2. As EMMA is a linear machine, each of the ring doublet magnets has only dipole and quadrupole components. However, as the accelerator diameter is large for the energy, the dipole component is significantly smaller than the quadrupole. As a result, the magnets are built as quadrupoles and the dipole component is obtained by using them off-axis. To achieve the flexibility required to study the non-scaling optics in detail, it necessary to independently vary these components. This is done by mounting the magnets on precise, computer controlled sliders.

To prevent field leakage into surrounding magnetic material, each doublet has clamp plates. As the amount of space between the magnets is too small, 5 cm, these are mounted only on each side of the doublet, with no clamp plates between the magnets. Further, it is believed that the only magnetic material that needs to be shielded is in the kicker magnets of the injection and extraction systems.

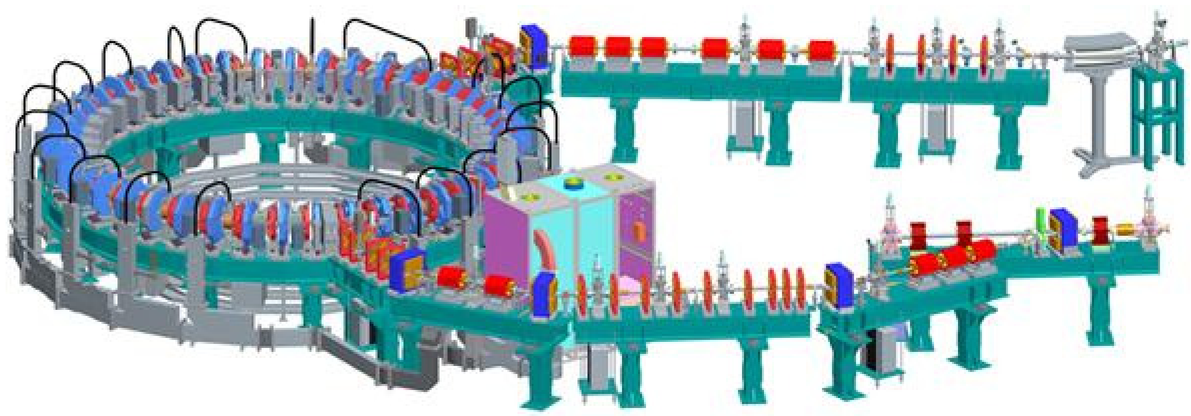

Figure 1: The layout of EMMA. Shown is a short section of the ALICE machine, with a new dipole magnet to steer the beam into the injection line (bottom of the picture). The EMMA ring, showing the 42 cells, is on the left and the diagnostics beam line at the top.

Figure 2: An EMMA girder, with 6 doublet cells mounted. The larger of the magnets is the D and the smaller is the F. RF cavities are mounted in almost every other cell and one can be seen at the end of the girder.

However, to maintain the symmetry of the ring and minimise the effects from resonances, clamp plates are mounted on all the doublets.

The most difficult part of the machine to design and build has been the injection and extraction systems. It must be possible to inject and extract the beam at any energy, into the full acceptance of the ring, 3πm.mrad, for 8 different lattices. The system chosen to do this is a septum and 2 kickers, in adjacent cells. Each of these must fit into the 20cm "long" straight of a cell. Further, to avoid the beam passing through the magnets in the neighbouring cells, the injection angle is 65^{o} and the extraction angle is 70^{o}. Finally, the leakage field from the septum into the ring and after or fore-pulses of the kickers must be less than 1% outside the 55ns revolution time of the beam. The resulting injection septum and the 2 injection kickers are shown in figure 3. Note that these achieve all the requirements other than the leakage field of the septum and oscillations in the kicker fields after the 55ns fall time. It is believe that these problems can be dealt with in other ways.

Figure 3: The injection septum and kicker magnets mounted on the injection girder. Note that the top half of each ring magnet has been removed, as has the top flange of the septum box.

The final magnets mounted in the ring are vertical steering magnets for vertical orbit correction. Although these are small, as they only need to produce a small field, there is only space for 16 of them.

RF System

Rapid acceleration is obtained by placing accelerating cavities in every other cell around the EMMA ring, with two cavities omitted for injection and extraction of the electron beams. The RF system consists of 4 major sub-systems: a high power RF amplifier system, a RF distribution system, a low level RF (LLRF) control system and finally RF cavities that transfer energy to the beam. All 19 RF cavities are driven from the same RF source, with a complex distribution scheme providing equal power to each cavity. Synchronisation of the electron bunches to the RF cavity is also required to tight tolerances, to ensure that the accelerating field is present as the electron bunches pass each RF cavity.

The high power RF amplifier system consists of a high voltage power supply, a 1 kW solid state amplifier and an Inductive Output tube (IOT). This system will provide 90 kW of pulsed RF power at 1.3 GHz. The pulse length for the RF is 1.6 ms, with a pulse repetition frequency of up to 20 Hz required. Due to the R&D requirements for EMMA, a 5.5 MHz operational tuning range is specified.

The EMMA RF system is unique in that the 19 cavities are all fed from the same RF source distributed around a compact ring. A bespoke waveguide section that includes circulator, load, phase shifter, directional coupler and waveguide to coaxial transformer has been designed and built to achieve this.

As it is essential that the RF is synchronised with the beam in order to place the beam at the correct place in longitudinal phase space, a LLRF system is required to monitor signals from each cavity and provide the necessary phase or voltage adjustment to ensure the optimum RF settings are maintained. In order to maintain this stability during operation, feedback signals from the cavity fields are monitored in the LLRF system.

The ultimate performance on the accelerator will be the ability of the cavities to efficiently transfer energy to the beam. For EMMA, a normal conducting single cell re-entrant RF cavity design has been optimised for high shunt impedance, working within geometrical constraints of 40 mm beam aperture and 110mm flange to flange length availability. The custom in-house design shown in figure 4 meets the operation specification.

Figure 4: An EMMA RF cavity under test.

Diagnostics

As EMMA is a purely experimental machine, diagnostic devices are of great importance. They are located in the injection line, to measure beam parameters before EMMA, in the ring and destructive devices are mounted in an external diagnostics beam line. The injection line is instrumented with 4 beam position monitors (BPM), 6 motorised YAG screens, including 3 in a tomography section for measuring the beam emittance, a wall current monitor and a Faraday cup, onto which the beam can be directed. In the ring, there will be 2 BPMs per cell (see figure 5), except around the injection and extraction regions, where there is insufficient space for 1 device in each region. There will be 4 motorised YAG screens that can be moved into and out of the ring. These will be driven in from the outside of the ring and will have no support on the inner face. This will make it possible to move the screen so that it sees higher energy orbits, while the lower energy orbits will be undisturbed. There will also be a wall current monitor in the ring.

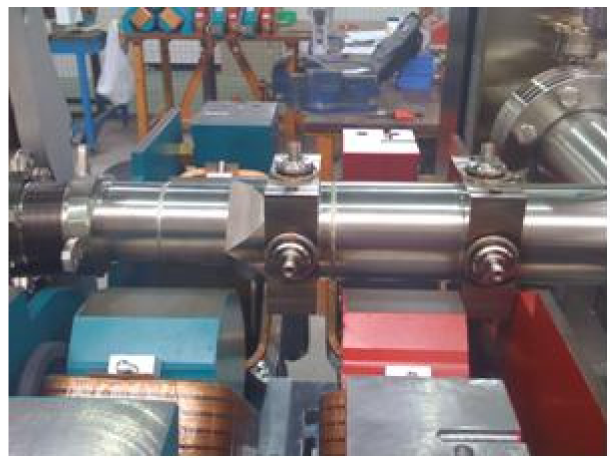

Figure 5: An external view of two 4-button BPMs. The top halves of the neighbouring ring magnets have been removed.

The diagnostics beam line will have 3 BPMs, 6 YAG screens, again with 3 in a beam emittance measuring section, a wall current monitor, an electro-optic monitor for measuring the longitudinal beam profile, a spectrometer for measuring momentum and a Faraday cup. The extraction system has been designed to enable extraction at any energy, so these measurements can be made at all energies.

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