MEBT DESIGN FOR THE FRONT END TEST STAND PROJECT AT RAL

J. M. Aslaninejad, J. Pozimski, P. Savage,
Imperial College of Science and Technology, London, UK

Abstract

The Front End Test Stand (FETS) linear accelerator at the Rutherford Appleton laboratory (RAL) will accelerate a 60 mA, 2 ms, 50 pps H$^-$ beam to 3 MeV. A new lattice for the Medium Energy Beam Transport (MEBT) with a fast-slow chopping system is presented. The new lattice has more free space to position the diagnostics. Beam dynamic simulation, with the space charge effects included, has shown very good particle transmission in the new lattice.

INTRODUCTION

High Power Proton Accelerators (HPPA) with beam powers in the several megawatt range have many applications including drivers for Spallation Neutron Sources, Neutrino Factories, Muon Collider, Accelerator Driven Sub-Critical System, Waste Transmuters etc.

The Front End Test Stand (FETS) under construction at the Rutherford Appleton Laboratory is the UK's contribution to research into the next generation of High Power Proton accelerators [1]. The FETS will demonstrate the production of a 60 mA, 2 ms, 50 pps chopped beam at 3 MeV with sufficient beam quality. The Front End Test Stand can be described in four zones. First is the ion source that creates the H$^-$ ion beam. Second is a three solenoid Low Energy Beam Transport (LEBT) where the beam is prepared for acceptance into the accelerator. Thirdly, a 324 MHz Radio Frequency Quadrupole (RFQ) accelerates the beam from energy of 65keV to 3MeV. The last stage is the Medium Energy Beam Transport (MEBT) which has two primary functions: to prepare the beam for a future stage of acceleration and to demonstrate a technique known as fast beam chopping [2]. FETS will also benefit from comprehensive diagnostics. Acceleration to energies higher than 3MeV is beyond the scope of the current FETS project. After the MEBT the beam runs through a laser diagnostics system before being dumped into a water-cooled cone structure. Beam chopping will be an essential part of the next generation of HPPAs. The beam loss in future machines must be kept to levels comparable to those of current facilities in order to avoid activation.

The Medium Energy Beam Transport

After the RFQ, the Medium Energy Beam Transport starts. The MEBT consists of four types of components that affect the particle beam. These are electromagnetic quadrupoles for beam focussing, RF cavities to maintain the beam bunch structure, beam choppers to remove sections of the particle beam and chopper beam dumps to absorb the removed beam. In-line non-destructive diagnostics will be employed to determine both the beam position within the MEBT and the beam current. The diagnostics will allow monitoring the beam quality and assessing precisely the quality of beam chopping.

While a lattice based on 4 re-bunching cavities, eleven quadrupoles, fast and slow choppers and beam dumps has been designed for the MEBT [3], the requirement for more longitudinal space to house diagnostics has derived the idea of designing a new lattice. As the primary purpose for FETS is to realize perfect chopping, a new lattice with fewer numbers of cavities and quadrupoles, but more free space for diagnostics has been designed.
This three cavity MEBT is compatible with a later upgrade to the four-cavity MEBT (same beam elements). The four -cavity MEBT is the benchmark, but would not allow for diagnostic.

The new lattice consists of eight quadrupoles all with the same length of seventy millimetres. It also houses three rebunching cavities with 20 cm length. The gap length of the cavities is 16 mm. Fast and slow choppers would each occupy 500 mm of the MEBT space. Finally, two beam dumps for both the fast and slow choppers would be positioned in the MEBT. The new lattice schematic is shown in Figure **1**.

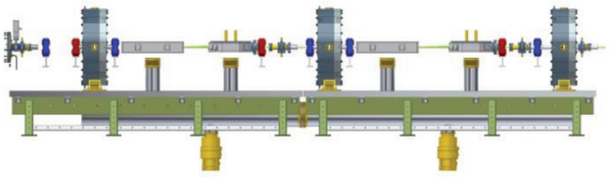

Figure 1: MEBT with 8 Quadrupoles: blue quadrupoles are focusing in y and red quadrupoles focus in x plane. Fast chopper and its beam dump are placed between the 1st and the 2nd cavities and the slow chopper and its beam dump are positioned between the 2nd and the 3rd cavities.

The parameters of the new MEBT components are shown in the Table 1. Quadrupole gradients range from 2.9 up to 16.65 T/m. Field maps for quadrupoles were created and implemented into the GPT code to include the effects of the fringe fields in the beam dynamics.

Table 1: Parameters of New MEBT Elements

Components	No.	Length	Description
Quadrupoles	8	70 mm	G=2.9-16.5 T/m
Cavities	3	200 mm	P=1.41-5.45 kW
Fast Chopper	1	530 mm	V= ±1.5 kW
Slow Chopper	1	530 mm	V= ±1.5 kW
Beam Dumps	2	380 mm	-

For comparison we have also shown in Table 2, the main Parameters of old MEBT elements.

Table 2: Parameters of the Four Cavity MEBT Elements

Components	No.	Length	Description
Quadrupoles	11	70 mm	G= 9-33 T/m
Cavities	4	200 mm	V = 75-160 kV
Fast Chopper	1	450 mm	V= ±1.3 kW
Slow Chopper	1	450 mm	V= ±1.5 kW
Beam Dumps	2	450 mm	-

Cavities are of a CCL type and have been modelled using Poisson-Superfish (PS) code. As PS creates a field map for half the cavity, the necessary field maps for the full cavities have been generated by computer programming. Based on observing a good longitudinal and also transversal beam dynamics, the voltage of the cavities to capture the particles properly have been determined. This gave in turn the necessary power for the amplifiers as detailed in Table 1. Summarizes of cavities specifications are written in Table 3.

Particle Transport

The simulation of the charged particles in the MEBT was accomplished using the General Particle Tracer (GPT) package [5]. We have shown in Figure 2 the energy distribution of nearly 100,000 particles before the first cavity using the relativistic factor γ .

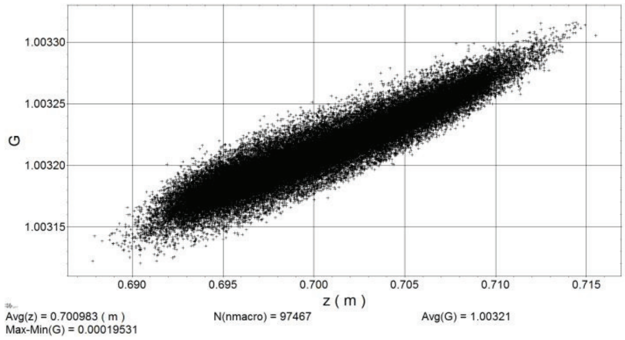

Figure 2: Energy distribution of the particles before the first cavity.

The first rebunching cavity will rotate the beam in longitudinal phase space as shown in Figure 3**.** The average energies before and after the cavity remain the same. This shows a perfect phase space rotation using the cavities in the MEBT.

In the longitudinal phase space normalized rms emittance does not show large growth as shown in Figure 4. The transverse phase space plot for emittance is illustrated in Figure 5. There can be seen some jump in emittances at the locations of quadrupoles. This can be related to an extra field seen by particles to the external magnetic field and the difference between the canonical and mechanical momentum calculation in GPT. The whole emittance growth is within the acceptable range.

Table 3 : Cavities Main Parameters

Parameter	**Value**
Length	200 mm
Gap length	16 mm
Bore radius	15 mm
Quality factor	27820
Shunt impedance	37.759 MΩ/m
Transit time factor	0.613
Frequency	324.04 MHz
First cavity power	5.45 kW
Second cavity power	2.15kW
Third cavity power	1.41kW

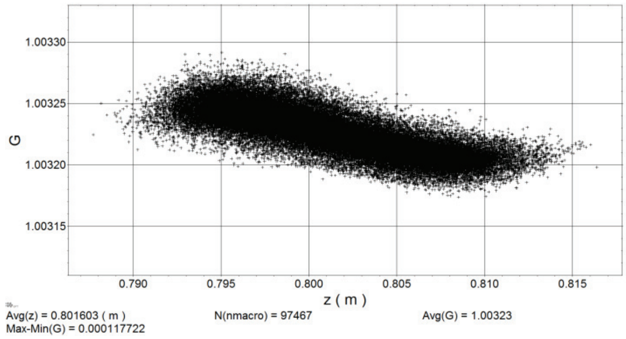

Figure 3: Energy distribution after the first cavity.

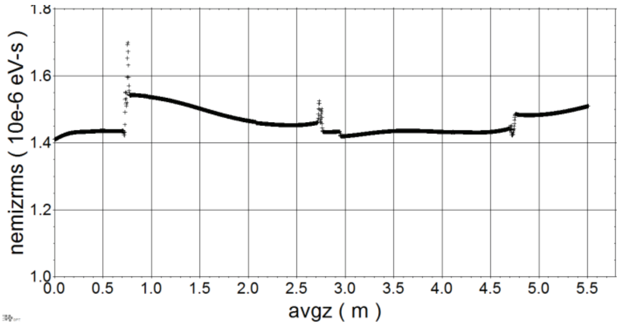

Figure 4: Longitudinal emittance in the MEBT. There is no emittance growth in the entire MEBT, although at the position of the three rebunching cavities, a jump in the emittance can be observed.

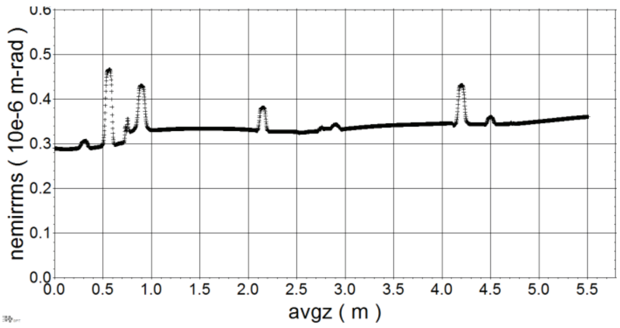

Figure 5: Transverse normalised phase space for 100,000 particles through the MEBT.

A large number of the particles survive and make it to the end of the LINAC. Figure 6 shows the beam transport of nearly 100,000 particles through the MEBT. A good transmission of around 96 percent is observed, but we aim to increase this by fine tuning the strength and position of the quadrupoles.

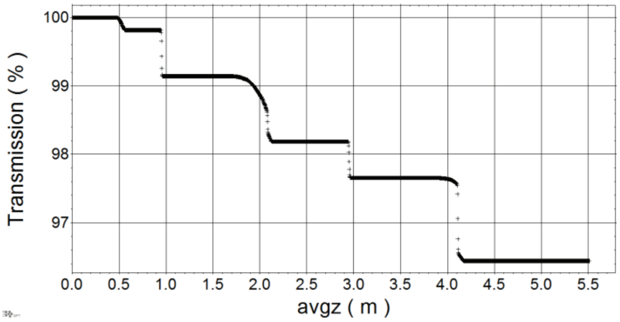

Figure 6: Beam transmission through the FETS MEBT. The beam losses mainly occur at the entrance of the choppers (at approximately 1 and 3 meters) and the exit of the chopper beam dumps (at 2 and 4 meters).

Choppers

A chopper beam dump is essentially a water-cooled plate that sits inside a vacuum vessel. The purpose of the water-cooled plate is to absorb the chopped beam that has been kicked off-axis by the choppers. There will be two identical models located downstream of each MEBT chopper. Part of the incoming bunches ($\approx 30\%$ of incoming beam) to the MEBT is planned to be perfectly chopped. This is done in two steps. In the first step a fast chopping system is used and 10 percent of the planned chopped beam will be deflected toward the first dump and in the next step a slow chopper will chop the rest to the second beam dump. The field for the fast chopper is generated by a pair of AC coupled fast transition time pulse generators (FPG). The electric fields are produced using pulse generator devices and are brought to and carried away from the chopper through 50 Ω cables and input-output pulse connecting pipes. The bunch distance after the 324 MHz RFQ would be about 3 ns. The fast chopper deflects only five bunches at the beginning and end of each chopped beam interval and creates two roughly 18 ns gaps in the bunch train. These gaps ensure that partial chopping of beam bunches is avoided in the downstream slow chopper. The field of slow chopper, on the other hand, is generated by eight DC coupled, slow transiting time pulse generators (SPG) that output high voltage pulses to a set of discrete, close coupled, electrodes. The slow chopper generates a long duration E-field that deflects the remaining bunches in each chopping interval onto a downstream beam dump. For the fast chopper a pulsed electric field will deflect the incoming beam. As the electric field travels faster than the beam, the electric field, therefore, needs to be slowed down by some transmission lines (meanders) to synchronize with the beam [6]. This ensures that the deflecting E-field propagates at the beam velocity to avoid the partial chopping of beam bunches. In fact, meanders impose a longer pass to the electric pulse so that the particles could feel the electric field for a longer time during the chopping procedure. Since the electric pulse should be slowed down, the fast chopper is also called slow wave chopper. The designed slow chopper, on the other hand, consists of 8 positive electrodes on one side (top), with a common negative electrode on the other side (bottom) to encompass the passing beam. The slow chopper will be supplied by a water cooling system, as most of the beam is chopped by it. Both beam dumps need to be cooled down by water. The dump plates make approximately 3° angles with the horizontal planes. Simulation results have shown a very good chopping with extinction of particles after fast chopper about 99.9%.

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