DISPERSION-FREE REGIONS AND INSERTIONS FOR EMMA

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Abstract

EMMA (Electron Machine with Many Applications) is a prototype non-scaling electron FFAG hosted at Daresbury Laboratory. The possibility of creating a dispersion-free region in the ring to facilitate injection and extraction is explored. A dispersion-free region may be created in two separate ways. The first is by using a layout of EMMA which is naturally dispersion-free at the start and end of each cell. This means that we can arrange for periodic dispersion-free sections in every cell or in-between cells. The second is achieved through the use of sextupoles, by going off-axis in these magnets one has essentially a quadrupolar force which can be used to match the dispersion to zero in a particular place and for a particular energy. The benefits and drawbacks of both methods are discussed from the point of view of practicality and space in general, and applicability to EMMA in particular.

INTRODUCTION

EMMA (Electron Machine with Many Applications) [1] has already shown great potential for use as a rapid acceleration accelerator [2] for use in a variety of scenarios. A dispersion free region is desirable from the point of view of injection and extraction into non-scaling FFAGs. Such a machine property would allow all injection/extraction elements to be located in identical positions for extraction at variable energies. In this paper we investigate the possibility of obtaining a zero-dispersion straight in a non-scaling FFAG, based on the EMMA lattice. We explicitly assume the same footprint as the existing machine, but with the allowance that magnet positions may vary. We take no account of existing vacuum chambers.

Non-scaling FFAG designs have been looked at by others [3] and are based on moving quadrupoles and changing their strength so that a dispersion free region can be created in a symmetric manner. Another possibility is to introduce sextupoles into the ring at locations of high dispersion and allow the beam to traverse these off axis - the sextupole thus acting as a quadrupole - and this can be used to match the dispersion to zero in a desired location for various energies at once. This possibility has some very serious drawbacks as will be shown. A third possibility, not explored here, would be to introduce a missing dipole, however this is not possible within the current EMMA footprint.

EMMA BASELINE

The EMMA baseline lattice can be modelled in MAD-X [4] in a way which keeps the quadrupoles on-axis but forces the resulting lattice to be periodic - this forces the modelled beam to go off-axis through the magnets. The difference in orbit is thus measured with respect to a reference orbit rather than the nominal zero-orbit of the model. The results of the model are shown in Figures 1 and 2 which display the beta functions and orbit respectively.

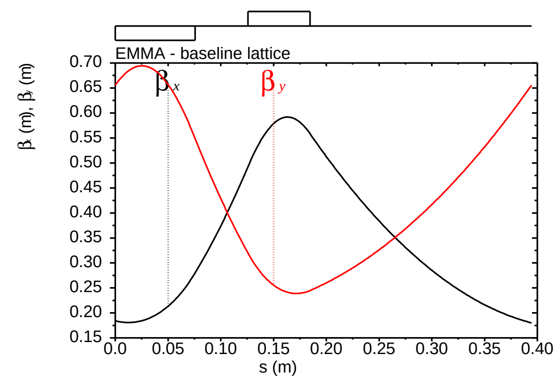

Figure 1: Beta functions for a single EMMA cell for the baseline model.

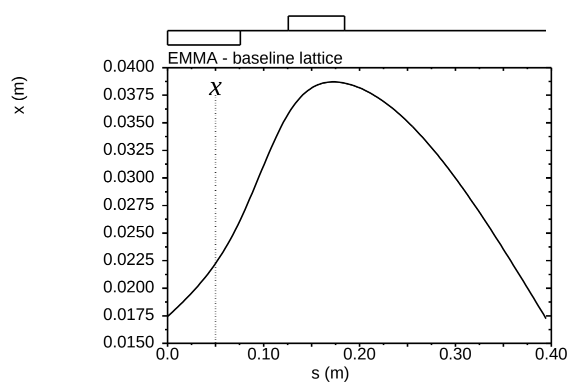

Figure 2: Orbit for a single EMMA cell for the baseline model.

ADVANTAGES

The advantages of a zero-dispersion straight within a rapid-acceleration machine such as EMMA are related directly to the difficulties in accommodating injection and extraction orbits for different energies. Commissioning experience on the EMMA machine has shown that the change in injection parameters with energy is very non-linear for a machine with large differences in the periodic orbit with energy (as is generally the case for ns-FFAGs). The same is also true for extraction, thus making changes to the extraction energy relatively difficult to accommodate without large changes to the extraction system. For any future ns-FFAG, it would be desirable to allow variable energy extraction to be as simple as possible. This becomes especially important for the use of ns-FFAG machines in medical applications - where rapid changes in the beam energy are required. Although a fully dispersion free extraction system, over the entire energy range of the machine, would be ideal, it is clear that the intended usage scenario for a ns-FFAG would involve injection at some nominal lower energy, and then extraction at a range of higher energies. Thus the system only necessarily needs to be dispersion free over a more limited range of energies than the total acceleration range of the machine. The change in orbit associated with the introduction of a dispersion free region may be induced by fast magnets within the ring. In this paper we will concentrate on generating a lattice with a zero-, or near-zero-dispersion at all energies.

QUADRUPOLE METHOD

By re-arranging the EMMA layout from a doublet to a triplet or quadruplet set-up, it is possible to create dispersion free sections at 15 MeV. In order to do this, it is necessary to reverse every other EMMA cell as shown in Figure 3 below, together with the beta function for two cells (back to back). Figure 4 shows the beta functions for the entire EMMA ring.

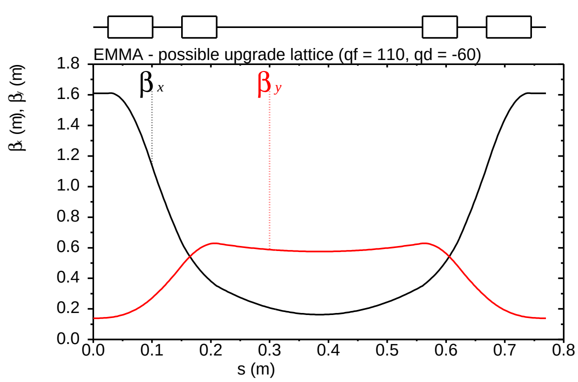

Figure 3: Beta functions when matching dispersion to zero in an EMMA straight at 15 MeV.

Figure 5 shows the dispersion and its derivative at the dispersion-free straight. Finally, Figure 6 show the orbit and angle at 15 MeV.

The dispersion is not matched exactly to zero at each energy and the increase is shown in Figure 7 below as a function of energy together with the orbit displacement in Figure 8. In principle, it is possible to extend the energy range to 35 MeV, however, this is unrealistic in terms of displacement of the existing EMMA quadrupoles.

Although the dispersion is not zero throughout the entire energy regime of EMMA, it is very close to zero around a

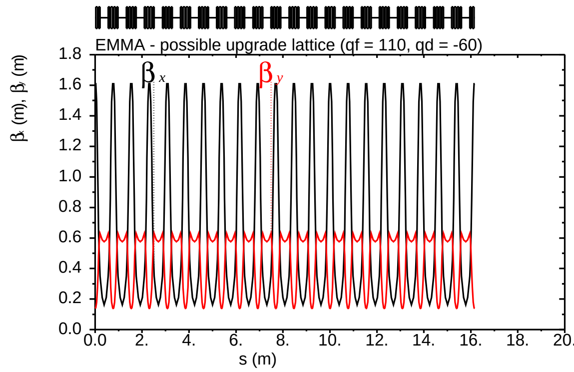

Figure 4: Beta functions when matching dispersion to zero in the EMMA ring at 15 MeV.

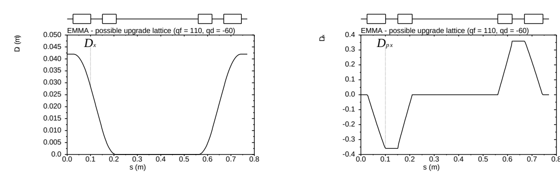

Figure 5: Dispersion and its derivative matched to zero in an EMMA straight at 15 MeV.

limited energy range. As noted, this is still beneficial for some usage scenarios of ns-FFAG machines. Variable extraction energy becomes only a function of the extraction timing, and no longer strictly of the position and angle of the extraction septum. As far as the application of this to EMMA is concerned, the distance of the short straight between the quadrupoles remains the same and the polarity of both is reversed with respect to the current layout but their strength specification may be conserved. Additionally, every other cell needs to be a mirror image of what it is now - how complicated this is is still under consideration.

SEXTUPOLE METHOD

By removing some of the EMMA cavities in the model so as to create additional space, it is possible to place a pair of sextupoles in a few chosen cells - as shown in the layout schematic at the top of Figure 9, along with the beta functions around the dispersion-free straight.

Figure 10 shows the dispersion and its derivative at the dispersion-free straight with the normal wave either side.

Unfortunately, the sextupole strength required for the model discussed above was found to be excessive. Further, many sextupoles were required to be able to match the dispersion at all - even now there is a blow-up of the beam around the dispersion-free straight. The biggest drawback, however, is that this works only at one energy meaning that the method is likely to have a very limited applicability. It also would interfere with acceleration as a match at one energy would become a mismatch at all other energies. The

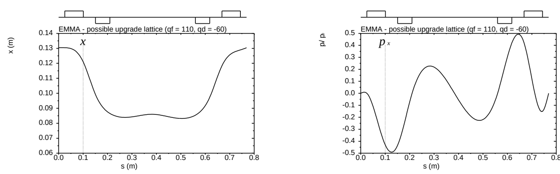

Figure 6: Orbit and angle when matching dispersion to zero in an EMMA straight at 15 MeV.

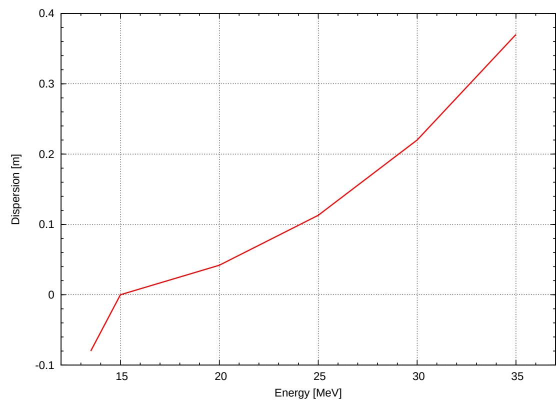

Figure 7: Dispersion versus energy in the dispersion-free straight.

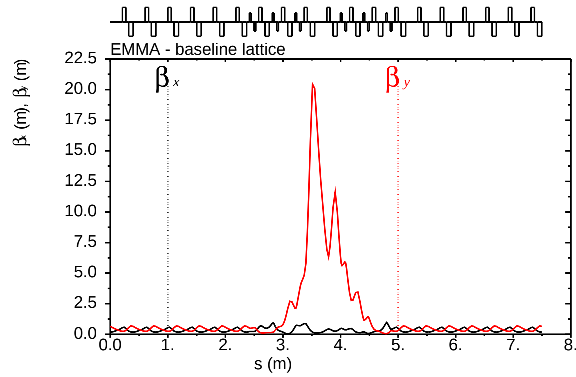

Figure 9: Beta functions with sextupoles used to match dispersion to zero in an EMMA straight.

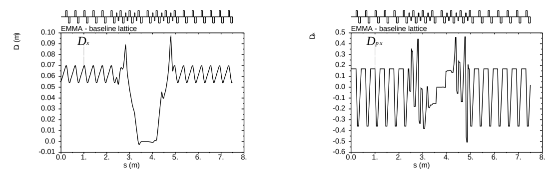

Figure 10: Dispersion and its derivative matched to zero in an EMMA straight.

method may nevertheless be found to be of use for a beamline which only contains a small number of energies and does not accelerate. The additional sextupoles would give a quadrupole correction only to substantially off-axis particles as could be the case in a NS-FFAG.

CONCLUSION / REMARKS

It was shown that a dispersion-free region is indeed possible and two ways of doing this were presented. The first is the most straightforward from an accelerator physics point of view but requires extensive changes to the present EMMA lattice to be implemented and is therefore less realistic from an engineering point of view. The second would keep the EMMA lattice as is and could be done with the removal of some cavities and the addition of sextupoles to match the dispersion to zero in the required sections. The only problem with the second method is that, for EMMA, the resulting sextupole strength is far too high and does not work at all energies. Therefore, the effect would be very disruptive during acceleration.

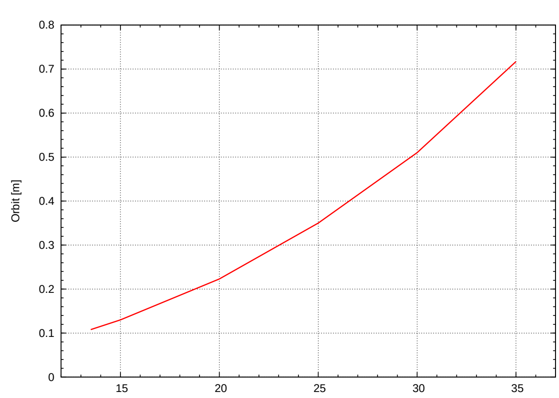

Figure 8: Orbit displacement vs. energy in the dispersion-free straight.

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[4] E. Keil (2010), private communication.