PARTICLE DYNAMICS CALCULATIONS AND EMITTANCE MEASUREMENTS AT THE FETS *

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Abstract

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) is being constructed at the Rutherford Appleton Laboratory (RAL) in the UK [3]. The aim of the FETS is to demonstrate the production of a 60 mA, 2 ms, 50 pps chopped beam at 3 MeV with sufficient beam quality. The results of numerical simulations of the particle dynamics from the charge separation dipole behind the ion source to the end of the MEBT will be presented. Previous measurements showed that the emittance of the beam delivered by the ion source exceeded our expectations by more than a factor of three [4]. Since then various changes in the beam extraction/post accelerator region reduced the beam emittance by nearly a factor of two. Simulations of the particle dynamics in the FETS based on distributions gained from recent measurements of the transversal beam emittance behind the ion source will be presented and the results for different input distributions discussed.

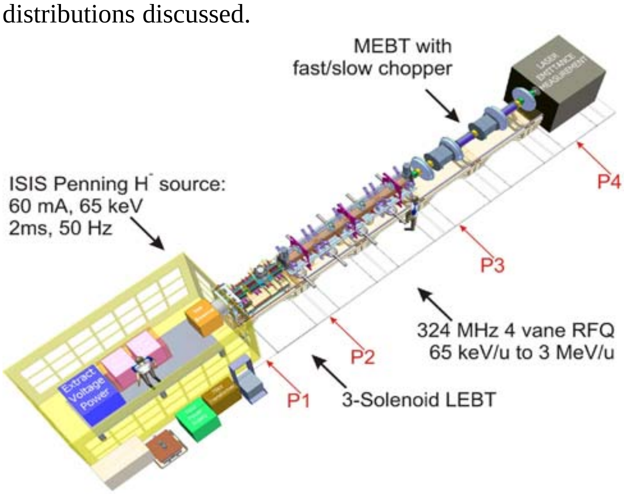

Figure 1: Schematic layout of the FETS set up. For the positions indicated (P1 behind post acceleration at the entrance of the LEBT [z=0mm], P2 at the entrance of the RFQ [z=1770mm], P3 at the RFQ exit [z=5770mm] and P4 at the end of the MEBT [z=10580mm]) the phase space distribution of the beam has been determined with GPT and TRACEWIN.

INITIAL PARTICLE DISTRIBUTION

The ion source development program, based on the highly successful ISIS H^- ion source at RAL, has already shown encouraging results. The aim is to increase the ion current from 35mA to 70mA, to increase the pulse length from 250µs to 2ms and to improve the beam quality [5]. In order to compare the recent status of the improvement of the ion source emittance and the consequences for the beam transport through the FETS end-to-end simulations have been performed for an idealized (shown in figure 2) and a real measured space phase distribution (shown in figure 3) based on pepper-pot emittance data.

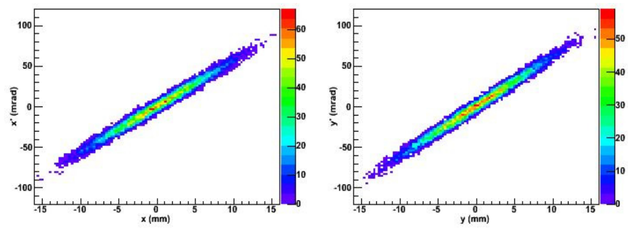

Figure 2: Input particle distribution into the LEBT (P1) for an ideal waterbag beam (input 1) ($\varepsilon_{x,rms}$=0.25 πmmmrad; $\varepsilon_{y,rms}$=0.25 πmmmrad).

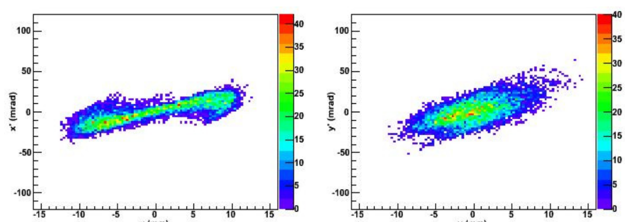

Figure 3: Input particle distribution into the LEBT (P1) for a measured beam distribution (input 2) ($\varepsilon_{x,rms}$=0.58 πmmmrad; $\varepsilon_{y,rms}$=0.52 πmmmrad).

LEBT SIMULATION AND RESULTS

A 3 solenoid LEBT system similar to the one used at the ISIS injector is under construction and the calculated 3D field distribution of the solenoids (figure 4) is used for particle transport simulation of the LEBT using the GPT code [6, 7].

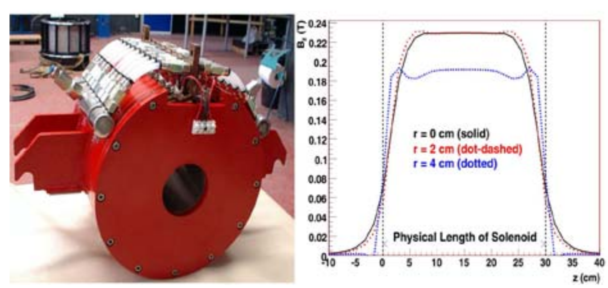

Figure 4: Left: one of three LEBT solenoids for FETS. Right: Magnetic field distribution in the z direction for different radii.

The field strengths of the three solenoids are chosen to optimise beam injection into the RFQ. The result of these optimisations for input distribution 1 is shown in figure 5. The estimated acceptance of the RFQ is drawn as an ellipse in the transversal phase space plots. There is no transversal beam loss in the LEBT and the total transmission (including stripping) into the RFQ acceptance is predicted to be above 90%.

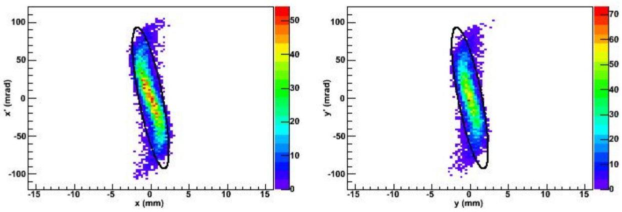

Figure 5: Phase space distributions in the transversal plane at the exit of the LEBT (P2) for input 1 ($\varepsilon_{x,rms}$=0.33 πmmmrad; $\varepsilon_{y,rms}$=0.33 πmmmrad).

The beam envelope in both transversal planes in the LEBT using distribution 2 is shown in figure 6 and the phase space distribution is shown in figure 7. Again the acceptance of the RFQ is drawn.

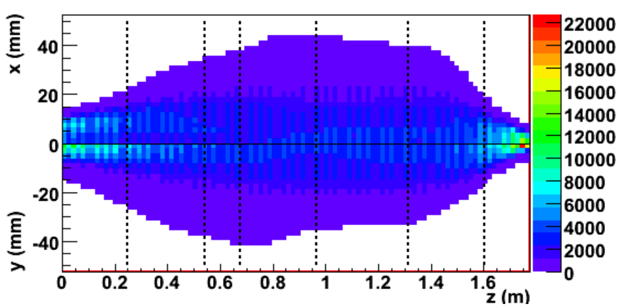

Figure 6:Beam envelope along the length z of the LEBT using the input distribution from the measured beam. Dotted vertical lines show the drift and solenoid sections.

Due to the relatively large size of the beam in the solenoids compared to their aperture (80%) non linear fields cause aberrations (already indicated by the slightly S-shaped phase space distribution in figure 5) and emittance growth. While the absolute increase of the emittance for the waterbag input distribution with $\Delta\varepsilon_{x,y,rms}$=0.08 πmmmrad is smaller than for the real beam ($\Delta\varepsilon_{x,rms}$=0.11 and $\Delta\varepsilon_{y,rms}$=0.12 πmmmrad), the penalty seems to be rather moderate.

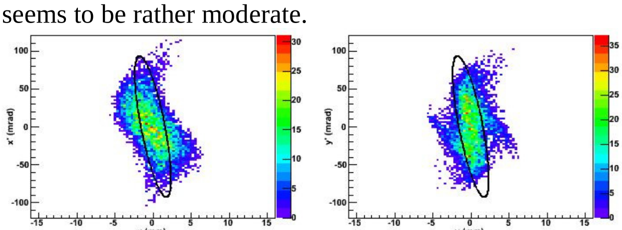

Figure 7: Phase space distributions in the transversal plane at the exit of the LEBT (P2) for input 2 ($\varepsilon_{x,rms}$=0.69 πmmmrad; $\varepsilon_{y,rms}$=0.64 πmmmrad).

Even for the presented very preliminary first data the result is surprisingly good and a total transmission into the RFQ acceptance is predicted to be 50%. The simulations performed also show that, independent of the degree of space charge compensation and using the available measured beam emittances, it is always possible to inject the core of the beam into the RFQ by just tuning the solenoid strengths.

PARTICLE TRANSPORT CALCULATION IN THE RFQ

A preliminary design of the 324 MHz RFQ has been used for particle dynamics simulations. The variation of the RFQ parameters along z is shown in Figure 8. The design was made for an optimized transmission of more than 90% under the estimate of an input beam emittance of 0.25 πmmmrad. In a first run the particle distribution gained from the GPT simulations of the LEBT with generated data was used for input into the RFQ.

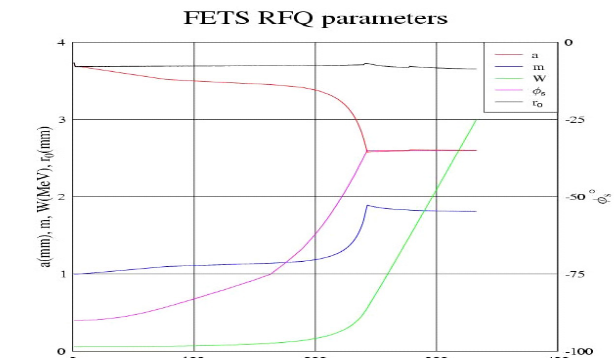

Figure 8: Development of the main RFQ parameters for the FETS along z.

The output distributions of this simulation are shown in figure 9. The transmission through the RFQ was ~96% for all energies and ~91% for an energy of 3MeV. The reduction of the emittance by 15% is caused by the particle losses. Considering this input distribution the design is likely to fulfil the requirements for the FETS.

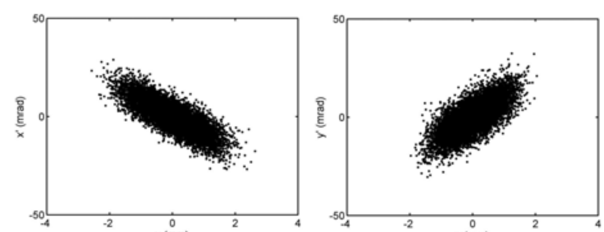

Figure 9: Particle distribution behind the RFQ (P3) for input 1 ($\varepsilon_{x,rms}$=0.28 πmmmrad; $\varepsilon_{y,rms}$=0.27 πmmmrad).

Using the second data set and taking into account that, while improved by nearly a factor of two over the last year, the input emittance is still a factor of two larger than the one used for the design, the achievable RFQ transmission of ~52% for all energies (50.5% for 3 MeV) seems to be reasonable but fails to meet the FETS specifications. The transversal output distributions are shown in figure 10. The emittance is reduced by up to 44 % due to the large particle losses but still 30 % larger compared to the results for the waterbag input

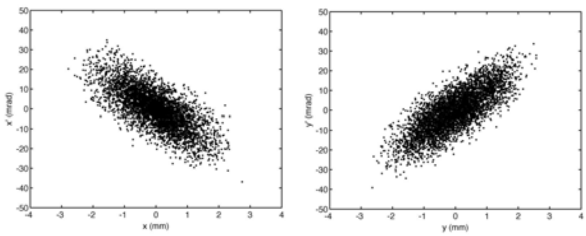

Figure 10: Particle distribution behind the RFQ (P3) for input 2 ($\varepsilon_{x,rms}$=0.46 πmmmrad; $\varepsilon_{y,rms}$=0.47 πmmmrad).

PARTICLE TRANSPORT CALCULATION IN THE MEBT

A preliminary design of the MEBT consisting of 11 quadrupoles, 4 bunching cavities and a slow and fast chopper with accompanying beam dumps is shown in Figure 11 [8].

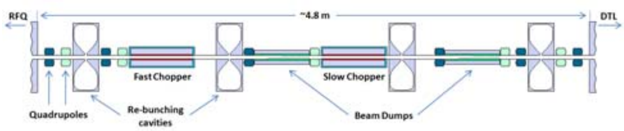

Figure 11: Design of the MEBT.

The output distributions of the simulation are shown in figure 12 and 13. For the ideal case the emittance growth is ~7% in x,x' and ~20% in y,y'. The transmission is ~98%.

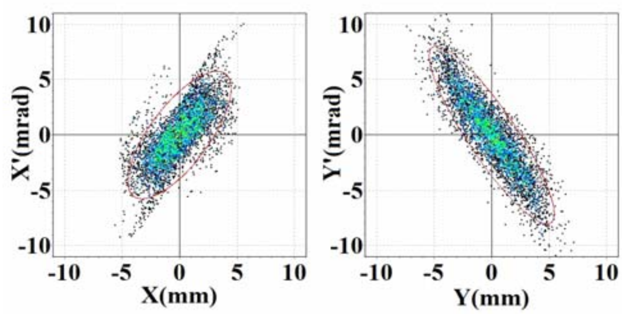

Figure 12: Particle distribution at the end of the MEBT (P4) for input distribution 1 ($\varepsilon_{x,rms}$=0.30 πmmmrad; $\varepsilon_{y,rms}$=0.34 πmmmrad).

For the real beam the emittance growth is -13% in the x,x' space (due to losses) and 4 % in the y,y' space. The transmission is reduced to ~89%.

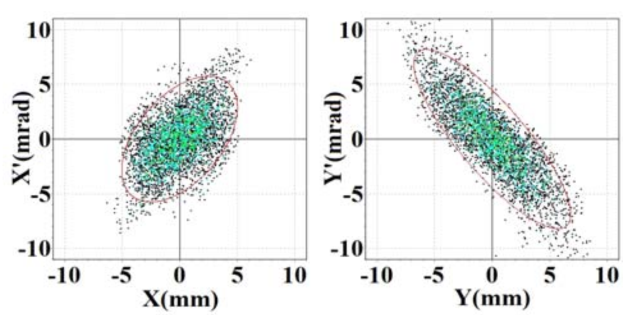

Figure 13: Particle distribution at the end of the MEBT (P4) for input distribution 1 ($\varepsilon_{x,rms}$=0.40 πmmmrad; $\varepsilon_{y,rms}$=0.49 πmmmrad).

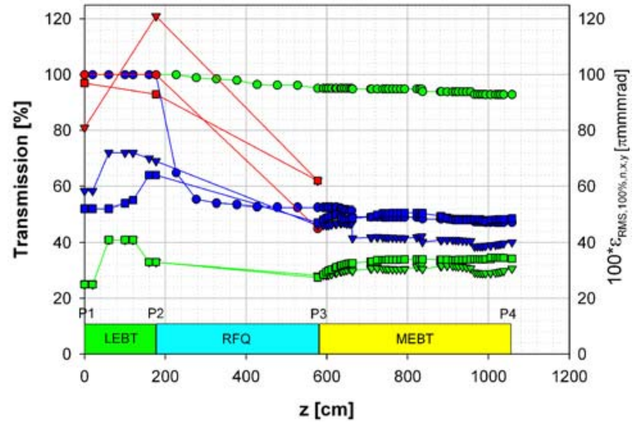

Figure 14: Development of Transmission (solid, circles), and transversal emittances (x is dashed, triangles, y dotted, squares), along beam propagation for ideal (green), initial (red) and new (blue) real input distributions.

DISCUSSION

The first simulations from the ion source exit to the output of the MEBT show a mixed picture. The presented results based on an artificial input distribution are quite encouraging and with a total transmission from the source to the exit of the MEBT of >90% (100% in the LEBT, 95% in the RFQ and 98% in the MEBT, see figure 14) the goals are nearly reached. This result further proves that the design of the individual sections is sound and the joint performance is satisfactory. On the other hand, the latest results using a measured initial distribution show a dramatic increase of the beam emittance with fatal consequences on beam transmission. For the current status the transmission is expected to be ~46% (100% in the LEBT, 52% in the RFQ and 89% in the MEBT). Due to the large beam losses in the RFQ the total emittance growth is moderate (-10% in x and 23% in y). Serious efforts to reduce the ion source emittance and improve the RFQ acceptance are under way and recent work has already increased the transmission through the RFQ by 10%, but further progress is required.

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