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 of 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 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 and the addition of OTR screens in parallel with the original YAG screens. 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.

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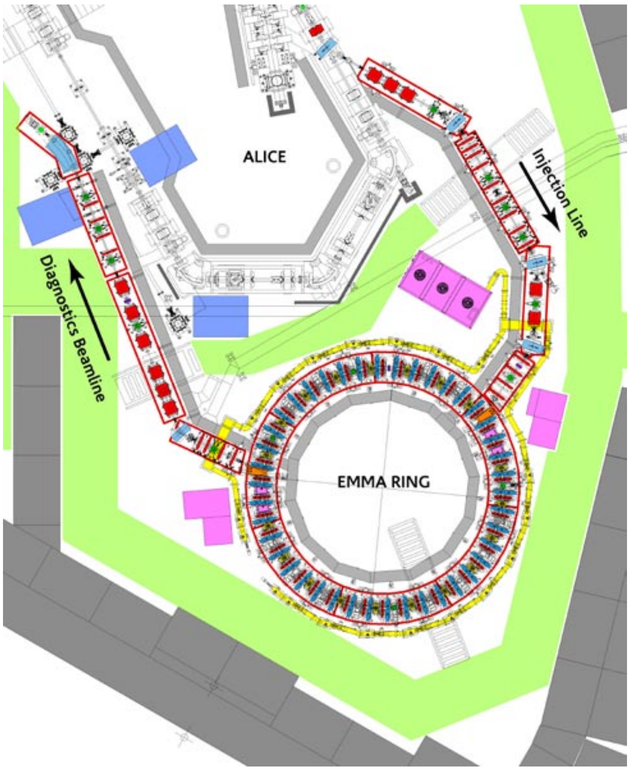

Figure 1: Layout of ALICE & EMMA.

DESIGN OF INJECTION LINE

The EMMA injection line (Fig. 2) consists of a symmetric 30° dogleg, the first dipole extracting the beam from ALICE and second dipole closing the dispersion with three intermediate quadrupoles.

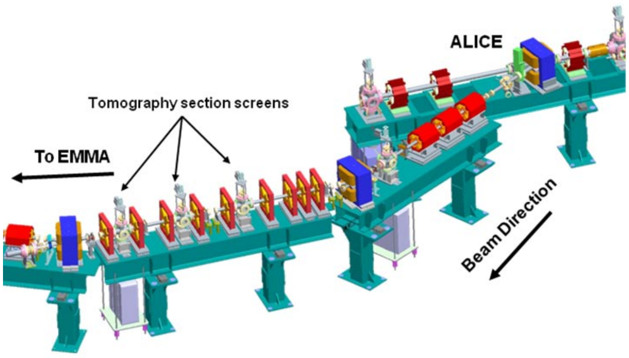

Figure 2: EMMA injection line.

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. Fig. 3 shows the beta functions obtained in both planes, starting at the exit of the first ALICE superconducting module up to the end of the tomography section, while Fig. 4 zooms in to the tomography section only.

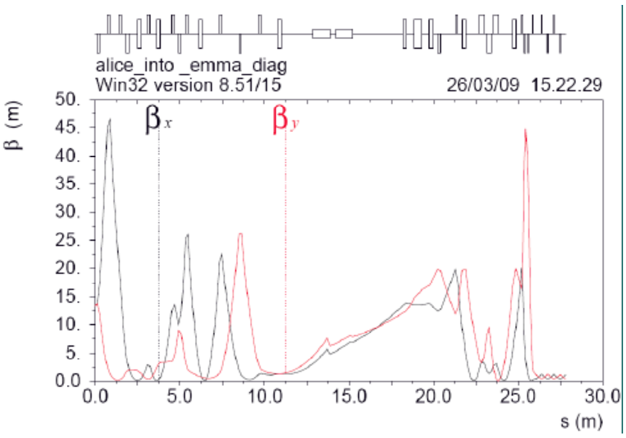

Figure 3: $\beta_{x,y}$ for the ALICE to EMMA injection line.

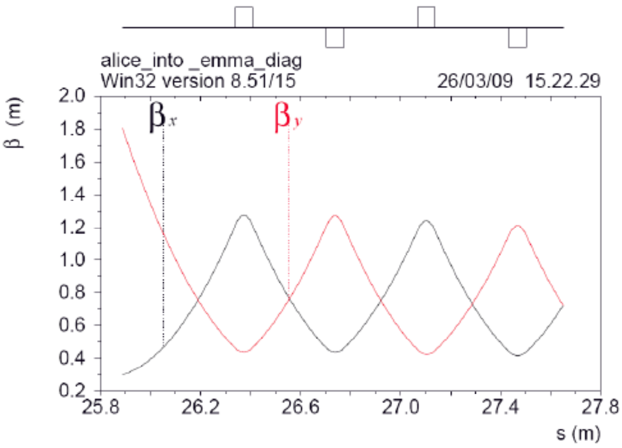

Figure 4: $\beta_{x,y}$ for the tomography section of the ALICE to EMMA injection line.

Matching in GPT

Previous studies [3] for the PITZ collaboration have shown that it is possible to eliminate almost entirely the mismatch induced by spacecharge in this situation by increasing the strength of the matching quadrupoles prior to the tomography section. In order to do this, GPT [4] was used to model the transport of the 35 MeV beam (with 80 pC bunch charge) from the exit of the second superconducting module, using the beam parameters at this point derived from the MAD modelling. The method followed is to repeat the matching 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. This technique is described in more detail here [5].

Initially the line was rematched in GPT using the full 3D spacecharge option but with zero bunch charge set, in order to provide a starting point (see Fig. 5). For the GPT optimiser to find a solution, it was necessary for the two quadrupoles in ALICE prior to the extraction dogleg to be as variables, as well as the four quadrupoles prior to the tomography section designated for matching. The constraints imposed were the values of the alpha and beta functions in both planes at the start of the tomography section. If the bunch charge is now increased to 80 pC, without any attempt to compensate for the effect of spacecharge, the result seen in Fig. 6 is obtained; comparison with the previous figure shows the degree of mismatch induced even at 35 MeV.

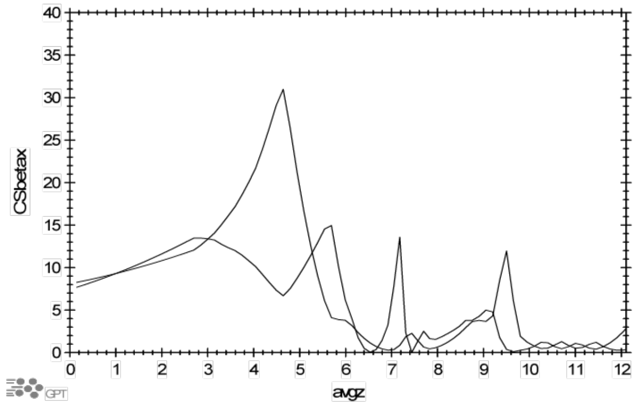

Figure 5: $\beta_{x,y}$ for the tomography section of the ALICE to EMMA injection line from GPT at 35 MeV and 0 pC. (Note that zero metres on this and subsequent plots correspond to s = 15.7 m on the MAD results)

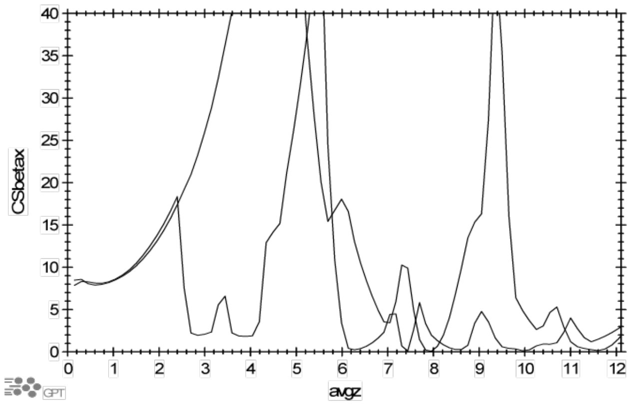

Figure 6: $\beta_{x,y}$ for the tomography section of the ALICE to EMMA injection line from GPT at 35 MeV and 80 pC, with no correction for spacecharge.

The optimisation was now repeated, at 1, 5, 10, 20, 40 and 80 pC, as described. Fig. 7 shows the beta functions at 80 pC after the effect of spacecharge has been reduced by progressively increasing the bunch charge and rematching at each step. The degree of agreement with Fig. 5 is very good; this suggests that the combination of 80 pC and 35 MeV is not too difficult for this technique.

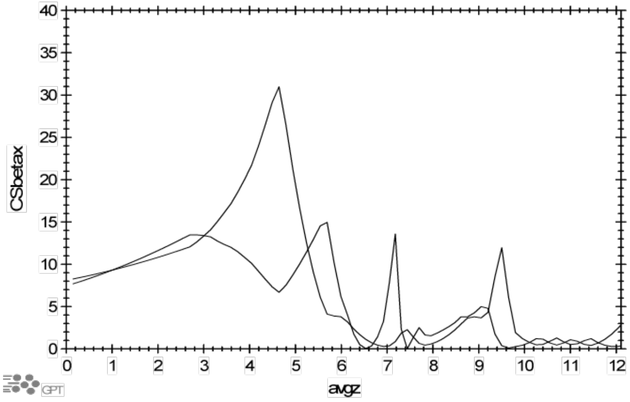

Figure 7: $\beta_{x,y}$ for the tomography section of the ALICE to EMMA injection line from GPT at 35 MeV and 80 pC, following correction for spacecharge.

The variation of the field gradient in ALICE ST1-QUAD-01 as a function of the bunch charge is shown in Fig. 8.

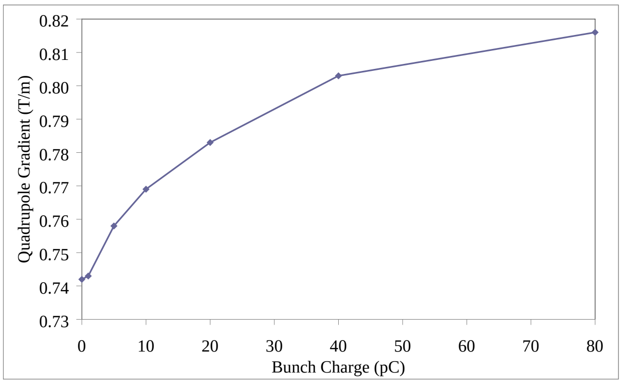

Figure 8: Gradient of quadrupole ALICE ST1-QUAD-01 (T/m) (in ALICE prior to the extraction dogleg) at 35 MeV and a range of bunch charges, after using GPT to re-match in the presence of spacecharge.

NEXT STEPS

Recent progress with ALICE commissioning has been made at a reduced beam energy of 20.8 MeV; the reasons for this are detailed here [6]. Clearly, the next step should be to repeat this work at this beam energy, where one would expect the effect of space charge to be greater. Similarly, although it is planned to inject a maximum bunch charge of 32 pC into EMMA, this will be in the range of 10 to 20 MeV only. Work is already underway to model the whole injection line in GPT, clearly the effect of spacecharge on the tomography diagnostic can be mitigated using this technique.

Installation of the EMMA injection line is currently underway. Once completed, measurements of the ALICE beam properties in the tomography section will be possible, probably later this year.

CONCLUSION

The conversion of the EMMA injection line into a useful diagnostic for measuring the properties of the full-energy ALICE beam has been described. In addition, a technique to counteract the effect of spacecharge on the matching of the electron beam into the tomography diagnostic 35 MeV with 80 pC bunches has been demonstrated. This involves using the code GPT to progressively re-calculate the matching as the bunch charge is increased. With this combination of energy and bunch charge it has been possible to apparently eliminate the effect of spacecharge almost entirely.

REFERENCES

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

[2] B.D. Muratori et al, "Injection and Extraction for the EMMA NS-FFAG", EPAC'08, Genoa, July 2008, http://www.jacow.org.

[3] B.D. Muratori et al, "Matching with Space Charge", EPAC'08, Genoa, July 2008, http://www.jacow.org.

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

[5] S.B. van der Geer et al, "Matching with Space Charge #2", this conference.

[6] S.L. Smith et al, "Progress on the Commissioning of ALICE, the Energy Recovery Linac-Based Light Source at Daresbury Laboratory", this conference.