MEBT DESIGN FOR THE RAL FRONT END TEST STAND

C. Plostinar, STFC/ASTeC, Rutherford Appleton Laboratory, UK

Abstract

The Medium Energy Beam Transport (MEBT) line for the Front End Test Stand (FETS) at Rutherford Appleton Laboratory (RAL) will transport a 60 mA, 2ms, 50 pps H^- beam at 3 MeV. It uses a number of quadrupoles, re-bunching cavities and a fast-slow chopping system. In this paper we present the underlying MEBT design philosophy, beam dynamics simulations and implementation details.

INTRUDUCTION

The Front End Test Stand currently under construction at RAL is the main R&D project in the UK focusing on high intensity, high power pulsed proton accelerators. Its development has been driven by the necessity to upgrade the aging ISIS Spallation Source as well as the requirement of a high intensity proton machine as the driver for the neutrino factory.

When completed, FETS will consist of an H^- ion source, a Low Energy Beam Transport Line (LEBT), an RFQ and a MEBT chopper line. The ion source will generate a 65 keV, 60 mA, 2ms, 50 pps H^- beam which will be focused and matched into an RFQ by a three-solenoid LEBT. The 4 m long, 324 MHz RFQ will bunch and accelerate the beam up to 3 MeV. The RFQ will be followed by the MEBT line which houses two choppers with dedicated beam dumps and it will transport the beam through a comprehensive set of diagnostics and into a dedicated target area, or matches the beam to the next accelerating structure [1].

MEBT DESIGN CONSIDERATIONS

One of the key components of FETS is the MEBT line. The design guidelines have taken into account the fact that this critical stage of acceleration defines the initial beam characteristics and dictates the operation and reliability of the downstream accelerators.

The main constraint comes from the requirement to minimize the emittance growth and halo development along the line. At 3 MeV, nonlinear space charge forces have a considerate impact and are the main source of emittance growth. In addition care has to be taken to other causes like coupling between the transverse and longitudinal planes and RF defocusing. To mitigate these effects, the lattice optics has to be regular and provide strong and uniform focusing both transversally and longitudinally [2], [3], [4].

On the other hand, the MEBT line has to provide sufficient space for the chopping elements. The choppers, however, are large devices and long drifts will have to be reserved in the MEBT line. At RAL, a "fast-slow" novel chopping scheme [5] will be employed consisting of two 45 cm long choppers with dedicated beam dumps. This requires ~60 cm long drift spaces for each chopper as well as for the beam dumps.

These two conflicting requirements (strong uniform focusing and long drifts without focusing elements), make the MEBT design particularly challenging and require breaking the periodicity of the line.

BEAM DYNAMICS

A layout of the MEBT line can be seen in Figure 1. It consists of a series of quadrupoles, RF re-bunching cavities, and the beam chopper system. Two sections have been added at the beginning and at the end of the line to match the beam from the RFQ and into the subsequent accelerating structures and to ensure a smooth phase advance variation at transition. A summary of the MEBT parameters can be seen in Table 1.

Table 1: MEBT parameters

Element type	No.	Length	Attributes
Quadrupoles	11	70 mm	G = 9-33 T/m
Buncher cavities	4	200 mm	V = 75-160 kV
Fast Chopper	1	450 mm	V = +/- 1.3 kV
Slow Chopper	1	450 mm	V = +/- 1.5 kV
Beam Dumps	2	450 mm	-

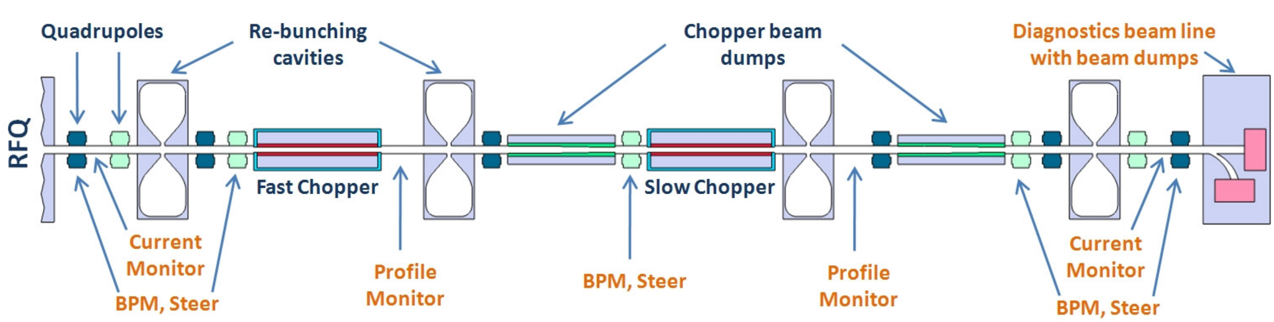

Figure 1: Schematic drawing of the FETS MEBT line with diagnostics (~4.5m long).

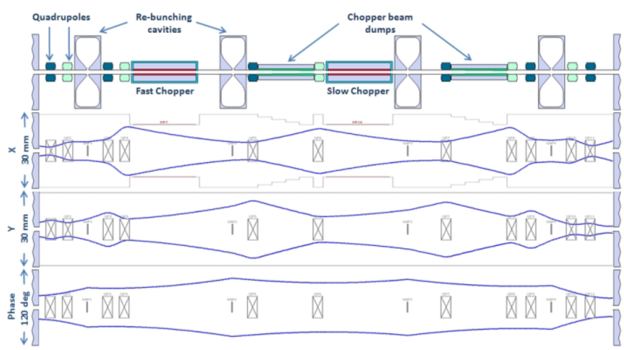

Figure 2: Beam envelopes in the MEBT line (transverse and longitudinal planes) with the beam choppers switched off (from TraceWin/Partran).

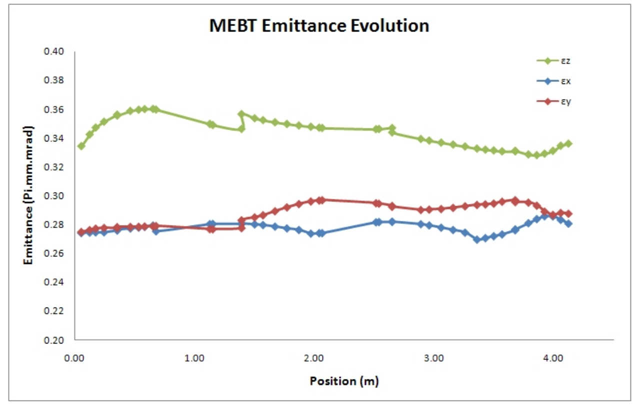

Figure 5: Longitudinal and transverse emittance evolution in the MEBT line (Normalised RMS).

The beam dynamics simulations (envelope calculations, matching, multi-particle tracking) were performed with TraceWin. The initial design has been done using a uniform distribution at the RFQ output (ideal case). Although this scenario is not realistic, it permits an analysis of the emittance increase and halo development generated in the MEBT itself by eliminating any halo or beam irregularities that might have been generated in the LEBT or the RFQ.

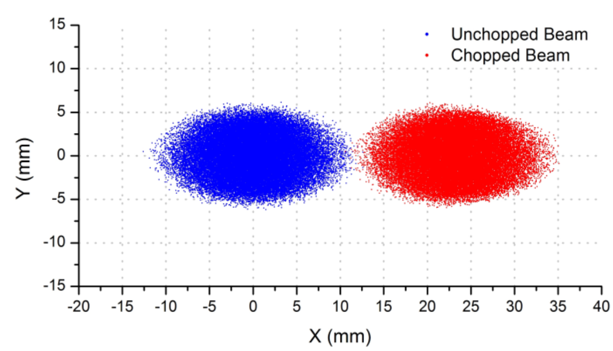

Figure 3: Chopped (red) and unchopped (blue) beam separation in the transverse plane at the end of the fast chopper beam dump.

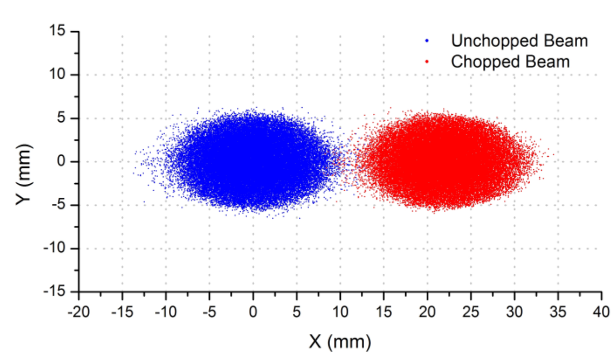

Figure 4: Chopped (red) and unchopped (blue) beam separation in the transverse plane at the end of the slow chopper beam dump.

A more realistic assessment of the MEBT line physics has been performed assuming 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 the RFQ. The MEBT input beam has the following parameters: 48000 particles, 60 mA beam current, 324 MHz bunch frequency, $\varepsilon_x = \varepsilon_y = 0.27$ π.mm.mrad, $\varepsilon_z = 0.12$ π.deg.MeV (Normalised RMS Emittance).

The beam envelope in the transverse plane and the phase spread in the longitudinal plane can be seen in Figure 2. The maximum extent of the envelopes is 18 mm in the transverse plane and 90 degrees longitudinally.

To estimate the chopping efficiency we have simulated the separation between the centres of the chopped and unchopped beams as well as the distance between the 100% emittance ellipses. For both choppers we have applied the maximum design voltage: +/- 1.3 kV on the fast chopper and +/- 1.5 kV for the slow chopper with a 20 mm gap between the plates. When using a uniform distribution the separation is very clear for both choppers. However, when running the simulation with the more realistic distribution described above, some overlap between the halo particles can be observed especially at the end of the slow chopper beam dump (Figure 4). This can be explained by the halo developed in the RFQ which continues to slowly follow an amplified oscillation throughout the MEBT line. The distance between the centres of the chopped and unchopped beams at the end of the fast chopper beam dump is 23.2 mm with a 4.5 mm separation between the 99% emittance ellipses (Figure 3). For the slow chopper the distance is 21.8 mm with a 2.6 mm gap between the 99% emittance ellipses.

The emittance evolution throughout the MEBT can be seen in Figure 5. As expected, some emittance increase can be observed (ε_x ~ 3%, ε_y ~ 5%, ε_z ~ 1%), however this is acceptable and comparable with similar MEBT designs at CERN and SNS [2], [3]. The transmission throughout the line is also within reasonable limits (~ 98.5%). Some particles are lost on the chopper beam dumps; however these losses can be reduced by increasing the aperture at the dump. For this, one would need a stronger deflection from the chopper plates, and hence a higher voltage which is already approaching an upper limit. Nevertheless, multi-particle simulations indicate that it is the outer most particles which are being lost, therefore beam dumps with an intentionally smaller aperture could provide the added beneficial effect of scraping the transverse halo, while easing the chopper requirements.

COMPONENTS

Beam Choppers

The chopper uses a configuration first developed for the ESS, and consists of a tandem combination of fast transition time, short duration and slower transition time, longer duration choppers (the 'fast-slow' beam choppers). The "fast-chopper" removes 3 adjacent bunches at the beginning and at the end of the chopping interval creating 2 gaps in the bunch train. These gaps will then be used by the second chopper field as a transition interval. This prevents bunches being partially chopped during the transition time of the second chopper [5]. The latest developments on the electrode designs and the high voltage pulse generator are presented in a separate paper [6].

Cavities

The re-bunching cavities maintain the longitudinal focussing as the beam proceeds through the chopper line. Four 324 MHz normal conducting cavities are required in the current MEBT configuration. A pill-box type design with nose-cones has been adopted derived from a Coupled Cavity Linac (CCL) cell. The cavity has been optimised for high shunt impedance while keeping its dimensions within the reserved beam line space. The maximum effective gap voltage is 160 kV, and the quality factor has a value of 26000 [7]. A cavity cold model is currently being constructed with Tekniker, Spain, as part of the FETS collaboration with ESS-Bilbao.

Quadrupoles

A hybrid quadrupole option is under investigation. The main aim is to address the requirement for a compact design, combined with a limited ability to adjust the field gradient. The hybrid quadrupole will be a concentric combination of PMQ and laminar conductor EMQ types (Lambertson quadrupole). Initial estimations indicate that the range of adjustment offered by the laminar EMQ is limited and alternatives are being investigated [8]. At the same time a standard EMQ design is being analysed.

Beam Dumps

A dedicated beam stop is currently being designed. At 10% duty cycle it is expected to dissipate a beam power in the 18 kW range. Pure Aluminium is the preferred material due to its excellent radiation performance, although its poor mechanical properties make the design more challenging from an engineering point of view [9]. If proven successful, a similar solution could be adopted for the chopper beam dumps.

Diagnostics

A movable diagnostics bench is foreseen for the commissioning stage of the MEBT. It will measure the beam profile, beam position, emittance and halo (transverse plane), as well as transmission, average beam energy, energy spread , bunch shape profile and chopping efficiency (longitudinal plane). In addition a permanent comprehensive set of diagnostics is envisaged for the entire line (Figure 1). It includes beam position monitors, current monitors, steering and profile monitors. A laser-based non-destructive emittance measurement instrument will be located at the end of the MEBT [10].

CONCLUSIONS

The MEBT work is progressing well. Beam dynamics simulations indicate that the line can match and transport a beam from the RFQ, through the chopping structure and into a downstream accelerator. The chopping efficiency is above 99% and losses are minimal. The MEBT components are currently being designed and prototyped. The following steps will include a detailed engineering analysis of the physics design.

REFERENCES

[1] A. Letchford et al., "Status of the RAL Front End Test Stand", Proc. of EPAC'08, Genoa, Italy
[2] A. Lombardi et al., "Study of the 3 MeV chopper line for the SPL", AB-Note-2003-038 ABP.
[3] J. Staples et al., "Design of the SNS MEBT", Proc. of LINAC'2000, Monterey, CA, USA.
[4] C. Plostinar, "Front end MEBT studies for a high power proton accelerator", Proc. of PAC'09, Vancouver, BC, Canada.
[5] M Clarke-Gayther, "Fast-Slow' beam chopping for next generation high power proton drivers", Proc. of PAC'05, Knoxville, TN, USA.
[6] M. Clarke-Gayther, "The Development of a Fast Beam Chopper for Next Generation High Power Proton Drivers", Proc. of IPAC'10, Kyoto, Japan.
[7] C. Plostinar et al., "Design progress of the re-bunching RF cavities and hybrid quadrupoles ofr the RAL Front End Test Stand (FETS)", Proc. of PAC'06, Edinburgh, Scotland.
[8] C. Plostinar et al., "A hybrid quadrupole design for the RAL Front End Test Stand (FETS)", Proc. of EPAC'08, Genoa, Italy.
[9] R. Emparantza et al., "Beam Stop Design and Construction for the Front End Test Stand at ISIS", Proc. of IPAC'10, Kyoto, Japan.
[10] C. Gabor et al., "Design report of a non-destructive emittance instrument for Rutherford Appleton Laboratory's Front End Test Stand FETS", Proc. of DIPAC'09, Basel, Switzerland.