FRONT END MEBT STUDIES FOR A HIGH POWER PROTON ACCELERATOR

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Abstract

Future projects like a neutrino factory or an advanced spallation neutron source require high power proton accelerators capable of producing beams in the multi-MW range. The quality of the beam delivered to the target is very much dictated by the accelerator front end and by the lower energy linac. Prompted by the Front End Test Stand (FETS) under construction at Rutherford Appleton Laboratory (RAL), a new 800 MeV H^- linac is being considered as part of a possible MW upgrade for ISIS. Preliminary simulations of high intensity beam dynamics and beam transport in the new linac suggest that a re-evaluation of the front end Medium Energy Beam Transport (MEBT) line is necessary. In this paper different optical designs for the 3 MeV MEBT line are presented and their impact on the subsequent Drift Tube Linac (DTL) section is being analysed.

INTRODUCTION

At Rutherford Appleton Laboratory, the development of the next generation High Power Proton Accelerators (HPPAs) capable of producing beams in the multi MW-range, is driven by two main factors:

- The requirement of a high intensity proton machine as the driver for the neutrino factory. Several design options are under consideration, all consisting of a ~200 MeV H^- linac followed by a series of synchrotrons or FFAGs to accelerate the beam up to an energy between 5 – 15 GeV and a beam power up to 5 MW.
- The necessity to upgrade the aging ISIS Spallation Neutron Source. One scenario is to develop a new 800 MeV, 30 Hz, H^- linac which will inject into a 3.2 GeV ring, increasing the current ISIS beam power of ~0.2 MW to 2 MW.

The low energy linear accelerator is the first critical stage of any HPPA, as it defines the initial beam characteristics and dictates the operation and reliability of the downstream accelerators. For the two projects mentioned above, the basic linac layout consists of an ion source, a low energy beam transport line (LEBT), a 3 MeV, 324 MHz Radio Frequency Quadrupole (RFQ) and a MEBT chopper line followed by a Drift Tube Linac (DTL) and other RF accelerating structures which will take the beam up to the desired energy. The front end of the linac is now being built at RAL as part of the Front End Test Stand (FETS) R&D project [1].

Numerical simulations recently performed for the ISIS upgrade linac, indicate that the MEBT line is a particularly problematic segment of the low energy linac and its design requires special attention.

MEBT DESIGN CONSIDERATIONS

The beam energy in the MEBT is sufficiently low for the space charge forces to have a considerable impact on the beam dynamics. In order to control the emittance growth, the lattice optics has to be regular and provide strong focussing [2]. Transversally, the requirement is for regular betatron oscillations amplitudes as equal as possible in both planes. For a typical FODO cell, this is equivalent to having a zero current phase advance below 90° and it's achieved by choosing the right quadrupole gradients. A strong and uniform longitudinal focusing is also imposed, this being accomplished by adjusting the voltages in the re-bunching cavities [3].

On the other hand, in order to minimise beam losses and induced radioactivity at injection into downstream circular accelerators, beam chopping at low energy is required. At RAL, a "fast-slow" novel chopping scheme [4] will be employed creating the required gaps in the bunch train. The choppers, however, are large devices and long drift spaces will have to be reserved in the MEBT line.

The MEBT design is especially challenging as it has to take into account the two conflicting requirements mentioned above: uniform focusing and long drift spaces without focusing elements, reserved for choppers and beam dumps.

A typical MEBT layout can be divided in three sections:

The Front Section

The front part of the MEBT matches the beam from the RFQ into the first chopper section by slowing down the phase advance and ensuring a smooth transition from the strong focusing provided by the RFQ. This is being done by using a combination of focusing elements (quadrupoles, solenoids and re-bunching cavities).

The Central Section

The central part of the MEBT comprises the fast and the slow choppers with their respective beam dumps as well as additional beam focusing elements. Each chopper is ~50 cm long, and the long drift spaces in the beam line as well as the now irregular lattice are largely responsible for degradation of the beam quality and the emittance increase.

The End Section

The final MEBT part matches the beam to the subsequent DTL section aiming for a smooth transition and avoiding sudden changes in the focusing strength.

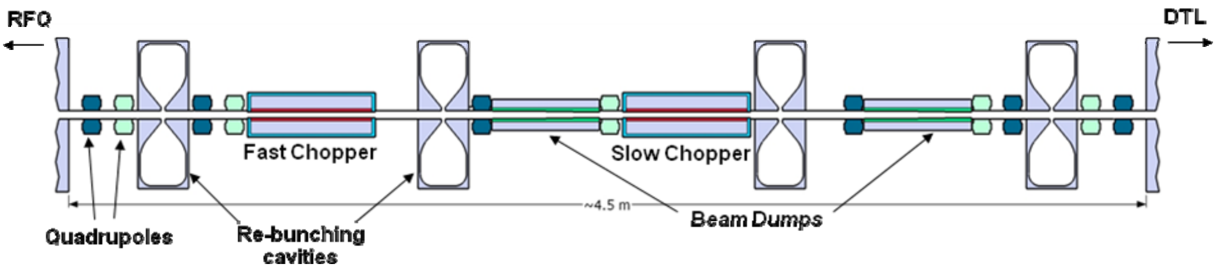

Figure 1: Schematic drawing of the MEBT Scheme 1.

POSSIBLE MEBT SCHEMES

Three different MEBT configurations have been included in this study. In order to compare the impact of each design on the emittance evolution and halo development in the downstream accelerators, a simulation study of high intensity beam dynamics and beam transport has been performed, when each design is fed into the same DTL structure.

The DTL is similar to the first tank of the ISIS upgrade linac. It operates at 324 MHz and it consists of 62 cells that accelerate the beam up to 16 MeV with the synchronous phase being ramped from -40° to -28°. The assumed input distribution is Gaussian with a normalised RMS emittance at the MEBT input of 0.27 π mm mrad in both transverse planes and 0.14 π deg MeV longitudinally.

MEBT Scheme 1

Scheme 1 represents the preferred design for the FETS project. The front and the end matching sections are similar and consist of a two doublet quadrupole configuration and a 324 MHz CCL-type re-bunching cavity. The choppers are arranged symmetrically, each followed by a dedicated beam dump and a defocusing quadrupole. The defocusing quadrupoles are used to amplify the deflection given by the choppers, thus reducing the required voltage on the chopper plates [5]. A schematic drawing of the MEBT Scheme 1 can be seen in Figure 1.

MEBT Scheme 2

Scheme 2 is currently being used in the ISIS upgrade linac design and it comprises two input quadrupoles, two solenoids, two sets of asymmetric triplet quadrupoles and four 324 Mhz re-bunching cavities (Figure 2). The input quadrupoles are used for matching the beam from the RFQ, while the solenoids focus the beam into a ~1.5 m long drift where the two choppers are placed. This is followed by a first set of triplets, a ~1.1 m long drift section for the beam dump, and a second set of triplets to match the beam into the DTL [6].

MEBT Scheme 3

The third scheme (Figure 3) investigates the possibility of using a more regular lattice. For this purpose, three sets of symmetric triplet quadrupoles and six re-bunching cavities are being used. They are equally spaced by long drift tube sections reserved for the two choppers and for the beam dump.

SIMULATION RESULTS

The beam envelopes in the chopping plane for the three MEBT designs and the DTL can be seen in Figure 4. While the two choppers perform similarly in all three schemes, with voltages between ±1.2 and ± 1.5 kV required for 99% chopping efficiency, the beam dynamics vary considerably.

In the first design, the two long choppers create an irregular lattice for the central section of the MEBT. However, by having a symmetrical scheme, the drift lengths are reduced to ~ 0.5 m. Shorter drifts are desirable from the beam optics point of view, and by carefully choosing the quadrupole gradients, the beta functions can be kept comparable in both transverse planes. Consequently, the emittance growth and the halo development are reasonably controlled, both in the MEBT line and the DTL.

For the second scheme, the chopper sections have a similar effect on the lattice. However, the reserved drift spaces are much longer (~1.5 and ~1.1 m) and as a result,

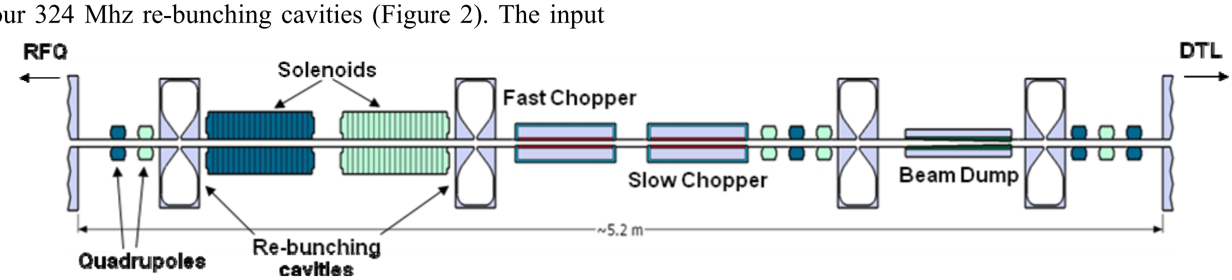

Figure 2: Schematic drawing of the MEBT Scheme 2.

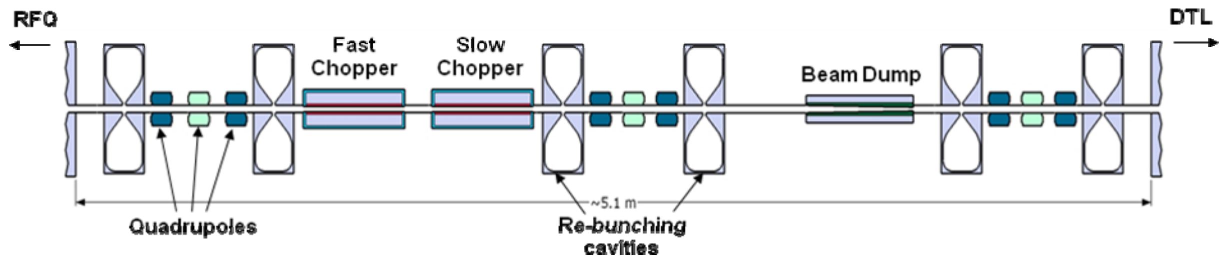

Figure 3: Schematic drawing of the MEBT Scheme 3.

the strong space charge forces will distort the beam structure more than for the first scheme, leading to a higher emittance growth.

The third MEBT also includes two long drift sections (~1.1 m each) but has the advantage of a periodic lattice. However, the betatron oscillations amplitudes vary significantly in the two transverse planes and the beam quality is deteriorating rapidly.

CONCLUSIONS

The RMS emittance evolution and the emittance increase for the three scenarios presented above are shown in Figure 5 and Table 1 respectively. As expected, a certain emittance growth can be observed for each MEBT design. For Scheme 2 the emittance is already larger than for Scheme 1 at the MEBT output, but after the beam is matched into the DTL, this difference is more or less preserved. On the other hand, the total emittance increase is much higher for Scheme 3 and although it is initiated at the MEBT level, it continues to grow along the DTL.

Halo formation can lead to beam loss and radio activation of the linac, a process that has to be avoided in high intensity linacs. We have observed an increase in the in the halo parameter [7] in all the planes at the DTL output: ~30% when using Scheme 1, ~60% when using Scheme 2 and ~150% when using Scheme 3. To reduce the halo, scrapers will have to been included at the transition between the MEBT and the DTL.

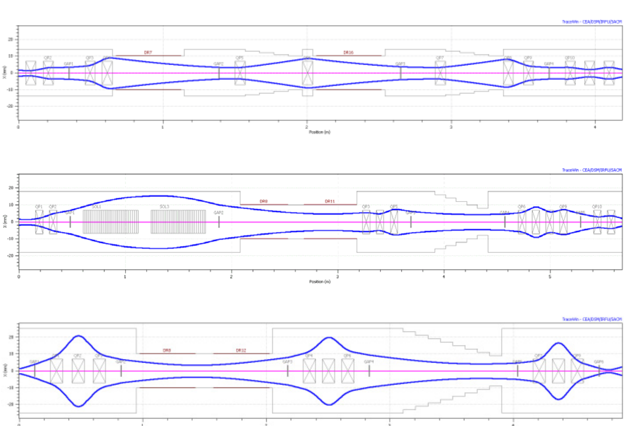

Figure 4: Beam Envelopes in the chopping plane for the three MEBT schemes: Scheme 1 (top), Scheme 2 (middle), and Scheme 3 (bottom) with the beam chopper switched off (from TraceWin/Partran, 5 RMS).

Figure 5: Longitudinal and transverse (average Ex and Ey) emittance evolution (Normalized RMS) for the three MEBT schemes and the DTL.

Table 1: Emittance Growth

Emittance Growth		DTL	MEBT1 + DTL	MEBT2 + DTL	MEBT3 + DTL
MEBT (%)	tr	-	10.1	22.3	25.6
	z	-	4.5	21.7	17.3
DTL (%)	tr	4	0	1.9	17
	z	6.5	3.9	1.1	12
Total (%)	tr	4	10.1	24.7	46.9
	z	6.5	8.6	23.1	31.5

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