MODELLING THE ALICE ELECTRON BEAM PROPERTIES THROUGH THE EMMA INJECTION LINE TOMOGRAPHY SECTION*

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Abstract

EMMA (Electron Machine with Many Applications) is a prototype non-scaling electron FFAG currently under construction at Daresbury Laboratory. The energy recovery linac prototype ALICE will operate as its injector, at a reduced the energy of 10 to 20 MeV, compared to its nominal energy of 35 MeV. An injection line has been designed which consists of a dogleg to extract the beam from ALICE, a matching section, a tomography section and some additional dipoles and quadrupoles to transport and match the beam to the entrance of EMMA. This injection line serves both as a diagnostic to measure the properties of the beam being injected into EMMA and also a useful diagnostic tool for ALICE operation.

This paper details the simulations undertaken of the electron beam passing through the matching and tomography sections of the EMMA injection line, including the effect of space charge. This will be an issue in the energy range at which this diagnostic is being operated when combined with high bunch charge. A number of different scenarios have been modelled and an attempt made to compensate for the effects of space charge in the matching and tomography sections.

INTRODUCTION

Construction the world's first non-scaling, Fixed-Field Alternating Gradient (FFAG) accelerator called EMMA commenced this year [1]. ALICE will act as an injector for EMMA and the injection line includes a tomography diagnostic originally intended just to measure the properties of the beam required for EMMA, with a bunch charge and energy of (up to) 32 pC and 20 MeV respectively. Fig. 1 shows the layout of both ALICE and EMMA with the injection and extraction lines, the latter incorporating additional diagnostics. The design of the injection and extraction lines is detailed in [2].

Following this initial design, it was decided to upgrade this injection line to operate at the nominal ALICE operating energy of 35 MeV, so that the tomography section can be used diagnostic to measure the properties of the ALICE full-energy beam. Fortunately, conservative specification of the magnets has meant that the only change required to the hardware is the uprating of the magnet power supplies. However, ALICE has a nominal maximum bunch charge of 80 pC, and therefore the effect of spacecharge on the operation of the tomography diagnostic must be considered.

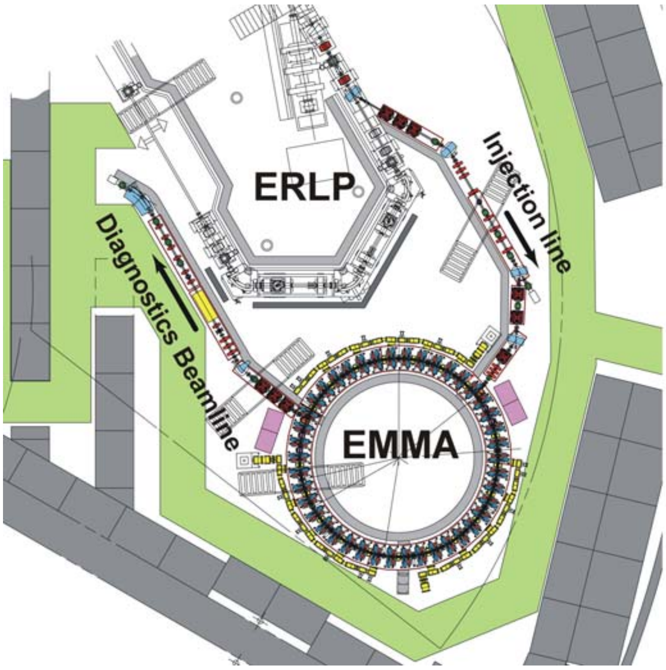

Figure 1: Layout of ALICE & EMMA.

DESIGN OF INJECTION LINE

The EMMA injection line consists of a symmetric 30° dogleg, the first dipole extracting the beam from ALICE and second dipole closing the dispersion with three intermediate quadrupoles. After the dogleg, a further four quadrupoles are used to match the beam into the tomography section. The tomography section consists of three screens with 60° of phase advance between them to allow for projected transverse emittance measurements.

Matching in MAD8

As before, the initial modelling of the ALICE to EMMA injection line was done with MAD8, the aim being to take the standard ALICE tuning (for a 8.35 MeV injector beam after the first superconducting module followed by further acceleration to 35 MeV by a second superconducting module) and match it into the tomography section design. The results are shown in Fig. 2 for the entire line with details of the tomography section shown in Fig. 3.

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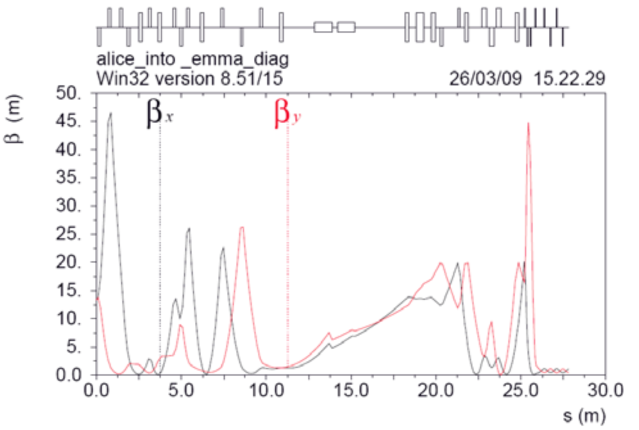

Figure 2: $\beta_{x,y}$ for the ALICE to EMMA injection line.

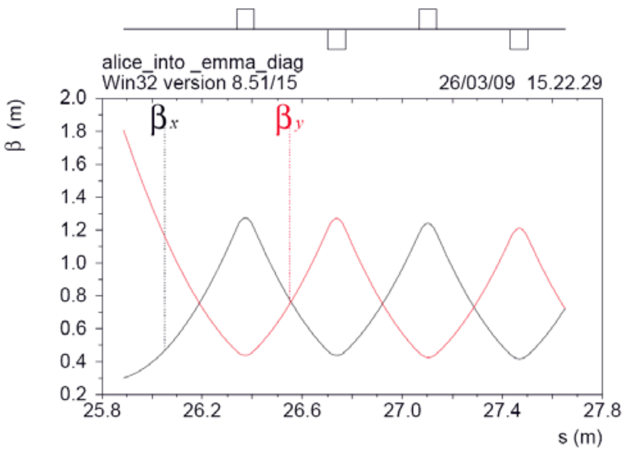

Figure 3: $\beta_{x,y}$ for the tomography section of the ALICE to EMMA injection line.

Matching in GPT

In order to take into account the defocusing effect of spacecharge on the beam after the second super-conducting module, GPT [3] was used to model the transport of the 35 MeV beam (with 80 pC bunch charge) from the exit of the module to the end of the tomography section. This proceeded in a number of steps:

- The line was rematched in the presence of spacecharge but with zero bunch charge, in order to provide a starting point for the reoptimisation (see Fig. 4);
- The effect of spacecharge on a beam of 80 pC bunches can be seen in Fig. 5, comparison with the previous figure shows the degree of mis-match induced by this bunch charge, even at 35 MeV;
- The beamline is now matched while progressively increasing the bunch charge from zero up to 80 pC, using as a starting point the quadrupole settings obtained at the previous (lower) bunch charge (see Fig. 6).

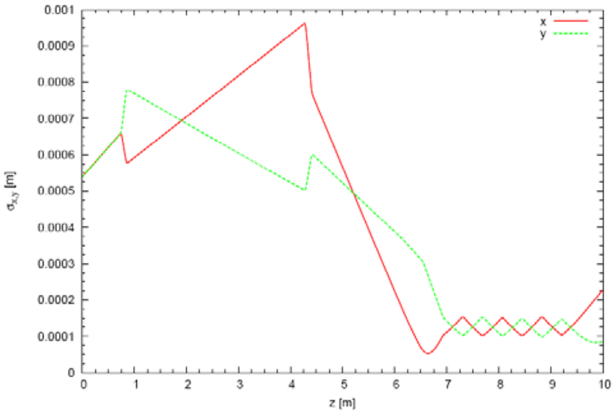

Figure 4: $\sigma_{x,y}$ for the tomography section of the ALICE to EMMA injection line from GPT at 35 MeV and 0 pC.

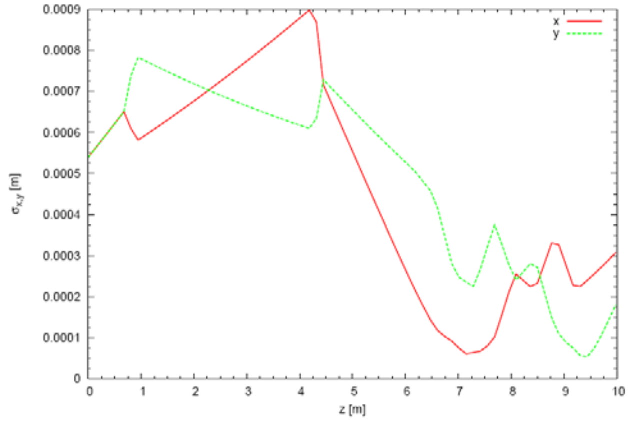

Figure 5: $\sigma_{x,y}$ for the tomography section of the ALICE to EMMA injection line from GPT at 35 MeV and 80 pC, with no correction for spacecharge.

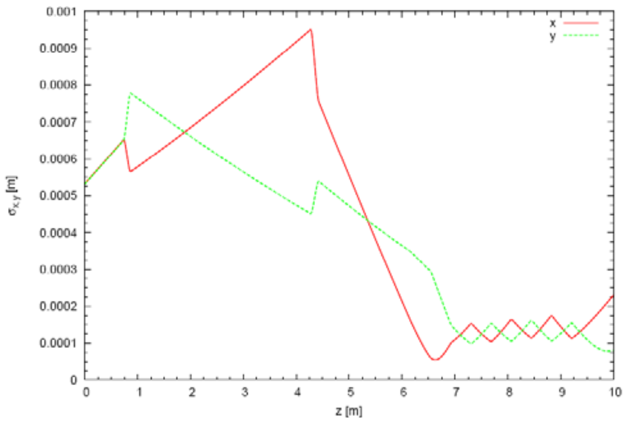

Figure 6: $\sigma_{x,y}$ for the tomography section of the ALICE to EMMA injection line from GPT at 35 MeV and 80 pC, following correction for spacecharge.

Table 1 shows the quadrupole strengths (k_1, m^{-2}) from the various steps in this optimisation.

Table 1: Quadrupole Strengths (k_1, m^{-2}).

Quadrupole	**MAD8**	**GPT (initial)**	**GPT (final)**
QUAD-01	14.48	14.48	14.48
QUAD-02	14.62	14.62	14.62
QUAD-03	14.48	14.48	14.48
QUAD-04	60.35	60.35	60.35
QUAD-05	44.90	44.90	44.90
QUAD-06	29.52	29.52	29.52
QUAD-07	132.43	132.43	132.43
QUAD-08	41.92	41.92	41.92
QUAD-09	41.92	41.92	41.92

Fig. 7 shows the strength of one of the quadrupoles in the matching section (QUAD-07) as a function of the bunch charge.

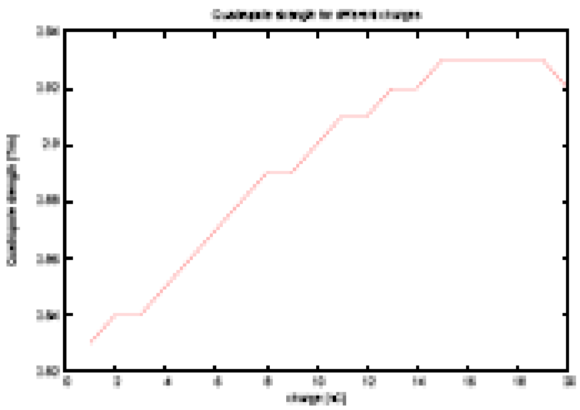

Figure 7: Strengths of one of the quadrupoles in the matching section QUAD-07 (k_1, m^{-2}) of the ALICE to EMMA injection line at 35 MeV and a range of bunch charges, after using GPT to re-match in the presence of spacecharge.

Operation at lower energy

If there is time I will repeat these results at a lower energy

CONCLUSION

The effect of spacecharge on the matching of a tomography diagnostic for ALICE at 35 MeV has been demonstrated, along with the use of the code GPT to re-calculate the matching and eliminate the effect of spacecharge almost entirely.

This will allow the injection line diagnostic, originally designed only to measure the properties of the beam as specified for EMMA injection, to be used at the higher energies and bunch charges of ALICE nominal operation.

REFERENCES

[1] S.L. Smith et al, “EMMA, the World's First Non-Scaling FFAG Accelerator”, this conference.

[2] B.D. Muratori, S.L. Smith, S.I. Tzenov, C. Johnstone, “Injection and Extraction for the EMMA NS-FFAG”, EPAC’08, Genoa, July 2008, http://www.jacow.org.

[3] GPT (General Particle Tracer), www.pulsar.nl/gpt/