

# INVESTIGATION OF SPACE CHARGE COMPENSATION AT FETS

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## Abstract

In order to contribute to the development of high power proton accelerators in the MW range, and 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 [1]. 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 ion source and LEBT are operational [2] with the RFQ under manufacture. In the LEBT a high degree of space charge compensation (above 90%) and a rise time of space charge compensation around  $\sim 50 \mu\text{sec}$  could be concluded indirectly from measurements. The FETS LEBT was updated to perform a detailed experimental analysis of space charge compensation as a more detailed knowledge is of interest for other high power proton projects. In this paper the results of the experimental work will be presented together with discussion of the findings in respect to beam transport.

## INTRODUCTION

Space charge forces are most prominent in the transport of high current low energy ion beams. The compensation of space charge effects by charge neutralisation using secondary particles produced in the interaction between ion beam and residual gas can significantly reduce the required focal strength and reduce emittance degradation. The FETS low energy beam transport line has been designed keeping space charge effects in mind. This was done mainly by two measures. Firstly a “low strength” focussing optics was chosen to avoid a focal spot between the solenoids (2 and 3). Secondly the beam line and magnets have been designed to be able to deliver the beam for compensation degrees between 0-100% into the acceptance of the following RFQ. This is necessary as the final degree of compensation in equilibrium cannot be determined a priori.

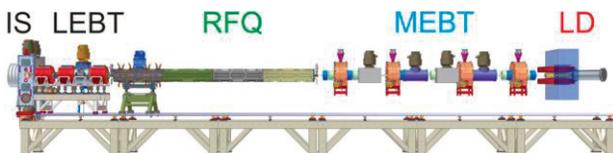


Figure 1: Layout of the FETS at RAL.

While the FETS LEBT system has proven to work as predicted and the degree of compensation has been determined to be in the range of  $\sim 95\%$  in equilibrium by comparison of experimental results with simulations, an experimental programme has been started to investigate the detailed dynamic process of space charge compensation for  $\text{H}^+$  beams with the main emphasis on

the time required to reach equilibrium. This is of interest for every pulsed high perveance beam as the time to reach equilibrium directly influences beam mismatch and beam losses due to those dynamic processes [3].

## EXPERIMENTAL SET-UP

The experiments were performed on the RAL FETS under construction illustrated in figure 1. Ion source and LEBT are operational, the RFQ is being machined and the MEBT is in the engineering phase while the Laser diagnostics (LD) is still in the physics design phase. An overview of the operational setup is shown in figure 2.

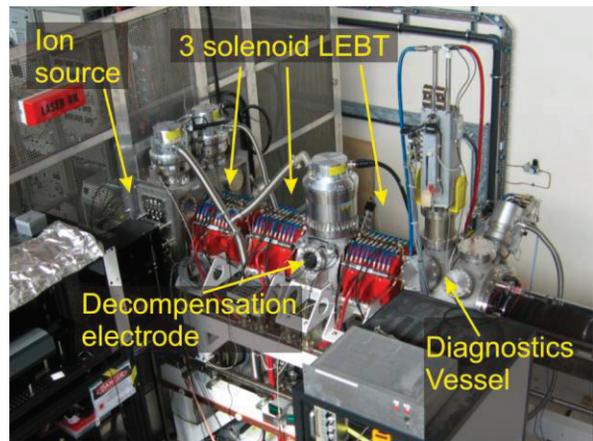


Figure 2: Overview of experimental setup.

For the measurements an insulated electrode was designed to fit onto the existing movable Faraday cup (FDC) in the drift vessel between solenoids 2 and 3 as illustrated in figure 3.

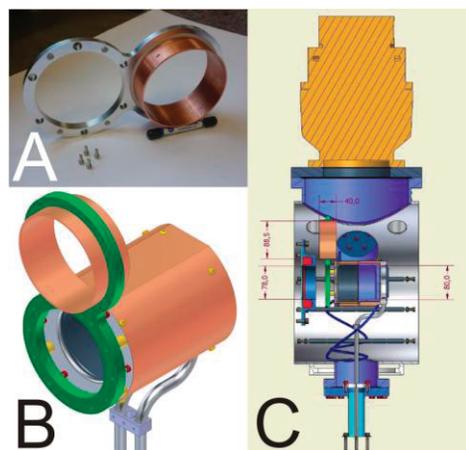


Figure 3: Details of decompensation electrode (A) mounted on the FDC mechanics (B) assembled in the drift vessel between solenoids 2 and 3 (C).

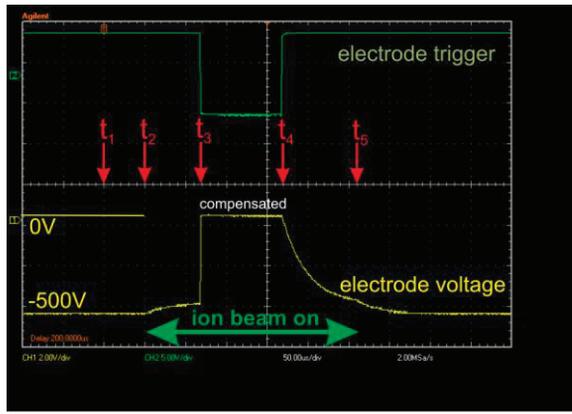


Figure 4: Overview of timing signals. Time<sub>1</sub> is defined by the master clock and starts the plasma formation in the ion source. At t<sub>2</sub> the beam extraction starts. At t<sub>3</sub> the decompensation voltage is switched off and at t<sub>4</sub> switched on again. Beam extraction is finished at t<sub>5</sub>.

An electrode of 40 mm length and 88.5 mm diameter is centred on the beam axis of the FDC is in the outermost position. The electrode can be biased with a fast HV switch to (-) 500 V. Details of the timing of the beam and the decompensation voltage are given in figure 4.

### EXPERIMENTAL RESULTS

The presented measurements were performed using a 65 kV H<sup>-</sup> beam with 40 mA of beam current. The pulse duration was set to 250 μs to enable measurements of a compensation time of up to 100 μs length after stabilisation of the ion source current (~150 μs). The results of time resolved emittance measurements are shown in figure 5. In this case the decompensation electrode was switched off permanently. This represents our default compensated operation mode.

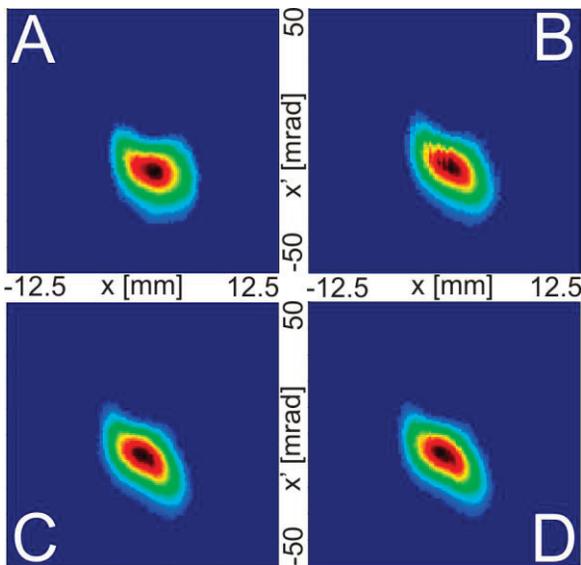


Figure 5: Transversal emittance at different times (A-D according to figure 6). Beam parameters do not change after ~ 150 μs when equilibrium is reached.

The results of time resolved emittance measurements, for the case that the decompensation electrode was switched as described in figure 4, are shown in figure 7 and compared with the previous dataset in figure 6.

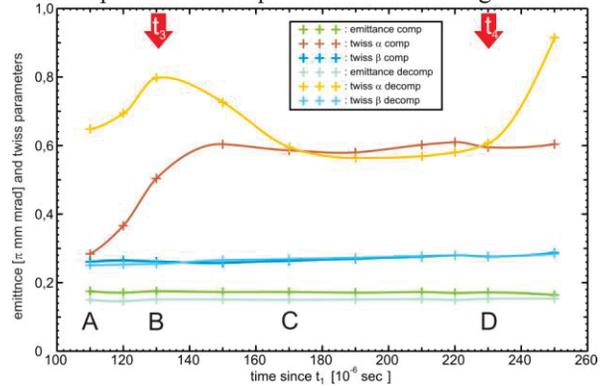


Figure 6: Development of emittance and twiss parameters as a function of time for the nominal beam (=comp.) and pulsed decompensated beam.

The decompensated beam (graph A & B) shows larger angular distribution due to the decompensation compared with the compensated transport. 50 μs after the compensation process started the beam has reached equilibrium which is practically identical with the undisturbed transport. As predicted by theory the compensation time is in the range of 40-50 μs. This behaviour is illustrated in figure 6. While the emittance in both cases is practically constant the change of the twiss parameter α can lead to mismatch and particle losses at the entrance of the RFQ. The fact that the rise time of space charge compensation (~50 μs) is shorter than the time required for the ion source to deliver a stable beam (~150 μs) means that a higher residual gas pressure in the LEBT will not reduce beam wastage at the pulse front.

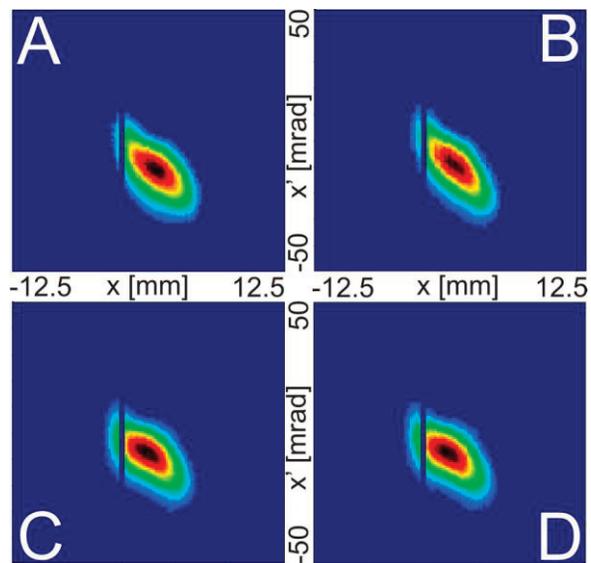


Figure 7: Transversal emittance at different times for pulsed decompensation operation. Beam parameters do not change ~ 50 μs after compensation started.

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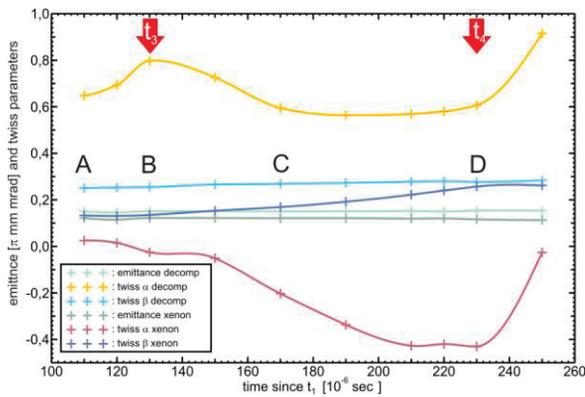


Figure 8: Development of emittance and twiss parameters as a function of time for the beam at nominal pressure (=decomp.) and with increased residual gas pressure (= xenon).

A further set of experiments has been performed at increase residual gas pressure. In general this should lead to a reduction in the rise time of compensation. While the nominal residual gas pressure in the drift vessel was in the range of  $2 \cdot 10^{-6}$  hPa mainly consisting of Hydrogen and Nitrogen this was increased to  $7 \cdot 10^{-6}$  hPa by injecting Xenon gas into the vessel.

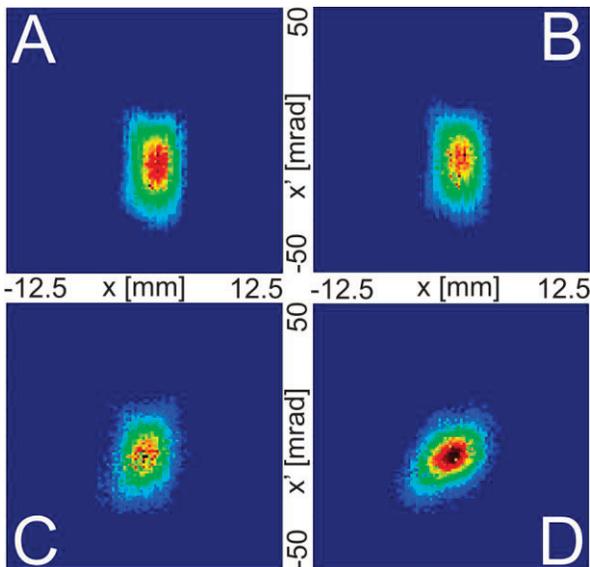


Figure 9: Transversal emittance at different times (A-D according to figure 8) for pulsed decompensation operation at increased pressure. Beam parameters do not change  $\sim 80 \mu\text{s}$  after compensation started.

From the results of the measurements it is obvious that the beam at increased pressure has a different twiss  $\alpha$  parameter at all times independent if the beam is compensated or decompensated. The orientation of the phase space ellipse indicates a compensation degree above the nominal pressure ( $>95\%$ ). Surprisingly, the time required to reach equilibrium compensation is longer than for nominal pressure which is in contradiction to theory except overcompensation is assumed.

## OUTLOOK AND DISCUSSION

The presented preliminary results have already allowed a better understanding of the different time dependent processes that lead to beam mismatch at the leading end of the beam pulse, but the data is not fully conclusive. To directly measure the potential distribution of the beam a Residual Gas Ion Energy (RGIE) spectrometer (see figure 10) [4] has been built and installed in the drift vessel. The first tests of the data acquisition software are underway and a further measurement campaign is planned for summer 2012. Those measurements should allow for a much more detailed analyses of beam transport and the rise time of space charge compensation as well as answering the question if overcompensation can be established in the presence of Xenon in the beamline.

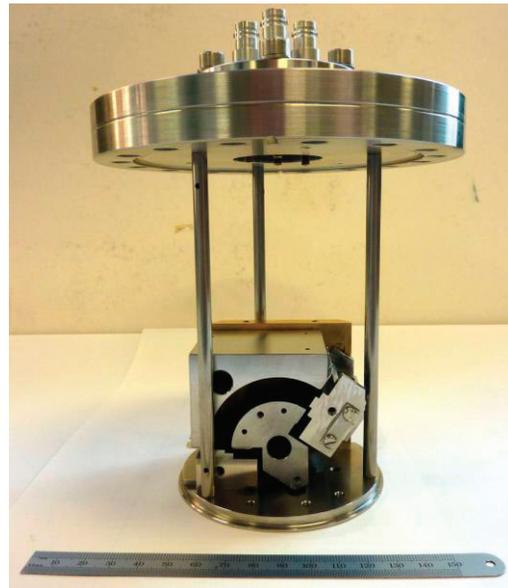


Figure 10: RGIE spectrometer to determine the potential distribution within the ion beam.

## ACKNOWLEDGMENTS

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## REFERENCES

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