INJECTION AND EXTRACTION FOR THE EMMA NS-FFAG

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Abstract

EMMA (Electron Machine with Many Applications) is a prototype non-scaling FFAG to be hosted at Daresbury Laboratory. NS-FFAGs related to EMMA have an unprecedented potential for medical accelerators for carbon and proton hadron therapy. It also represents a possible active element for an ADSR (Accelerator Driven Sub-critical reactor). This paper will summarize the design of the extraction and injection transfer lines of the NS-FFAG. In order to operate EMMA, the ALICE (Accelerators and Lasers In Combined Experiments) machine shall be used as an injector and the energy will range from 10 to 20 MeV. Because this would be the first non-scaling FFAG, it is important that as many of the bunch properties are studied as feasible, both at injection and extraction. To do this, a complex injection line was designed consisting of a dogleg to extract the beam from ALICE, a matching section, a tomography section and some additional dipoles and quadrupoles to transport the beam to the entrance of EMMA. Further, an equivalent tomography module was placed in the extraction line together with several other diagnostic devices including the possibility of using a transverse deflecting cavity.

INTRODUCTION

The ALICE accelerator is used as an injector to the EMMA ring. The energy delivered by this injector can vary from a 10 to 20 MeV single bunch train with a bunch charge of 16 to 32 pC at a rate of 1 to 20 Hz. ALICE is presently designed to deliver bunches which are around 4 ps and 8.35 MeV from the exit of the booster of its injector line. These are then accelerated to 10 or 20 MeV in the main ALICE linac after which they are sent to the EMMA injection line. The EMMA injection line ends with a 70° septum for injection into the EMMA ring itself followed by two kickers so as to direct the beam onto the correct, energy dependent, trajectory.

After circulation in the EMMA ring, the electron bunches are extracted using what is almost a mirror image of the injection set-up with two kickers followed by a 65° extraction septum. The beam is then transported to a diagnostic line whose purpose it is to analyse in as much detail as possible the effect the NS-FFAG has had on the bunch.

The paper is divided according to injection and extraction, going through each in some detail, but shall not mention the injection and extraction kickers and septa as these are covered in [1, 2].

INJECTION

The entire EMMA layout is shown in Fig. 1 together with all the diagnostics described below for both the injection and extraction lines. The EMMA injection line con-

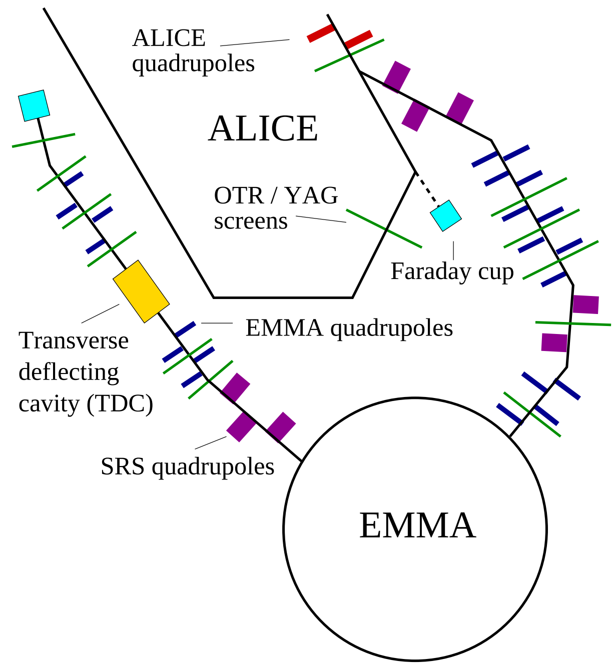

Figure 1: EMMA layout.

sists of a symmetric 30° dogleg whose first dipole extracts the beam from the ALICE accelerator and second dipole closes the dispersion with the help of three quadrupoles. It is possible to make energy, energy spread and bunch length measurements using either the first dogleg extraction dipole and the screen in the dogleg as shown, or with a similar set up, but going straight ahead and using the ALICE outward arc dipole and subsequent screen. Bunch charge is measured with the Faraday cup as shown in Fig. 1. After the dogleg, some quadrupoles are used to match the beam into a tomography section. This tomography section consists of three screens with 60 degrees of phase advance between them to allow for projected transverse emittance measurements. Further, this tomography section has the dual purpose of keeping the beam small at an early stage because of the very stringent requirements, in terms of Twiss parameters and dispersion, of the EMMA machine. Subsequently, the beam enters into a dispersive section consisting of two 30° dipoles and a septum, with six quadrupoles and two screens as shown in Fig. 1 (bending magnets not shown). At the first screen is also a vertical slit with which the measurement of energy and energy spread is done on the second screen. In the last leg of the dispersive section are also steerers, both vertical and horizontal and placed roughly $\pi/2$ phase advance apart in both planes, so as to be able to exactly centre the beam with the correct position and angle, at the entrance of the EMMA ring. The steerers also have the additional purpose giving an offset to the bunch when we wish to do phase space painting. Phase space painting consists in the exploration of the entire acceptance of the EMMA ring which should be based on a normalised emittance of 3 mm rad as opposed to the ALICE probe beam which has a 3 mm mrad emittance. Phase space painting in the vertical plane is done with the steerers whereas the horizontal one is done with the kickers inside the EMMA ring. Finally, in order to steer the beam appropriately beam position monitors are located at the entrance of all dipoles throughout the injection line.

The modelling of the ALICE to EMMA injection line was done with MAD8 and the results are summarized in Fig. 2 for the entire line with details shown in Fig. 3 for the tomography section and in Fig. 4 for the last dispersive straight before the EMMA ring. Not all the quadrupoles and dipoles were new and it was possible to re-use SRS ones where space was not restricted. Despite the fact that the requirements on the Twiss and dispersion parameters were very stringent, those achieved were remarkably close to those requested (to within $< 0.1\%$) in the model. However, because this is a new machine and there is a considerable degree of uncertainty, a large contingency was allowed for in the quadrupole strengths and these are therefore specified at 8.5 T/m.

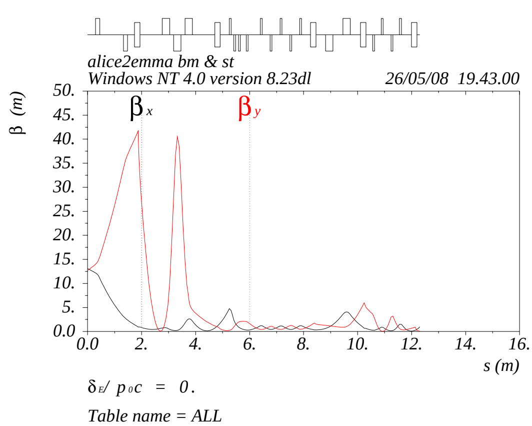

Figure 2: $\beta_{x,y}$ for the ALICE to EMMA injection line.

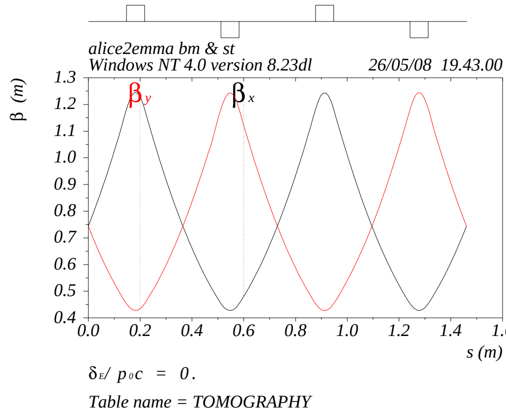

Figure 3: $\beta_{x,y}$ for the tomography section of the ALICE to EMMA injection line.

EXTRACTION

The extraction line from the EMMA ring consists of an extraction septum with the dispersion closed by some quadrupoles and an additional dipole forming an irregular dogleg set-up as shown in Fig. 1. This irregular dogleg shall also be equipped with steerers operating in both planes to aid with the extraction process. The extraction septum bends $65°$ and the subsequent dipole used to close the dispersion only by $10°$. This makes this line challenging due to the difference between the two bend angles. This still has to be investigated because the available settings so far give a beam size which is slightly too big and therefore more quadrupoles are likely to be required. As a result, only the following dispersion-free diagnostic straight shall be considered in this present paper.

As part of this irregular dogleg, there is a screen whose function it is to measure the energy, together with an additional screen in the following dispersion-free straight. In the straight following the dogleg are some matching quadrupoles to match the beam either directly into a tomography section or into a transverse deflecting cavity. The tomography section is identical to the one in the injection line. The idea is to be able to make direct comparisons with

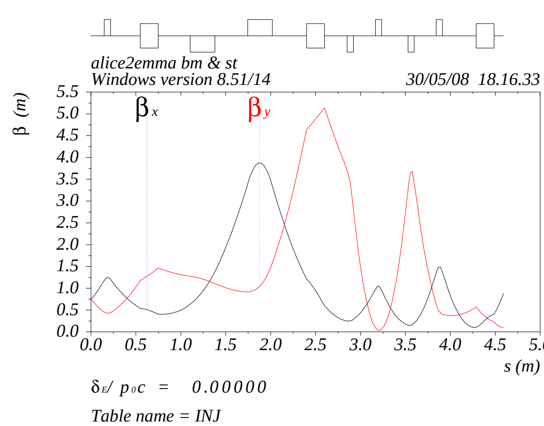

Figure 4: $\beta_{x,y}$ in the last dispersive section of the ALICE to EMMA injection line before entrance into the EMMA ring.

the measurements made earlier (projected transverse emittance), thereby quantifying the exact effect the non-scaling FFAG has had on the bunch. Further measurements can be done with the transverse deflecting cavity, such as bunch length and projected transverse slice emittance to try to see the profiles of the bunch as much as possible. After the tomography section there is a spectrometer dipole as shown. This allows us to measure the energy and energy spread of the beam in the usual way. Further, if we streak the bunch, with the deflecting cavity, at the same time then we are able to measure the slice energy spread of the beam as well. Between the tomography section and the spectrometer dipole, there will also be an EO section to measure bunch length and longitudinal profiles via electro-optic techniques. The matching for the later part of the extraction line is shown in Fig 5 where some reasonable initial assumptions were made about the Twiss parameters and the transverse deflecting cavity is not shown. In the first instance and de-

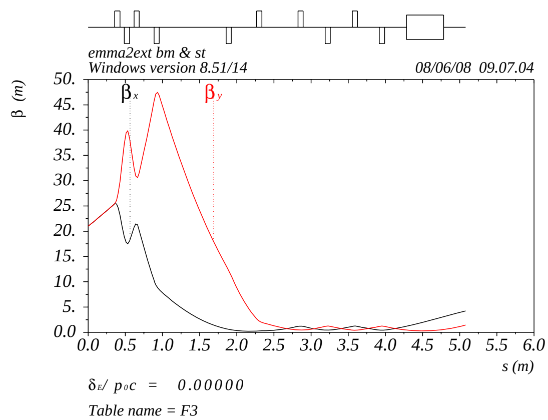

Figure 5: $\beta_{x,y}$ for EMMA extraction line.

pending on availability, a reduced version of the extraction line is also planned. This would be the same as that shown in Fig. 1 but reduced in length and without the tomography section or the transverse deflecting cavity. This is why an EO section is also planned as this would give some of the measurements planned with the deflecting cavity.

An updated version of all the proposed measurements, diagnostics and their location and number for the EMMA complex, from [3], is shown in Table 1 below, where the abreviations for transverse deflecting cavity (TDC) and resistive wall monitor (RWM) have been used as well as the more standard ones.

As a result of the phase space painting described earlier, it was found [4] that the beam decoheres and, instead of having a well defined probe beam, one ends up with a ring in the vertical or horizontal phase space. This makes extraction difficult and, as a result, it is proposed [5] to simply extract a portion of the beam. Therefore, collimation is required in order to have a known and well-defined transverse phase space area that can be measured and looked at.

Table 1: Diagnostics summary for the EMMA injection and extraction / diagnostic lines.

Measurement	Device	Number
Beam position	BPMs	2/plane/cell
		4 inj. & ext.
Beam profile	OTR / YAG	6 inj. & ext.
		1 in ring
	Wire scanner	4 in ring
Beam current	RWMs / F. cup	1 inj. & ext.
Transmission	RWMs / F. cup	1 inj. & ext.
Beam Loss	BLM	4 in ring
Momentum	BPMs &	82 in ring
	RWMs	1 in ring
Emittance	OTR / YAG	3 inj. & ext.
Slice emittance	TDC &	1 at ext.
	OTR / YAG	3 at ext.
Extracted momentum	Spectrometer	1 at ext.
Longitudinal Profile	TDC &	1 at ext.
	OTR / YAG	3 at ext.
Energy spread	Spectrometer	1 at ext.
Slice energy spread	TDC &	1 at ext.
	Spectrometer	1 at ext.

This could be achieved through a combined function OTR (or YAG) screen and collimator object so that the screen could be lowered when required and otherwise one would have the jaws of the collimators. This is possible because tomography is not required at the same time as painting and hence collimation.

CONCLUSIONS

A short description of the injection and extraction lines of the EMMA machine was given. Diagnostics for both were briefly described together with those of the EMMA ring itself. Some work remains to be done on the extraction line but, otherwise, the components are specified.

REFERENCES

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