PARTICLE DYNAMICS CALCULATIONS AND EMITTANCE MEASUREMENTS AT THE FETS *

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Abstract

High power proton accelerators in the MW range have many applications including drivers for spallation neutron sources, neutrino factories, transmuters (for transmuting long-lived nuclear waste products) and energy amplifiers. In order to contribute to the development of HPPAs, to prepare the way for an ISIS upgrade and to contribute to the UK design effort on neutrino factories, a front end test stand (FETS) is being constructed at the Rutherford Appleton Laboratory (RAL) in the UK. 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. An overview on the status of the project together with the results of numerical simulations of the particle dynamics from the ion source to the RFQ exit will be presented. The particle distributions gained from the particle dynamics simulations will be compared with recent measurements of the transversal beam emittance behind the ion source and the results discussed.

INTRODUCTION

For the short pulse operation necessary for neutron spallation sources and neutrino factory [1] drivers, only much lower beam powers have been used so far (0.08MW for PSR and 0.16MW for ISIS) [2]. Both machines use H^- injection to accumulate intense short bunches and need an increase of at least a factor of 30 to reach the goal of 5MW for future HPPAs. A front end test stand (see figure 1 [3]) is being constructed at the Rutherford Appleton Laboratory in the UK. The presented work on particle dynamics for the FETS is focussed on the input particle distribution delivered by the ion source and the beam transport calculation through the LEBT and RFQ.

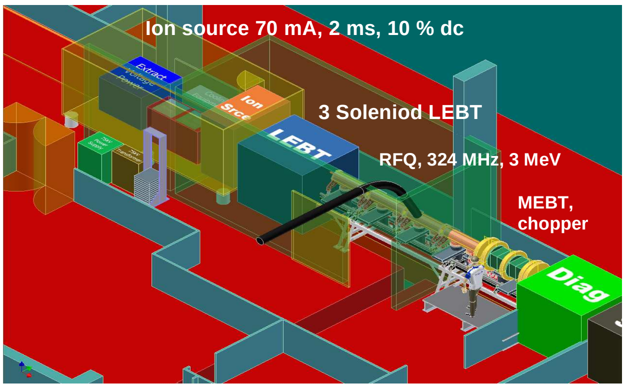

Figure 1: Schematic layout of the FETS set up.

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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 [4]. Results from earlier beam transport simulations indicate a strong dependency of the LEBT results from the input particle distribution. First simulations of the ion beam extraction have been performed using MAFIA code [5] and the results are shown in figure 2.

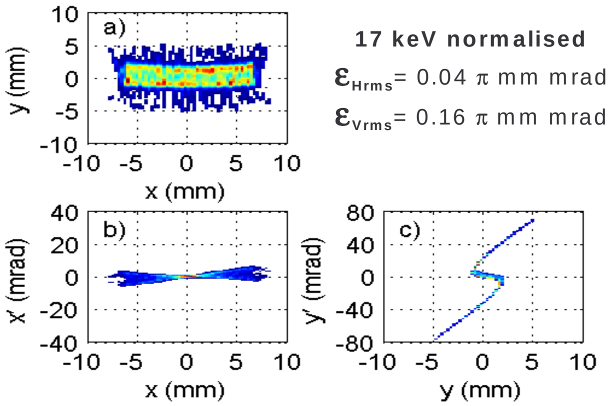

Figure 2: Calculated ion density distribution delivered by the ion source at the exit of the cold box (z=0).

Additionally to the simulations using MAFIA the emittance of the beam was investigated by the use of a slit-slit scanner device [6] 485 mm downstream the cold box exit. One typical result of these measurements is shown in figure 3. The extension of the emittance in both planes looks quite similar compared with the results of the extraction simulations for the same position, but the measured values are much larger and the S-shaped abberation in the y,y' plane could not be observed. Additionally a transverse density distribution, as required for the further simulations cannot be derived from the measured available data.

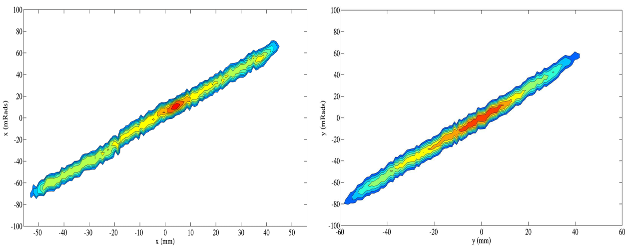

Figure 3: Measured transversal phase space distributions ($\varepsilon_{x,rms}$ = 0.88πmmmrad; $\varepsilon_{y,rms}$ = 0.94πmmmrad).

To perform simulations of the beam transport through the LEBT section and the RFQ, a preliminary particle distribution at the exit of the cold box (z=0, see figure 4) similar to the measured one was generated.

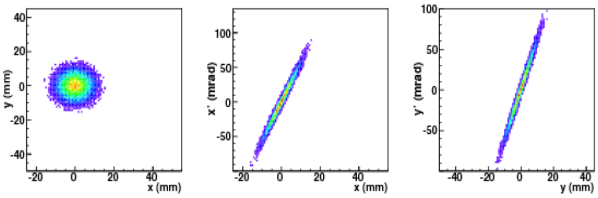

Figure 4: Spatial and phase space distributions in the transversal plane used as input for the LEBT transport simulations ($\varepsilon_{x,rms}$=0.25πmmmrad; $\varepsilon_{y,rms}$=0.25πmmmrad).

To further investigate the phase space distribution delivered by the ion source, a pepper pot emittance measurement device is under construction [7] and first very preliminary results are available. A particle distribution based on these results is shown in figure 5 (z=355mm). Surprisingly the distribution in x,x' shows a similar but reverse bending like the prediction from MAFIA (fig. 2) for y,y' indicating space charge forces to be the cause, while the other distributions in all cases are quite linear. The measured spatial distribution is like in the simulation a more rectangular shape.

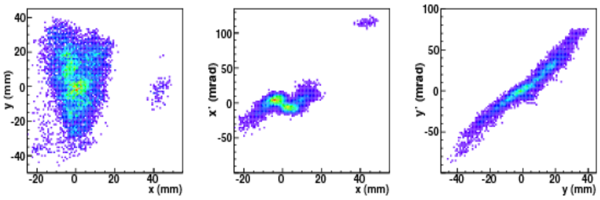

Figure 5: Spatial and phase space distributions in the transversal plane used as input for the LEBT transport simulations ($\varepsilon_{x,rms}$=0.81πmmmrad; $\varepsilon_{y,rms}$=0.97πmmmrad) gained from measurements with the peppe rpot device.

LEBT SIMULATION AND RESULTS

A 3 solenoid LEBT system similar to the one used at the ISIS injector is under consideration (see also figure 1). A preliminary solenoid design [8] has been made and the field distribution has been determined using MAFIA. For the particle transport simulation of the LEBT using the GPT code, a layout of the solenoid as shown in figure 6 together with the resulting field distribution, was chosen.

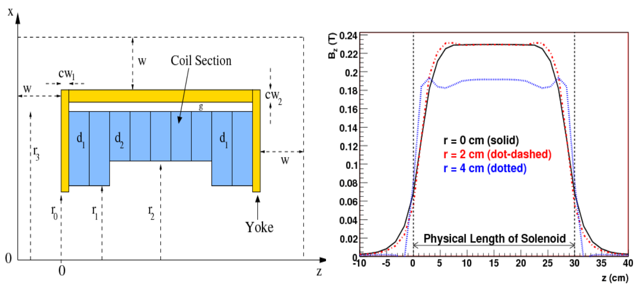

Figure 6: Design study of a 2-5-2 solenoid for the LEBT (left) and the calculated (using MAFIA) magnetic field strength distribution (in Tesla) along the z axis (right).

Then the field strength of the three solenoids was altered to optimise beam injection into the RFQ. One result of these simulations is shown in figure 7. The estimated acceptance of the RFQ is drawn as an ellipse in the transversal phase space plots. From the results a total transmission (including stripping) into the RFQ acceptance of 90% is predicted.

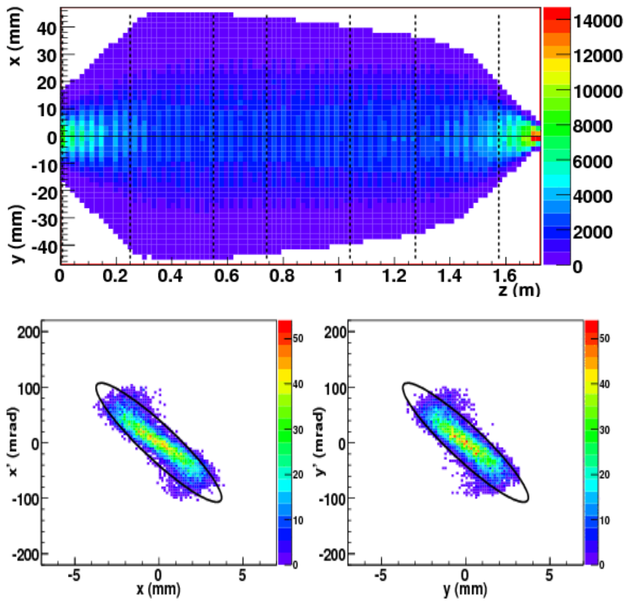

Figure 7: Trajectory plot (above) and output emittances in the transversal plane (below) based on LEBT simulations, using the input data shown in Figure 4 ($\varepsilon_{x,rms}$=0.33πmmmrad; $\varepsilon_{y,rms}$=0.33πmmmrad).

The results of the LEBT simulations using the measured distribution shown in figure 5 for input, is shown in figure 8. Again the acceptance of the RFQ is drawn. Even for the presented very preliminary first data the result is surprisingly good and a total transmission into the RFQ acceptance of 50% is predicted. This work is still ongoing and will further stimulate the optimisation of the beam extraction and LEBT design.

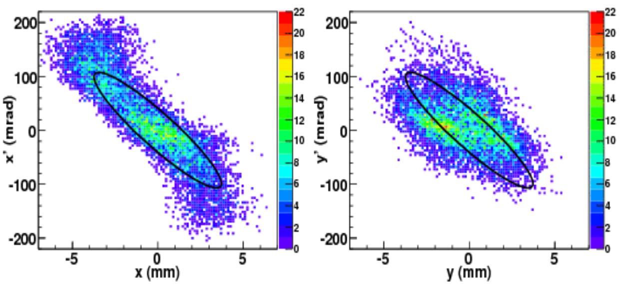

Figure 8: Phase space distributions in the transversal plane at the exit of the LEBT using the input data shown in Figure 5 ($\varepsilon_{x,rms}$=1.21πmmmrad; $\varepsilon_{y,rms}$=0.93πmmmrad).

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 9.

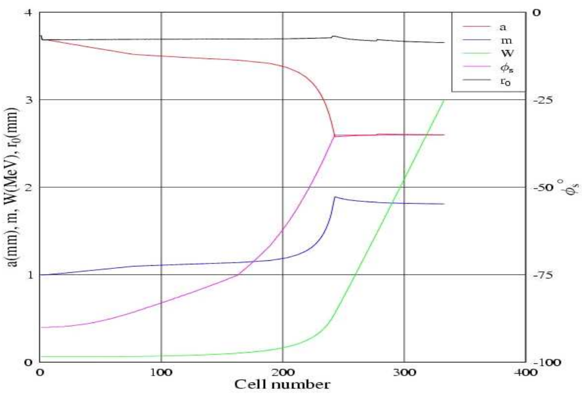

Figure 9: Development of the main RFQ parameters for the FETS along z.

A preliminary design of the 324 MHz RFQ has been used for the particle dynamics simulations presented further. 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. Taking into account a 25% increase in the input emittance, the simulations showed good results. The transmission through the RFQ was 83% and the beam current in the chopper would be 50-55 mA and with minor modifications the design is likely to fulfill the requirements for the FETS. The output distributions of this simulation are shown in figure 10.

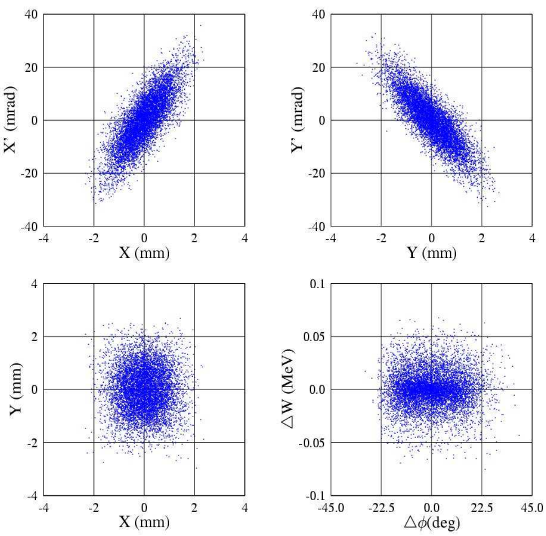

Figure 10: Particle distribution behind the RFQ for the input distribution shown in Figure 7 ($\varepsilon_{x,rms}$=0.35 πmmmrad; $\varepsilon_{y,rms}$=0.35πmmmrad, $\varepsilon_{z,rms}$=0.19πdeg MeV).

Additionally to the results of the simulations shown in figure 10 using the artificial data, the distribution gained from the LEBT simulations using the data from the pepper pot measurements was used as input for the RFQ. Even for this data set based on preliminary measurements, the simulations showed encouraging results. Taking the drastically increased emittance at the entrance into account, 47% of transmission through the RFQ seems to be reasonable but the current of 32 mA would fail to meet the FETS specifications. The transversal and longitudinal output distributions are shown in figure 11.

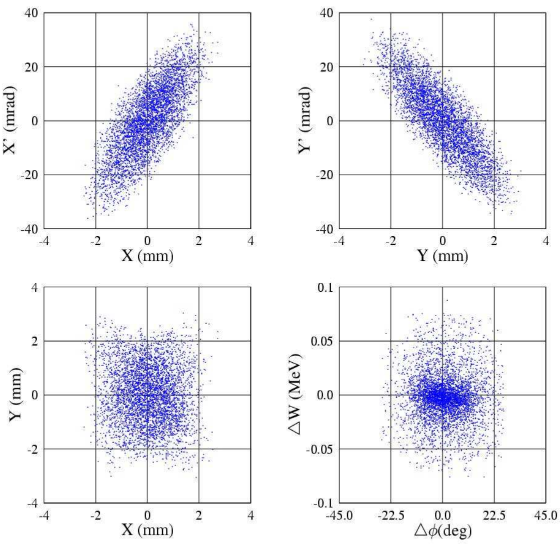

Figure 11: Particle distribution behind the RFQ using the input distribution shown in Figure 8 ($\varepsilon_{x,rms}$= 0.62πmmmrad; $\varepsilon_{y,rms}$=0.62πmmmrad, $\varepsilon_{z,rms}$=0.21π deg MeV).

DISCUSSION

The first simulations from the ion source exit to the output of the RFQ show a mixed picture. Some of the presented results are quite encouraging and with a total transmission from the source to the exit of the RFQ of 80% (90% in the LEBT) the goals are nearly reached. On the other hand the latest results on the measurement of the initial distribution shows a dramatic increase of the beam emittance with fatal consequences on beam transmission and emittance growth. But we also should keep in mind that these results are a snapshot of the actual status of the design effort and therefore preliminary. Serious efforts to reduce the source emittance and to increase the RFQ acceptance are already underway.

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