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MODELLING OF THE EMMA NS-FFAG INJECTION LINE USING GPT

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Abstract

EMMA (Electron Machine with Many Applications) is a prototype non-scaling Fixed Field Alternating Gradient (NS-FFAG) accelerator presently under construction at Daresbury Laboratory, UK. The energy recovery linac ALICE [1] will serve as an injector for EMMA within the energy range of 10 to 20 MeV. The injection line consists of a symmetric 30^o dogleg to extract the beam from ALICE, a matching section and a tomography section for transverse emittance measurements. This is followed by a transport section to the injection point of the EMMA ring. Commissioning of the EMMA injection line started in early 2010.

A number of different injection energy and bunch charge regimes are planned; for some of the regimes the effects of space-charge will be significant. It is therefore necessary to model the electron beam transport in this line using a code capable of both calculating the effect of, and compensating for, space-charge. Therefore the General Particle Tracer (GPT) code [2] has been used. A range of injection beam parameters have been modelled for comparison with experimental results.

INTRODUCTION

Commissioning of the injection line for EMMA (the world's first NS-FFAG) commenced in March of 2010. The energy recovery linac ALICE acts as the injector for EMMA, providing single bunches of electrons at an energy between 10 to 20 MeV with a maximum bunch charge of 32 pC. A schematic of the ALICE to EMMA injection line is shown in Fig. 1 which highlights some of the important diagnostic components of the beamline.

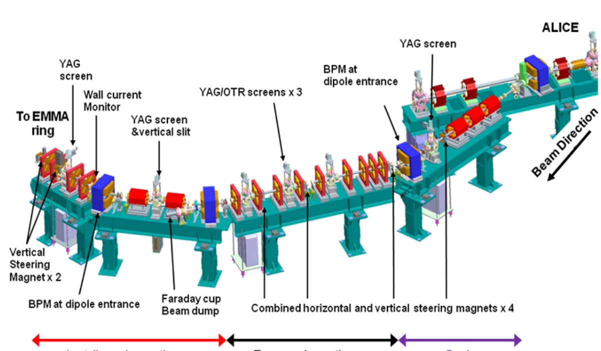

Figure 1: The ALICE to EMMA injection line.

Because the beam injected from ALICE into EMMA is at quite a low energy there may be significant space-charge emittance growth, depending on the input conditions. Therefore rigorous analysis of the effects of space-charge is necessary. Consequently the particle tracking software used must incorporate the ability to model the effects of space-charge; thus `GPT` was chosen. This paper is an account of the `GPT` modelling of the whole of the ALICE to EMMA injection line using and including the effect of space-charge, in the standard range of injection parameters.

ALICE TO EMMA INJECTION LINE

Modelling in `MAD` *and* `GPT`

`MAD` [3] (Methodical Accelerator Design) is an analytical program designed to model accelerators using a transfer matrix method and, as such, ignores space-charge. The initial modelling of the ALICE to EMMA injection line was conducted using `MAD`, with an example of the output produced in Fig. 2. This shows the beta functions obtained in both transverse planes, starting with the two quadrupoles in ALICE upstream of the first dipole of the injection line up to its end (including an approximation of the EMMA injection septum).

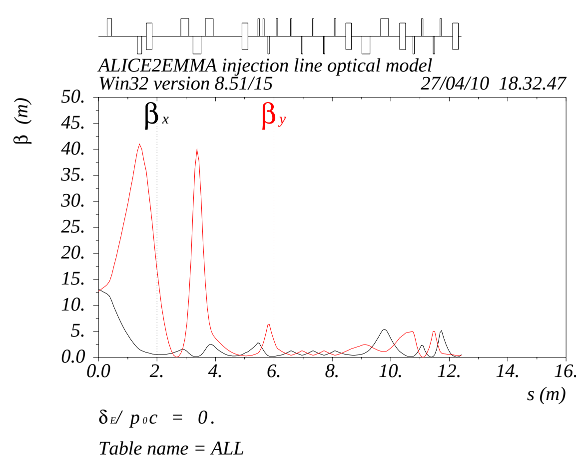

Figure 2: Beta functions, $\beta_{x,y}$, for the ALICE to EMMA injection line, as modelled by `MAD`.

This same stretch of beamline was then modelled in `GPT` for comparison with `MAD`, transporting a beam of 10 MeV (as well as a nominal bunch charge of 0 pC) with the

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same initial transverse beam parameters as was used for the MAD modelling. In addition the bunch was initiated with a uniform energy and finite length for ease of computation. The quadrupole gradients obtained from MAD were used as a starting point, and GPT tasked to re-optimise the four quadrupoles prior to the tomography section, subject to constraining the alpha and beta functions in both planes at the first screen of the tomography section to the values required for tomography. The constraint is placed at the start of the tomography section as any mismatch at this point would result in an increase in beam-size. The main source of the difference in the results from MAD and GPT (without space-charge) appears to be the amount of edge focussing in the horizontal plane due to the dipoles. The result of this matching is shown in Fig. 3.

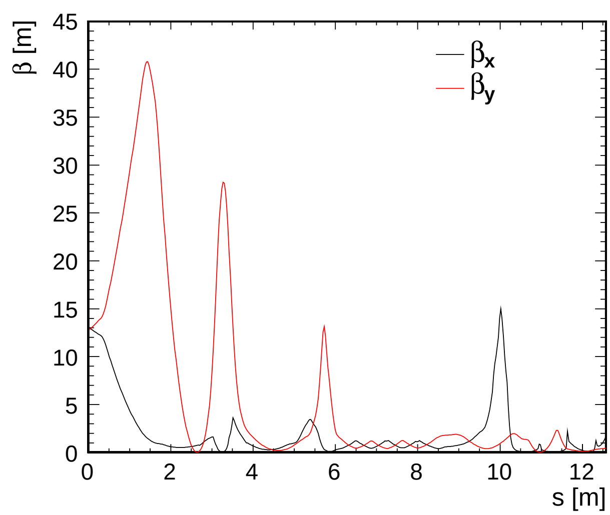

Figure 3: Beta functions, $\beta_{x,y}$, for the ALICE to EMMA injection line, as modelled by GPT.

The two plots are similar until after the end of the tomography section (at approximately $s = 9$ m) where further quadrupole gradient optimisation is required. This work is still in progress.

Space-charge in GPT

The quadrupole optimisation initially performed in GPT was for a bunch charge of 0 pC with the full 3D space-charge function enabled. Within a drift-length, space-charge is locally equivalent to a quadrupole field, defocusing in both the x and y planes. Thus space-charge directly affects the beam-size such that the transverse beam emittance evolves according to

$$\epsilon_x = \epsilon_{x0}\sqrt{1+\beta_{x0}^2\left[\left\langle\frac{1}{F_x^2}\right\rangle - \left\langle\frac{1}{F_x}\right\rangle^2\right]}, \qquad (1)$$

(for a Gaussian beam only) where ϵ_{x0} and β_{x0} are the initial emittance and beta function respectively, and F_x is the focal length of the bunch (with a similar expression for the vertical plane) [4]. Due to our interest in this beam blowup we will now consider the transverse beam-size as opposed to $\beta_{x,y}$. The transverse beam-size can be seen in Fig. 4, corresponding to the beta functions of Fig. 3.

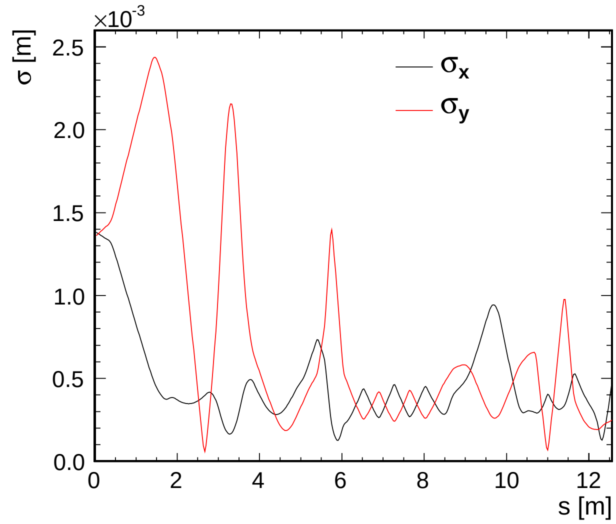

Figure 4: Beam-size, $\sigma_{x,y}$, for the ALICE to EMMA injection line, produced by GPT.

The results of Fig. 4 were then recalculated for three different bunch charges within the range that may be injected into EMMA from ALICE: 10, 20 and 30 pC. The effect of the inclusion of bunch charge can be seen in Fig. 5, where the transverse planes have been separated for clarity. The gradients of the matching quadrupoles have not been re-optimised for each bunch charge.

Again, the different bunch charge regimes are similar until just downstream of the tomography section, where for now we must ignore the results. This similarity will allow the desired beam-sizes to be achieved expediently during data taking through modest quadrupole strength adjustments.

Fig. 6 zooms into the σ_x plot of the tomography section from Fig. 5. This demonstrates the effect of space-charge on beam-size in more detail. One solution to this would be to rematch the line for each different injected bunch charge, such as in [5]. However, as the YAG screens (designed to analyse transverse emittance) are positioned at phase-advance intervals of $\pi/3$, where the beam-size values are equivalent, it may be possible to vary other beam parameters rather than rematching the quadrupoles for each different bunch charge.

In this analysis the beam is given a Gaussian one sigma bunch length of $\sim$ 4 ps, however a longer bunch length would reduce space-charge effects as the total charge of the bunch would be extended over a larger physical volume. Similarly the beam being propagated through the GPT beamline has an energy of 10 MeV - at the lower end of the

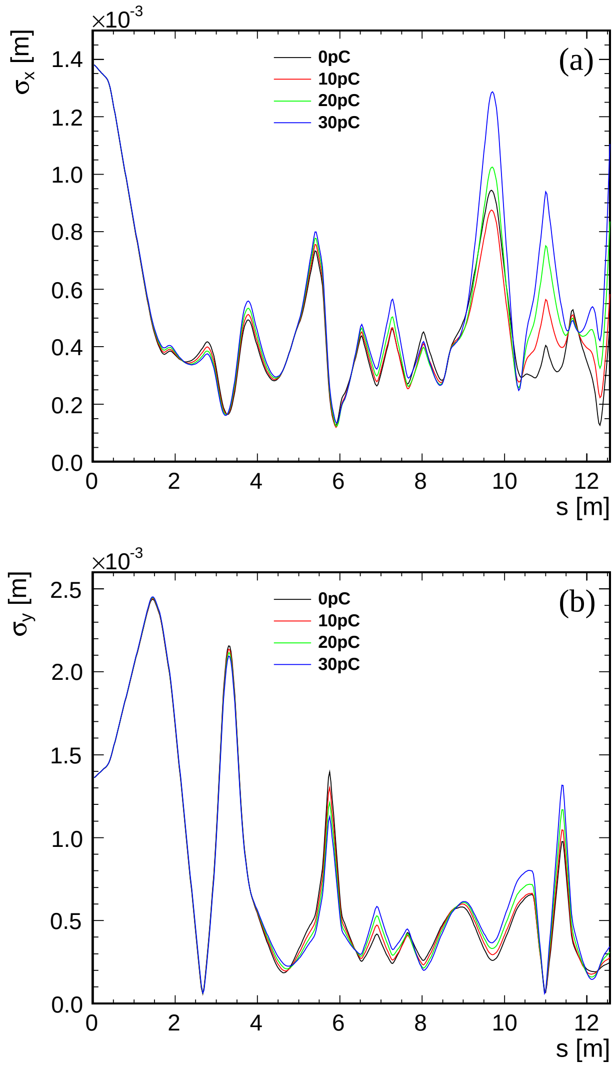

Figure 5: Beam-size in the a) x- and b) y- plane for the ALICE to EMMA injection line, detailing a range of bunch charges with a spread of 0 to 30 pC.

injection energy range - where the effects of space-charge will be more profound.

FUTURE WORK

Once the remainder of the ALICE to EMMA injection line has been successfully optimised in GPT , the next step is to repeat the analysis while varying other beam parameters such as bunch length, emittance, and energy. The impact of these parameters on the beam-size should indicate the necessity of rematching the quadrupole values for differing bunch charges.

Installation of the EMMA injection line is now complete. Initial data has already been taken with very preliminary results in [6]. In parallel to further collection and analysis of the data from the injection line, measurements in the EMMA ring will begin in the coming months, which will

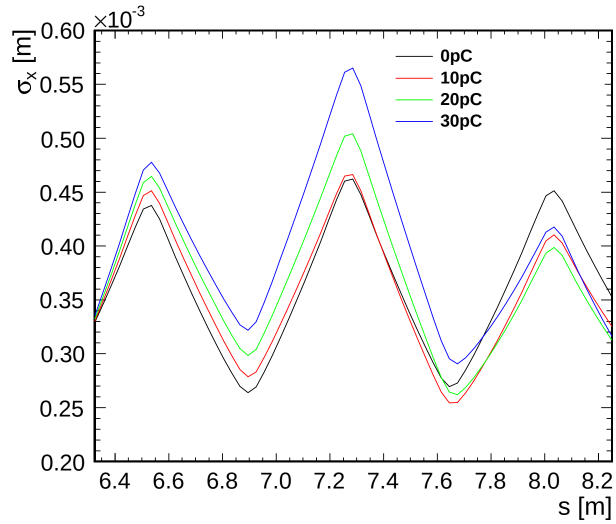

Figure 6: Beam-size in the x-plane, demonstrating the effect of a range of bunch charges on the tomography section of the ALICE to EMMA injection line.

then be compared to further GPT simulations.

CONCLUSIONS

The modelling of the entire ALICE to EMMA injection line in both MAD and GPT has been compared and the effect of space-charge on the beam-size at 10 MeV demonstrated. Further work, such as rematching the line in GPT to attempt to eliminate the effect of space-charge and also varying certain initial beam conditions, has been verified.

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