MODELLING OF THE FETS MEBT LINE USING GPT

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Abstract

The Front End Test Stand project (FETS) currently under construction at Rutherford Appleton Laboratory (RAL) will accelerate a 60 mA, 2 ms, 50 pps H- beam up to 3 MeV. It consists of an H- ion source, a three-solenoid low energy beam transport line (LEBT), an RFQ and a medium energy beam transport line (MEBT) with a fast-slow beam chopping system. As part of the MEBT development, a GPT simulation model has been prepared. The aim is to analyse and understand the transport of intense beams and the beam behaviour in the space-charge dominated regime. The beam quality is then evaluated in terms of RMS emittance growth, beam loss, chopping efficiency and halo development. Results previously obtained with different simulation codes are discussed throughout the paper.

INTRODUCTION

The Front End Test Stand project (FETS) is a successful collaboration between RAL, several UK universities and international partners. It aims to demonstrate that high quality, low energy fast beam chopping is achievable, creating a test stand for studying various high intensity beam operating conditions.

FETS consists of an H- ion source producing a 65 keV, 60 mA, 2 ms, 50 pps beam, followed by a three-solenoid Low Energy Beam Transport Line (LEBT) which will transport and match the beam into a 324 MHz, 3 MeV RFQ. After the RFQ, a Medium Energy Beam Transport Line (MEBT) housing a two stage chopper with dedicated beam dumps, will match and transport the beam through a comprehensive set of diagnostics and into a target area [1].

MODEL DETAILS

An outline of the MEBT can be seen in Figure 1 with component details in Table 1. It consists of a series of quadrupoles, RF re-bunching cavities and the beam chopping system. Matching sections are added at the beginning and at the end of the line to control the beam at transition from the RFQ to the chopper line and into potential subsequent accelerating structures [2].

Table 1: Current MEBT parameters.

Element Type	No.	Length	Attributes
Quadrupoles	11	70 mm	G= 6 – 30 T/m
Buncher Cavities	4	200 mm	V = 50 – 150 kV
Fast Chopper	1	450 mm	V = ± 1.3 kV
Slow Chopper	1	450 mm	V = ± 1.5 kV
Beam Dumps	2	450 mm	P = 18 kW

The current MEBT optical scheme has been designed with the help of simulation tools like TraceWin (Partran), Parmila, and Trace3D [3]. To investigate further the ability of the MEBT to correctly handle space charge dominated beams, a new model has been created using GPT (The General Particle Tracer) [4]. The model allows not only beam dynamics simulations (multi-particle tracking, matching, beam chopper characterisation, etc.), but permits comparison and confirmation of previously obtained results. At the same time it opens the way for a full end to end LEBT-RFQ-MEBT integrated simulation of FETS.

For the simulation setup a hard edge quadrupole model has been used. Efforts are currently being put into designing a 2D/3D quadrupole model. Introducing quadrupole field maps will allow us to study the effects of fringe fields, higher harmonics, gradient in inhomogeneity, etc. [5]

Field maps from a Superfish [6] 2D model have been used for the re-bunching cavities. Different possible cavity types have been evaluated and a decision has been made to adopt a single gap pillbox type cavity with nose cones. The cavity is 20 cm long and can provide effective voltages of up to 160 kV. A cavity cross-section can be seen in Figure 2 as well as the field map on axis [7].

A 2D Superfish model has also been created for the chopper, as it can be seen in Figure 3. It consists of two 45 cm long parallel plates at fixed potential, separated by a 2 cm gap (see Table 1). The resulting electrostatic field is an approximation of the field created by the strip line structure used in the real chopper electrodes and as a result a field scaling factor had to be included.

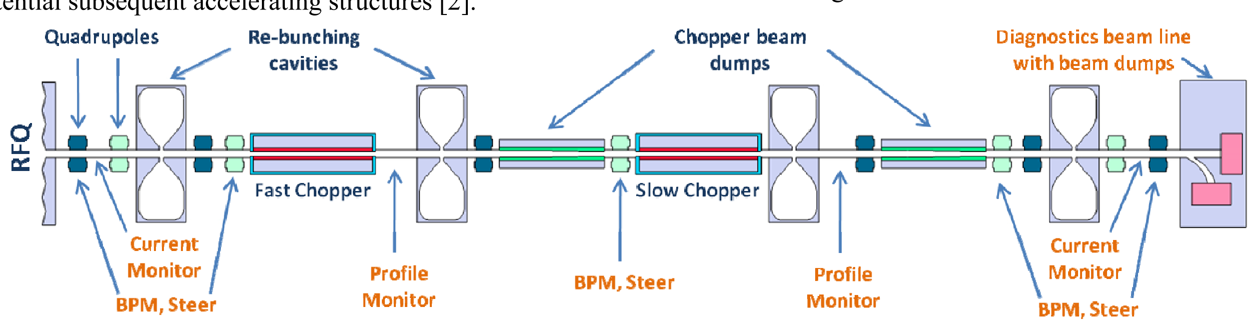

Figure 1: The Medium Energy Beam Transport Line (MEBT)

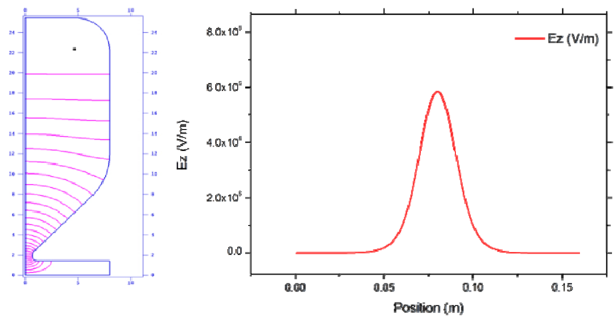

Figure 2: Cavity cross-section as modelled by Superfish and the resulting electric field map on axis.

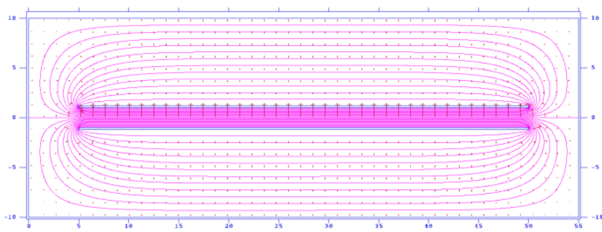

Figure 3: Superfish beam chopper model.

BEAM DYNAMICS RESULTS

Simulations have been initially performed with ideal beam distributions generated at the input of the MEBT. Although not very realistic, these cases allow the analysis of the emittance increase generated in the MEBT itself by eliminating any halo that might have been generated in the RFQ or the LEBT. More realistic simulations have been performed using different input particle distributions. For the results presented here, we have used a 4D waterbag distribution generated at the input of the RFQ and tracked through a full 4 m long 3D RFQ field map [8]. The RFQ output beam has the following parameters: ~8500 macro-particles, 60 mA beam current, 324 MHz bunch frequency, $\varepsilon_x \sim \varepsilon_y$ = 0.31 Pi.mm.mrad, $\varepsilon_z \sim$ 0.18 Pi.deg.MeV (RMS, Normalised).

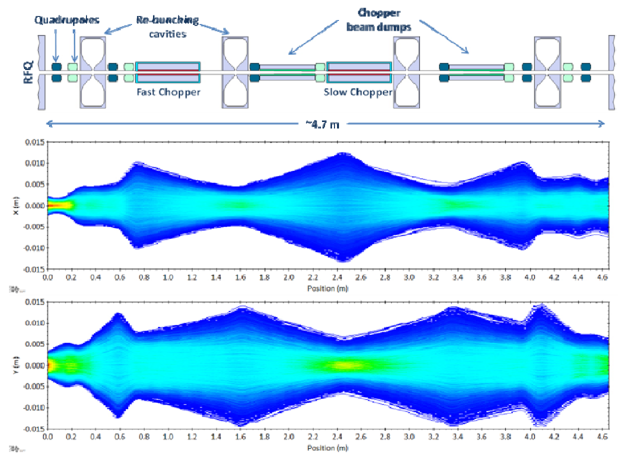

Figure 5: Characteristic particle trajectories through the MEBT line, with the beam choppers switched off (horizontal and vertical planes).

A typical beam trajectory through the MEBT can be seen in Figure 5 (transverse plane). The design limits the extent of the envelopes to ~20 mm in the transverse plane and ~90 degrees longitudinally. The MEBT output distribution can be seen in Figure 6.

As expected, a certain degree of beam loss has been observed when using the above mentioned distribution (~2.5%). Particles are mainly lost on the two chopper dumps with some additional beam scraping the chopper plates. A higher transmission is achievable by increasing the aperture at the beam dumps, although this would require a stronger chopper deflection and hence a higher electrode voltage. However, particle tracking indicates that the losses are mostly caused by the outer most particles hitting the beam dump. As a result, the small apertures have the added benefit of reducing the transverse beam halo. Halo formation is an important source of emittance growth and by intercepting it at this stage, losses further downstream can be controlled and limited to values that permit machine operation. The beam loss throughout the MEBT can be seen in Figure 7.

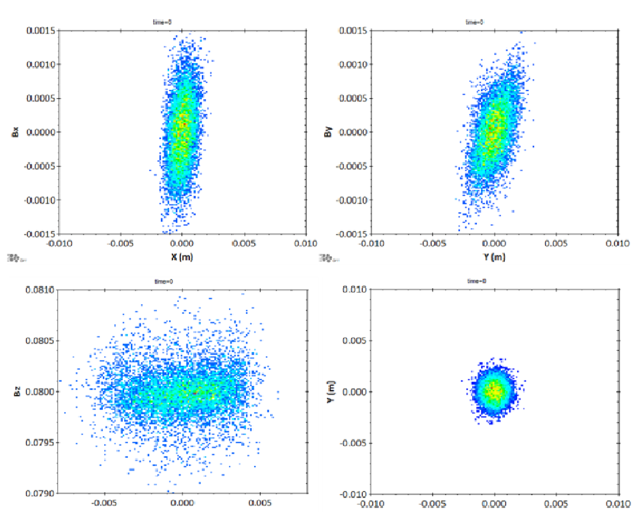

Figure 4: Input MEBT beam distribution: ε_t ~0.31 Pi.mm.mrad, ε_z~0.18 Pi.deg.MeV (RMS, Normalised).

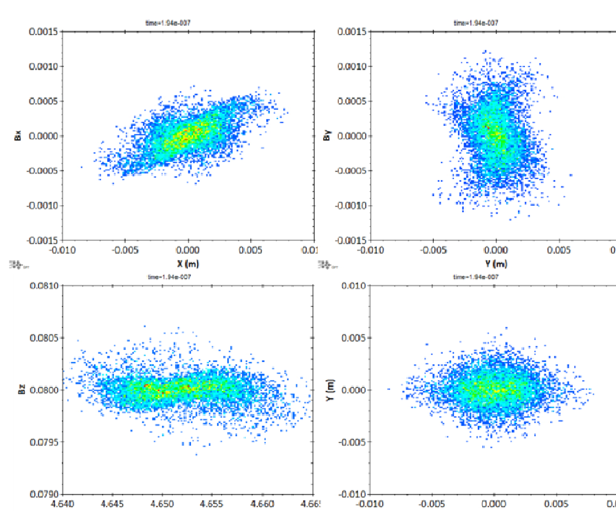

Figure 6: Output MEBT beam distribution: ε_t ~0.37 Pi.mm.mrad, ε_z~0.18 Pi.deg.MeV (RMS, Normalised).

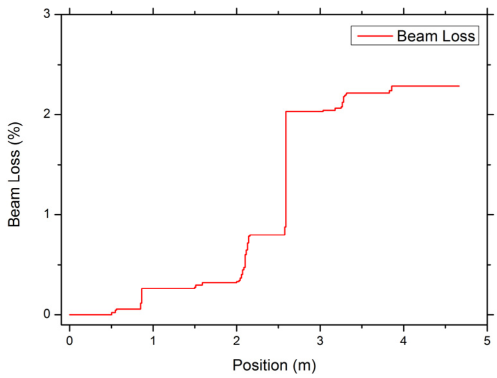

Figure 7: Particle Beam Loss in the MEBT.

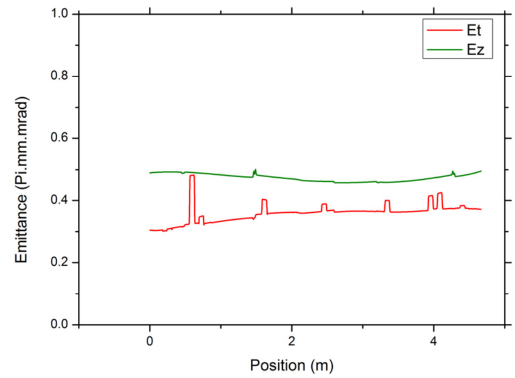

Figure 8: Emittance evolution in the MEBT.

The RMS emittance evolution can be seen in Figure 8. An increase of ~20% has been observed transversally, while there is almost no increase in the longitudinal plane (see Figure 6 for details). The growth is higher than previous simulations have indicated. We believe that this is caused by factors related to the input beam distribution. By employing a more realistic beam, the halo that has developed in the RFQ will continue to be tracked through the MEBT following an amplified oscillation.

Furthermore, the MEBT has been optimised for a lower input emittance (ε_t ~0.25 Pi.mm.mrad, ε_z ~0.14 Pi.deg.MeV - RMS, Normalised). The current MEBT input distribution (see Figure 4) has an RMS emittance more than 20% higher than the design value. This distribution reflects the latest beam emittances achieved in the FETS ion source and LEBT. Efforts are currently being put into reducing the ion source output emittances to lower values. Consequently, this will improve the beam transmission and quality throughout the LEBT, RFQ and MEBT. At the same time various MEBT configurations are being tested to improve the input emittance acceptance.

The chopper simulations have generally confirmed previously obtained results. In all simulations we have applied a ±1.5 kV voltage on the slow chopper electrodes and a ±1.3 kV on the fast chopper. When using ideal distributions, the separation between the 99% emittance ellipses of the deflected and undeflected beams is very clear for both the fast and slow choppers indicating a nearly perfect chopping.

When using a more realistic beam, some overlap between the halo particles is observed. The chopping efficiency is slightly reduced to ~99%. The main limit to increasing this efficiency is given by the voltage that can be applied on the chopper plates. However, as the available voltages are already approaching an upper limit, it is quite important to understand the behaviour of the residual chopped beam. We have discovered that a very small fraction of the deflected beam will survive to reach the end of the MEBT. This can be quite problematic especially if these particles are accelerated to higher energies. To mitigate this, collimators will have to be placed at key locations in the MEBT and linac [9].

CONCLUSIONS

A new model has been prepared to simulate the beam behaviour in the FETS MEBT line. It uses The General Particle Tracer to run particle dynamics simulations. The model uses inbuilt GPT elements as well as field maps generated with external EM simulation tools. It allows the characterisation of the MEBT performance and the beam quality in terms of emittance growth, beam halo, transmission and chopper efficiency. While the new model has confirmed many results previously obtained with other beam dynamics codes, it has highlighted possible issues in particular to do with emittance growth when using a more realistic beam distribution with higher input emittance.

The new model opens the way for a full start to end beam dynamics simulation study of the Front End Test Stand using a single simulation tool.

REFERENCES

[1] A. Letchford et al., “Status of the RAL Front End Test Stand”, Proc. of EPAC’08, Genoa, Italy.

[2] C. Plostinar, “MEBT Design for the RAL Front End Test Stand”, Proc. of IPAC’10, Kyoto, Japan.

[3] S. Nath, et al., “Comparison of Linac Simulation Codes”, Proc. of PAC’01, Chicago, IL, USA.

[4] The General Particle Tracer, www.pulsar.nl/gpt.

[5] M. Larrañaga et al., “Initial 2D Investigations into the Design and Parameters of an EM Quadrupole for FETS”, Proc. of IPAC’11, San Sebastian, Spain.

[6] Poisson Superfish, http://laacg1.lanl.gov.

[7] M. Larrañaga et al., “Design Optimisation of the Re-bunching Cavities for the Front End Test Stand at RAL”, Proc. of LINAC’10, Tsukuba, Japan.

[8] J. Jolly et al., “Integrated Design Method and Beam Dynamics Simulations for the FETS Radiofrequency Quadrupole”, Proc. of IPAC’10, Kyoto, Japan.

[9] C. Plostinar, E. Sargsyan, “Comparative Study of Beam Dynamics in Linac4 Using CERN and RAL MEBT Lines”, Proc. of PAC’07, Albuquerque, NM, USA.