AN EMMA RACETRACK

B.D. Muratori and J.K. Jones, ASTeC, Daresbury Laboratory (STFC) and Cockcroft Institute, UK
H.L. Owen, Manchester University and Cockcroft Institute, UK

Abstract

EMMA (Electron Machine for Many Applications) is the world′s first prototype non-scaling electron FFAG hosted at Daresbury Laboratory. Several upgrade possibilities for EMMA are explored, from creating a dispersion-free region in the ring to facilitate injection and extraction to making an insertion in EMMA by turning it into a racetrack-style machine. Alternative methods of injection and extraction into the EMMA ring are explored together with their feasibility and implications. The option of developing nested racetracks to achieve a particular desired energy is also explored.

INTRODUCTION

EMMA is the world′s first non-scaling FFAG and it has recently demonstrated acceleration [1]. Further experiments are still ongoing to determine and correct the closed orbit [2] as well as to examine the acceptance of the machine, both transversely and longitudinally [3]. In conjunction with these more detailed experiments, several EMMA upgrades are also under consideration. Some of these upgrades are of a short term nature, for example additional diagnostics [4], while others are in the medium or long term. One of the longest term upgrades, which still requires additional feasibility studies, consists of turning the EMMA ring into a racetrack with non-scaling FFAG-type arcs. Exactly how this is done is still to be determined and may involve minor modifications to EMMA as it is now or more substantial ones. For example and ideally the arcs, which are made by dividing EMMA into two semicircles, stay exactly of the same diameter as they are, are still based on a doublet configuration, and all the present EMMA magnets are re-used. On the other hand, it may be necessary to create a totally new machine with a different diameter and stronger magnets. In this paper, we explore the possibility of having a dedicated experiment to make dispersion-free straights in EMMA.

To this end, a solution based on the reversal of the polarity of the EMMA quadrupoles in every other cell is presented, based on roughly the same quadrupole strengths used at present, together with some energy acceptance studies. The initial modelling was done in MAD-X. The work is an extension of previous work done [5]. A rough model of the racetrack is also shown, together with the idea of building a sequence of nested racetracks. This involves many energies going down the same straight, together with a large acceptance chicane. Elementary feasibility studies of this large acceptance chicane are also given. If possible, such a system would allow for injection and extraction to and from ns-FFAG machines without the need for septa or kickers as is the present case with EMMA [6]. This would constitute a substantial step forward in the operation of ns-FFAGs as pulsed magnets introduce an additional level of complexity to the running of any ns-FFAG. It should be emphasized that, the modelling shown in the next section involves only the investigation of how the present EMMA lattice could be reconfigured to allow for dispersion-free straights, without any engineering changes to the magnetic components or positions, and represents only one of the possibilities investigated for the arcs of a racetrack based on EMMA. The main problem with this choice is the very small energy acceptance this new ring configuration has which implies an even smaller acceptance for the racetrack built using those arcs. However, the racetrack configuration suggested does not need to keep the arcs identical and another configuration was already suggested in [5] with the acceptance of roughly 10 (from 15 to 25 MeV). In fact, even keeping to the EMMA diameter is not a strict requirement and, most likely, better solutions exist with a larger radius or cell number.

MODELLING AND POSSIBLE EMMA EXPERIMENT

Below we show how, starting with the original EMMA cell as designed by Scott Berg [6], it is possible to achieve 21 dispersion-free straights by reversing the polarity of every other cell in the EMMA ring. The main properties of the initial EMMA cell design are shown in Figs. 1 which show beta functions, dispersion and orbit at 15 MeV.

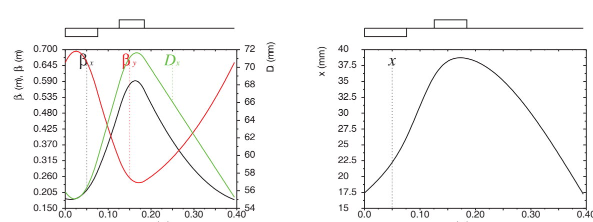

Figure 1: Beta functions, dispersion and orbit for a single EMMA cell for the baseline model at 15 MeV.

The polarity of both quadrupoles in every other EMMA cell can now be reversed and a new match found which should be dispersion-free in the centre. The modelling was done with MAD-X and treats the quadrupoles as combined function dipoles with a quadrupole component. As this model is known to give only an approximate solution in the case of ns-FFAGs, the model is repeated in GPT, particularly for looking at the energy acceptance of this new

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configuration. The model is based on three free parameters, two quadrupole strengths and the dipole component of one of the quadrupoles with respect to the other. The second dipole component is not available as this is fixed by the requirement that, two EMMA cells put together must bend the beam by $\pi/21$ radian. Nevertheless, several options result. Two of the new cells are shown in Fig. 2 below. The trade-offs of the solutions with minimum beam-size

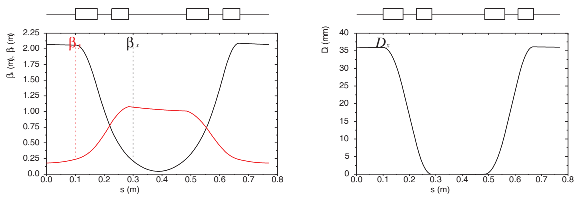

Figure 2: Beta functions and dispersion for two EMMA cells, one with reversed polarity and matching to a dispersion-free straight in the middle, at 15 MeV.

are summarized in Fig. 3 below.

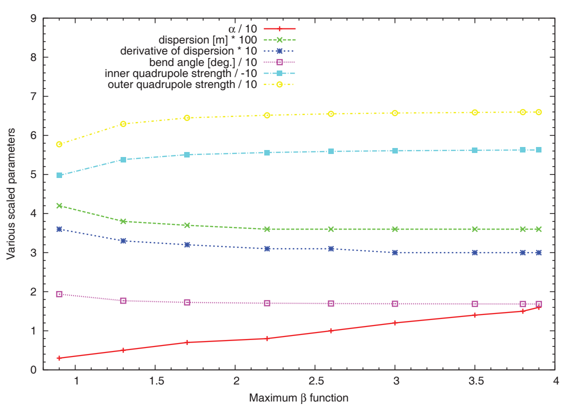

Figure 3: Trade-offs of the properties of the various lattices found as a function of maximum β function.

Unfortunately, none of the configurations discussed above can be applied to EMMA as they all require very substantial bending to take place in the quadrupoles. For the beam to be bent by the correct amount would require the quadrupoles to go very much off-axis and this cannot be done without engineering modification. The extent of the work required is still under investigation.

RACETRACK

A tentative layout of a racetrack based on ns-FFAGs with almost dispersion-free straights is shown in Fig. 4. It consists of two ns-FFAG arcs with an even number of cells, two straights and a large acceptance chicane which is used both for injection and extraction. How large the acceptance of the chicane is depends on the energies going through it. The injection takes place from inside the racetrack with an injector as shown in Fig. 4 in red. This injector can consist of a gun, thermionic, DC or RF followed by a linac to ensure the output energy is around 10 MeV. Various possible injectors are discussed in [7]. Transport from the exit of the injector to the chicane is done via a transport line and a dogleg whose last dipole is the same as the last one of the chicane. This ensures the beam reaches the first ns-FFAG arc dispersion-free. Unfortunately, such a set-up probably

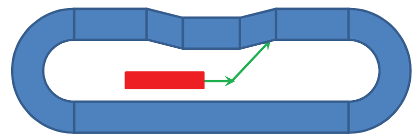

Figure 4: Racetrack based on two nsFFAG arcs and a large acceptance chicane (blue) with a standard injector (red).

means a smaller acceptance, this is inferred from the fact that, making a dispersion-free section and coming out or going in to an arc is, if anything, done at the expense of at least some of the acceptance as it represents a lack of symmetry.

After the first racetrack, it is possible to inject the beam into a subsequent, larger, racetrack of the same type as shown in Fig. 5. In this way, it should be possible to have a Russian doll set-up of what should be relatively cheap ns-FFAG rings with simple injection and extraction to and from each with the number of racetracks determined by the final energy one wishes to attain. Another clear benefit of such a set-up is that it can even operate in CW mode if required - something which, because of the outside injection and the septum and kickers, EMMA could never do.

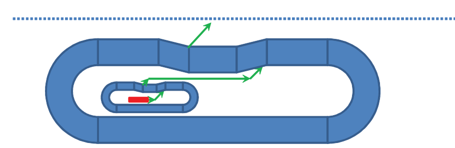

Figure 5: Nested sequence of racetracks based on two ns-FFAG arcs and a large acceptance chicanes (only first two shown).

INITIAL CHICANE CONSIDERATIONS

As well as the overall dimensions of the chicane and its individual dipoles, the R_{56} must also be taken into account as it would be preferable if the bunch did not gradually compress itself as this may introduce unwanted effects. However, operation of EMMA requires as small an energy spread as possible - this means that virtually no compression should occur. Further, this should remain so after successive turns because it is not possible for the energy spread caused by the ns-FFAG arcs to accumulate so as to produce a proper 'chirped' bunch which would be compressed. Nevertheless, the chicane should have an R_{56} as small as possible so as to attempt to limit any additional disruption to the bunch. The only contributions to R_{56} in a four dipole

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chicane come from the distance from the outer two dipoles to the central ones (L), the length of the dipoles (L_D) and the bend angle of the dipoles (θ) as shown in Fig. 6. Now, from a practical point of view, we want to make the bend angle of the dipoles as small as possible as this would ensure being able to have a large acceptance at a hopefully modest cost. Therefore, we can use the approximate expression for the R_{56} for small angle dipoles which is given by

$$R_{56} = -2\theta^2 (L + \frac{2}{3} L_D) \qquad (1)$$

We also would like to have a maximum separation of the

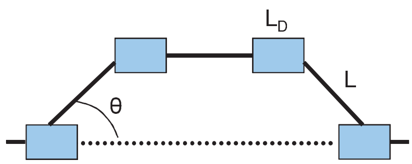

Figure 6: Standard four dipole chicane.

orbits (at least 2 cm) after the first dipole of the chicane so as to be able to extract the beam with ease. This separation is given by $r\theta$ where r represent the bend radius of the dipole plus some distance after it. Hence the requirements of the chicane, in order of importance for minimizing the R_{56}, are: dipoles be made with the smallest bend angle possible, shortest outer drift length L as shown in Fig. 6, shortest possible dipoles (L_D). To assist with the extraction, a further dipole, septum or system of dipoles is required to kick the beam outwards and towards the next racetrack. A detail of both injection and extraction is shown in Fig. 7 below.

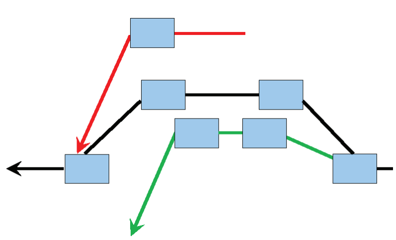

Figure 7: Injection (red) and Extraction (green) to and from the chicane, together with the circulating beam (black).

Note that it is not at all necessary for the racetrack to be oval in shape, there may be advantages in making it triangular or another polygonal shape.

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CONCLUSIONS

Several solutions for an EMMA layout with dispersion-free sections was presented. Unfortunately, it is unlikely that any of these solutions can be easily realised as all of them imply that the quadrupoles need to be considerably further off axis than is currently permissible with the movers.

A preliminary design of a racetrack style machine, with ns-FFAG arcs was also presented. Several aspects still need to be investigated, for example the chicane, but it is hoped that such a machine can be used in future as a better way to inject and extract from ns-FFAGs as this is currently one of the biggest challenges. Next steps include making the dispersion free sections isochronous as well. If this can be done, that would remove one of the main impediments towards accelerating non-relativistic particles in ns-FFAG machines. The ultimate goal being a ns-FFAG for non-relativistic particles, operating CW and with injection and extraction not relying on the use of pulsed magnets in any way.

The original idea was to use both new EMMA layout and the ALICE straights, whose arcs are almost identical in radius to those of EMMA [8], together. But, as was shown in this paper, such a solution would require major engineering modifications to be realised.

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