DESIGN REPORT OF A NON–DESTRUCTIVE EMITTANCE INSTRUMENT FOR RUTHERFORD APPLETON LABORATORY'S FRONT END TEST STAND FETS

C. Gabor*, STFC, ASTeC, Rutherford Appleton Laboratory (RAL), OX11 0QX, UK
A.P. Letchford, STFC, ISIS, RAL, OX11 0QX, UK
J.K. Pozimski, STFC, ISIS, RAL, OX11 0QX, UK and
Imperial College London, High Energy Physics Department, SW7 2AZ, UK

Abstract

The RAL front end FETS is currently under construction to demonstrate a fast chopped, high power H^- ion beam at 3 MeV of up to 18 kW. Therefore emittance instruments should use photo detachment because mechanical parts could be affected by heat loading. This emittance instrument uses a dipole to separate negative ions from produced neutrals and a scintillator to measure particle distribution and deflection. This means a careful design of the diagnostic instrument according to other beam parameters and existing focusing elements because reasonable results require high enough phase space advance. A conceptual design layout will be presented considering the current status of the MEBT simulations along with a discussion

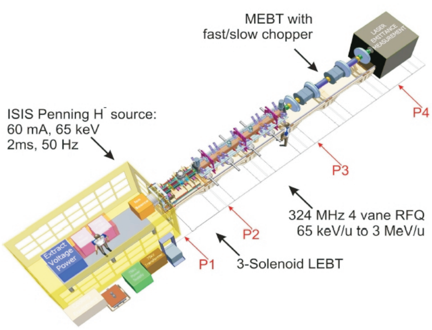

Figure 1: Overview of the FETS set up. The main elements are a Penning type ion source, 3 solenoid LEBT, RFQ and the MEBT consisting of quadrupoles, four buncher cavities and the chopper. The emittance diagnostic and beamdump are located at the end of the beamline.

INTRODUCTION

In order to contribute to the development of high power proton accelerators in the MW range, to prepare the way for an ISIS upgrade and to contribute to the UK design effort on neutrino factories [1, 2] a Front End Test Stand FETS (see Fig. 1) is being constructed at the Rutherford Appleton Laboratory RAL in the UK [3]. The aim of FETS is to demonstrate the production of a 50 to 60 mA, 2 ms, 50 pps chopped beam at 3 MeV with sufficient beam quality. This means in particular very high demands for the chopper unit which provides a fast unit for short rise time and a slow chopper for the long pulse duration. The chopper itself is integrated in a MEBT which firstly has to match

* christoph.gabor@stfc.ac.uk

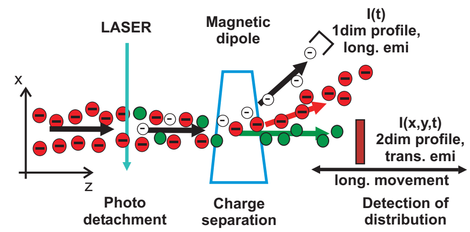

Figure 2: Basic principle of photo detachment ion beam diagnostics The H^- ions get neutralized by laser light. The diagnostics is in general a three stage process: detachment, charge separation and detector.

the RFQ output to the chopper and secondly to a DTL further downstream both in longitudinal and transverse phase space. The MEBT design is still under discussion [4] and all design schemes are confined by constraints given by a future LINAC but the actual end of the FETS beamline will consist of an emittance instrument and two beam dumps ("diagnostic beam line").

Thus, first studies to investigate changes to adapt the beam parameters to the demands of the test facility FETS are presented. A brief introduction of the applied diagnostics and main parameters of the bending dipole are also provided.

LASER BASED ION BEAM DIAGNOSTICS

The basic principle of the implemented Photo Detachment Emittance Instrument (PD–EMI) is illustrated in Fig. 2. Compared to more common devices like a slit–grid (harp) and pepperpot scanner the laser acts like a slit whereas the particle detector takes the place of a pepperpot device, therefore the transfer function of PD–EMI is a so called slit–point mapping. In Fig. 2 the laser is parallel to the x–axis therefore the yy' emittance can be measured in a direct way by gathering angle profiles for each y–position of the laser [5, 6].

According to this idea the laser has to rotate to access information of the xx' plane. Previous studies have shown that this would be possible but means a very complicated magnetic design: since the gap of the dipole has to provide enough clearance for a second set of mirror the fringe field can be significant and, even without considering the poor field homogeneity, could cause avoidable beam perturbations. Therefore, in [7] another possibility is presented where a longitudinally movable detector in combination with an image reconstruction method (Maximum Entropy,

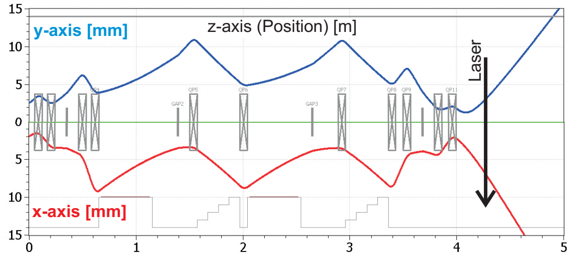

Figure 3: Envelope in x and y direction. The MEBT matches the beam to a future DTL. The possible laser position is marked, at $\approx$ 4.8 m would be end of diagnostic section followed by beamdump(s).

also called MaxEnt [8]) are able to produce good results of the missing plane, as long as the phase advance, i.e. the differences of the spatial distributions are big enough. The emittance computation is based on several intensity profiles with their transformation matrix $\mathbf{R}$ back to the measurement point. First applications in accelerator science are published in [9, 10] and more recently in [11].

MEBT WITH DIAGNOSTIC DIPOLE

The MEBT is described in [4], the envelope is shown in Fig. 3 matching a DTL (all simulations have been performed with Tracewin [12]). Typically, one plane is convergent and vice versa. Due to a horizontal bending magnet and vertical scanning of the laser the horizontal plane should have a waist to provide a large enough phase advance [7]. The change of the field strength of the last four quadrupoles typically is enough to prepare the ion beam for diagnosis as long as aperture and field strength offer sufficient flexibility.

Important design criteria for the dipole are the reference length which is restricted due to a lack of strong focusing, growing beam size[1] and a long focus. The latter would reduce the phase advance affecting the MaxEnt. The deflection angle and radius are limited by a sufficient returning yoke interfering with the overall length. But the main purpose is to separate three different kind of species: straight forward a beam dump either terminates the undeflected ion beam or neutrals produced by gas stripping (H^o_{RGI}) further upstream. Since the laser scans the beam somewhere in the first half of the magnet the neutrals produced by photo detachment (H^o_{PD}) get a kick and are separated via the following drift from H^- and H^o_{RGI}. All beamlets have to be fully separated to go to either the beamdump or the detector head. For the parameters given in Tab. 1 a max. beam(pipe) of $R_{\max.} = \pm 30$ mm is assumed. That gives some safety margin providing more flexibility for other beam conditions (the relatively large gap height should be seen in the same context). This is equivalent with the z_0 position mentioned in Tab. 1 and means the nearest possibility to mount the detector head. But the detector itself might move closer to the photo detachment. Regarding the separation it turns out that the best location for the laser scan is in general close to 30% of total deflection, here at $\approx$18°. By varying the last four quads of the beamline a mild waist in one plane and a slight divergent beam in the other plane could be achieved (Fig. 4). Compared to Fig. 3 the two transverse planes are swapped to give the waist in the horizontal plane. This is not ideal but technical possible; an alternative is to add more quadrupole. But the latter, as well changing the aperture, is avoided in order to reduce changes to the present MEBT scheme. The field strengths are reduced (not more than 25 T/m) but it could be an issue that the combined PM and EM quadrupoles do not offer enough variability in their field strength [13].

[1] Typical dipole focusing should be avoided since the element's purpose is diagnosis and not beam transportation and it might complicate a point–to–point transformation.

Table 1: The main parameters of the sector dipole. At the moment no gradient or edge focusing is assumed.

Parameter	
Gap height g	60 mm
Pole width	200 mm
Magnetic field, $H^-_{3\,\mathrm{MeV}}$	500.5 mT
Deflection angle α_{H^-}	60°
Bending radius R	0.5 m
Reference path length $l_{arc,\,H^-}$	523 mm
Deflection angle α_{PD}	≈18°
Reference path length $l_{arc,\,\mathrm{laser}}$	164 mm
Drift, straight $d_{H_{PD}}$, z_0 position	360 mm
Total drift, straight $d_{H^0_{\mathrm{RGI}}}$	549 mm

DISCUSSION

Here, in this example the xx′ emittance is reconstructed using MemSys5 [14]. The assumed measurement point is exactly at the laser position. The backward transformation can then be described as a pure drift. But this is not mandatory, the phase advance could be also provided by a quadrupole scan or a combination of both. Only the measurement point should be adapted. The assumed example

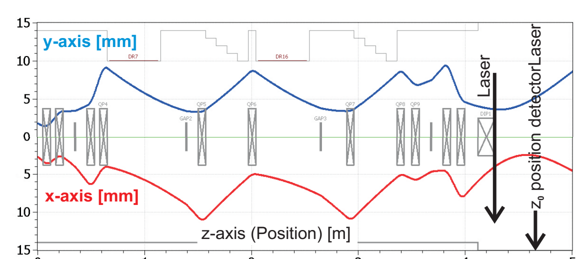

Figure 4: Envelope with adjusted quadrupoles to transport beam through sector magnet and creating a waist in horizontal plane, end of the diagnostic magnet at $\approx$ 4.8 m.

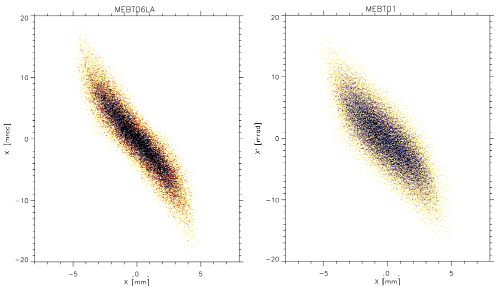

Figure 5: Comparison between original distribution (left) and reconstructed phase space pattern (right) based on MaxEnt.

illustratives some interesting aspects: if the beam path for backward transfromation consists only of the drift of H^o_{PD}, the transfer matrix cannot be affected by any other non–linear effects. The angular resolution is given by the drift length of H^o_{PD} and spatial resolution of the detector and since the variation of the distance it also changes the resolution. Assuming to transport the beam further upstream back through the dipole the distribution would only see hone fringe field. The result of the investigated example is shown in Fig. 5 and Fig. 6. Five profiles are extracted, at $z_n = 100$, 200 275 375 500 mm, all given in respect to the laser position. This means that the detector has to move from its origin position $z_0 = +360$ mm -160 mm inwards and 240 mm outwards. The total range of 400 mm should be feasible but the nearest position to the laser is close to limit because the H^- beam can either affect the measurement or destroy the detector. Both the emittance pattern as well the fractional emittance show very good agreement between original beam and reconstruction, i.e. the general beam optics and parameters are suitable for MaxEnt. The constant bias in rms–emittance in Fig. 6 is caused by different numbers of particles phase space "pixels".

SUMMARY & OUTLOOK

The paper investigates how good the existing MEBT scheme can match a beam in a diagnostic magnet. It is possible to obtain a beam with a waist in one transverse plane as necessary. Enough phase advance can provided just by a waist, more general a combination of quad–scan and less movable detector are more likely. Some thoughts and parameters important for the design of the sector magnet are discussed. Further studies are important to include fringe field effects and the general influence of the sector magnet compared to an undisturbed beam. Transport simulations regarding the variable field strength of the quadrupoles are also planned, at least for the last four of the MEBT.

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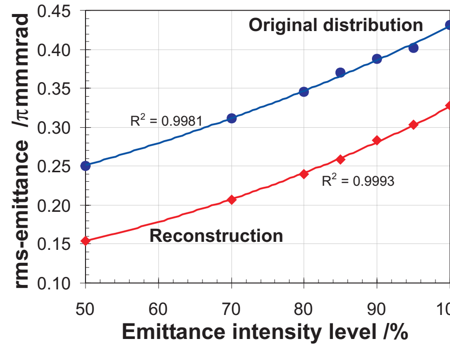

Figure 6: Comparison of the fractional emittance for several intensity levels. The difference is very likely ascribed different numerical integrations (different number of particles).

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