LATTICE AND COMPONENT DESIGN FOR THE FRONT END TEST STAND MEBT AT RAL

M. Aslaninejad, J. Pozimski, P. Savage, Imperial College London, UK
M. A. Clarke-Gayther, A. Letchford, C. Plostinar, S. Robert Lawrie, STFC RAL, Didcot, UK

Abstract

The Front End Test Stand (FETS) linear accelerator at Rutherford Appleton Laboratory (RAL) will accelerate a 60 mA, 2 ms, 50 pps H^- beam to 3MeV energy. The aim of FETS is to demonstrate perfect chopping using a novel 2 stage (fast / slow) chopper scheme. The beam chopper and associated beam dumps are located in the MEBT. Achieving a low emittance-growth under the influence of strong, non-linear space-charge forces in a lattice which has to accommodate the long chopping elements is challenging. The baseline FETS MEBT design is 4.3 m long and contains 7 quadrupoles, 3 rebunching cavities, a fast and slow chopper deflector and two beam dumps. In particle dynamics simulations using a distribution from an RFQ simulation as an input, beam loss for the un-chopped beam is below 1% while the chopping efficiency is >99 % in both choppers. The final MEBT lattice chosen for FETS will be presented together with particle tracking results and design details of the beam line components.

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 in the UK's will demonstrate the production of a 60 mA, 2 ms, 50 pps chopped beam at 3 MeV with sufficient beam quality [1] . The Front End Test Stand consists of the ion source that creates the H^- ion beam; a three solenoid Low Energy Beam Transport (LEBT) where the beam is prepared for acceptance into the accelerator; a 324 MHz Radio Frequency Quadrupole (RFQ), which accelerates the beam from energy of 65keV to 3MeV. The last stage is the Medium Energy Beam Transport (MEBT) which prepares the beam for a future stage of acceleration and to demonstrate a technique known as fast beam chopping [2]. Beam chopping will be an essential part of the next generation of HPPAs. The beam loss in future machines must be kept to a minimum. After the MEBT the beam runs through a laser diagnostics system before being dumped into a water-cooled cone structure.

THE MEBT

After the RFQ, the Medium Energy Beam Transport starts. Different lattices for the MEBT were extensively studied [3] and designed [4]. The final MEBT lattice for FETS (Fig. 1) is based on 7 quadrupole (green) and 3 rebunching cavities (blue), two fast and slow choppers (yellow) and two beam dumps (grey). The two red quadrupoles after the MEBT match the beam from the MEBT to the other sections. The diagnostics will allow monitoring the beam quality and assessing precisely the quality of beam chopping. The main issue is to observe a perfect chopping procedure with beam transmission including the space charge effects for a low energy beam. While chopping at LEBT energies would require lower technical efforts, clean chopping can only be performed after the RFQ, where bunched beam allows for the rise time of the chopper voltage in the gaps. In order to understand the transport of the intense beam through the MEBT extensive simulations using the General Particle Tracer (GPT) software [5] code have been carried out. The parameters of the MEBT components are shown in the Table 1. Field maps for quadrupoles were implemented into the GPT code to include the effects of the fringe fields in the beam dynamics.

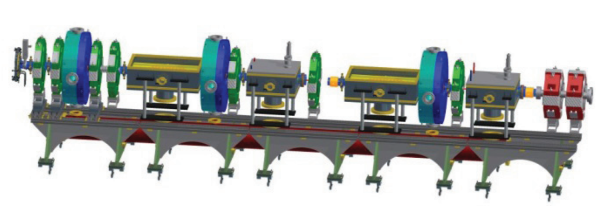

Figure 1: Lay out of the MEBT for the FETS linear accelerator at Rutherford Appleton laboratory.

Cavities are of a CCL type and 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 2. To account for the fact that our beam is always larger horizontally in the cavities and very close to the bore, a type of non-cylindrically symmetric cavity was designed for the MEBT.

ISBN 978-3-95450-132-8

Table 1: Parameters of MEBT Elements

Components	No.	Length	Description
Quadrupoles	7	80 mm	G=4.14-18.37 T/m
Cavities	3	200 mm	P=1.41-5.45 kW
Fast Chopper	1	604 mm	V= ±1.375 kV
Slow Chopper	1	604 mm	V= ±1.5 kV
Beam Dumps	2	380 mm	-

The first attempt (Fig. 2) was to take a 3 dimensional model of the cylindrically symmetric cavity with 17 mm bore radius(blue circle) and scale the whole geometry by 1.1 horizontally and 1/1.1 vertically(green ellipse) to give an extra 1.7mm on the bore radius in the horizontal plane. The rebunching cavities could rotate the longitudinal phase space such that the average energies before and after the cavities remained the same.

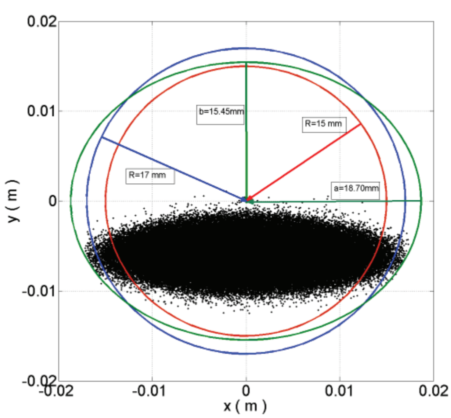

Figure 2: Cavity bore geometry scenarios for FETS MEBT.

Table 2 : Cavities Main Parameters

Parameter	Value
Length (internal, External)	140, 200 mm
Gap length	9 mm
Bore radius (average)	17 mm
Quality factor	27820
Shunt impedance	37.759 MΩ/m
Transit time factor	0.613
Frequency	324.04 MHz
Cavities powers	1.41-5.45 kW

Particle Transport

The simulation of the charged particles in the MEBT was accomplished using the General Particle Tracer (GPT) package. We have shown in Fig. 3 the trajectories of 20k particles in the y-z plane, with the space charge effects included. Red, yellow, blue, green and black rectangles show the BPM, quadrupoles, cavities, choppers and beam dumps, respectively.

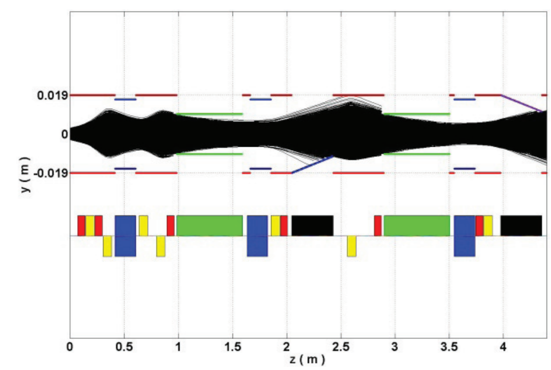

Figure 3: Trajectory in the vertical plane.

In Fig. 4 we have shown the beam loss at the different positions of the MEBT. For the purpose of having more precise statistics the simulation was done using nearly 100k particles coming from the RFQ exit. The transmission showed above 99.3 percent survival. The beam losses mainly occur at the entrance of the choppers and the exit of the chopper beam dumps.

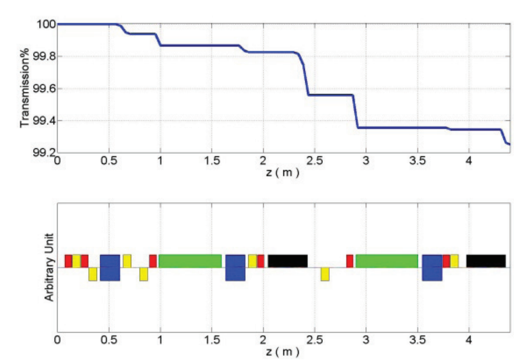

Figure 4: Beam transmissions through the FETS MEBT.

In the longitudinal phase space normalized rms emittance did not show any large growth. The transverse phase space plot for emittance showed a few jumps in the emittances at the locations of quadrupoles, but the whole emittance growth remained within the acceptable range.

A large number of the particles survived and make it to the end of the LINAC.

Choppers

Part of the incoming bunches 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 part of the beam which is planned to be chopped 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 chopper timing should suit the ISIS synchrotron RF frequency of 1.5 MHz [6]. The frequency of the RFQ in the FETS is 324 MHz (~3.09 ns), and for a beam with 2 ms duration, there would be 648000 bunches. As the ratio of the FETS to ISIS radio frequency is 216, the chopping cycle needs to be repeated for 3000 times. In this scheme from each 216 bunches 4 bunches will be chopped to the fast chopper dump in 12.36 ns and 57 bunches will be chopped to the slow chopper dump with 176.13ns and finally 4 bunches will be chopped to the fast chopper dump with 12.36ns duration. The gaps generated by the fast chopper ensure that partial chopping of beam bunches is avoided. There would remain 151 un-chopped bunches with 466.59ns duration. This gives a total cycle time of 667.44ns.

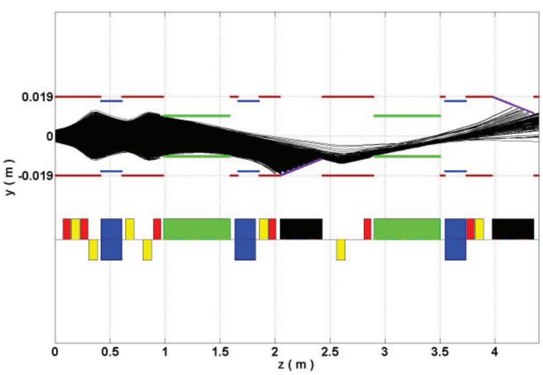

Figure 5: The vertical trajectories of the beam when the fast chopper deflects the beam toward the first dump.

The fast and the slow choppers are 604 mm long. 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 in the fast chopper will be slowed down by transmission lines (meanders) to ensure that the deflecting E-field propagates at the beam velocity [2]. 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 DC coupled generators. There would be 8 positive electrodes on one side (top), with a common negative electrode on the other side (bottom) to encompass the passing beam [4]. The slow chopper will need a water cooling system and most of the beam is chopped by it. The purpose of the water-cooled beam dump plates is to absorb the chopped beam that has been kicked off-axis by the choppers. In the final lattice design two identical beam dumps, each 380 mm, are located downstream of each MEBT choppers. We have shown in Fig.5 the beam trajectory in y-z plane after the beam has received a vertical kick from the first chopper. The number of particles in the simulation was roughly 20k. The chopping efficiency (extinction rate) seemed very promising and only 169 particles escaped the exerting vertical kick of the chopper. This means that only 0.85% of the particles could escape the electric kick of the chopper and remained un-chopped. The applied voltage is +/- 1.375 kV and the coverage factor equals 80%. On the other hand, for the slow chopper, a voltage of +/-1.5kV and a coverage factor of 85% have been considered.

REFERENCES

[1] A. Letchford et al., “Status of The RAL Front End Test Stand”, Proc. Of IPAC’13, Shanghai,China.
[2] M. Clarke-Gayther “The Development of a Fast Beam Chopper for Next Generation High Power Proton Drivers”, Proc. Of IPAC’10, Kyoto, Japan.
[3] C. Plostinar “MEBT Design For the RAL Front End Test Stand”, Proc. Of IPAC’10, Kyoto, Japan.
[4] M. Aslaninejad, et al., ”MEBT Design For The Front End Test Stand project At RAL”, Proc.Of IPAC’13,Shnaghai,China.
[5] Pulsar Physics, http://www.pulsar.nl/gpt/index.html
[6] http://www.isis.stfc.ac.uk

ISBN 978-3-95450-132-8