INVESTIGATION OF SPACE CHARGE COMPENSATION AT FETS

J. Pozimski, P.Savage, S. Alsari, Imperial College, London, UK, A. Letchford, D. Faircloth, ISIS, STFC, Chilton, UK

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, 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 being assembled and tested. As a more detailed knowledge is of interest also for other projects like ESS, LINAC4 or PIXIE the FETS LEBT was updated to perform a detailed experimental analysis of space charge compensation utilizing a pulsed decompensation electrode together with a residual gas ion energy spectrometer and a fast emittance measurement device. In the FETS LEBT a high degree of space charge compensation (~90%) and a rise time of space charge compensation around ~ 50 µsec could be concluded from measurements [2]. In this paper the results of further experimental work will be presented together with discussion of the findings.

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 influence beam transport. The FETS low energy beam transport line has been designed keeping space charge effects in mind. 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.

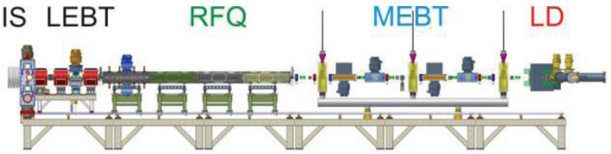

Figure 1: Layout of the FETS at RAL.

While for FETS the degree of compensation has been determined to be in the range of ~95% in equilibrium by comparison of experimental results with simulations, an experimental programme to investigate the detailed dynamic process of space charge compensation for H^- beams with the main emphasis on the time required to reach equilibrium [3] is underway. This is work is of general interest for every pulsed high perveance beam as the time to reach equilibrium directly influences beam mismatch and beam losses.

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 machined [4] and the MEBT is in the engineering phase while the Laser diagnostics (LD) in the design phase. An overview of the operational setup is shown in Figure 2.

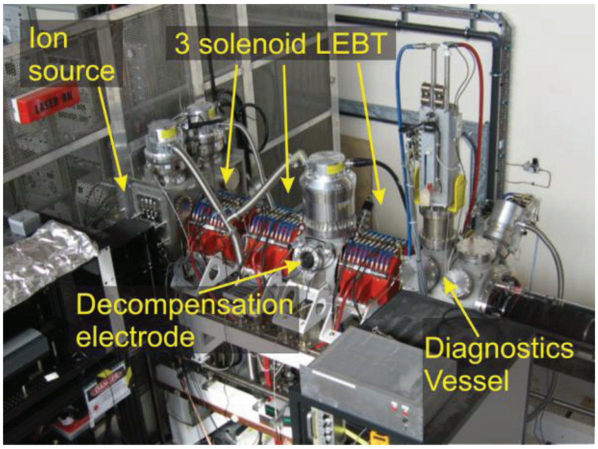

Figure 2: Overview of experimental setup.

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.

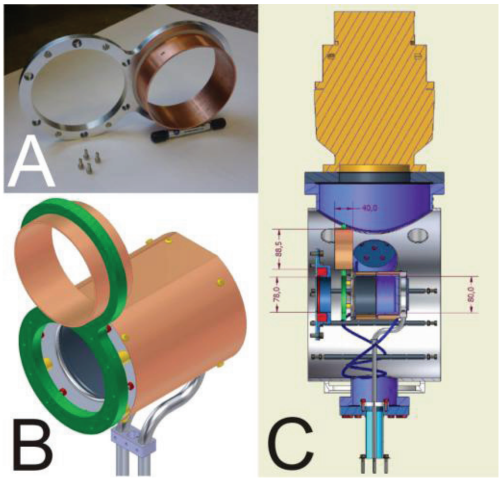

Figure 3: Details of decompensation electrode (A) mounted on the FDC mechanics (B) assembled in the drift vessel between solenoids 2 and 3 (C).

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.

ISBN 978-3-95450-122-9

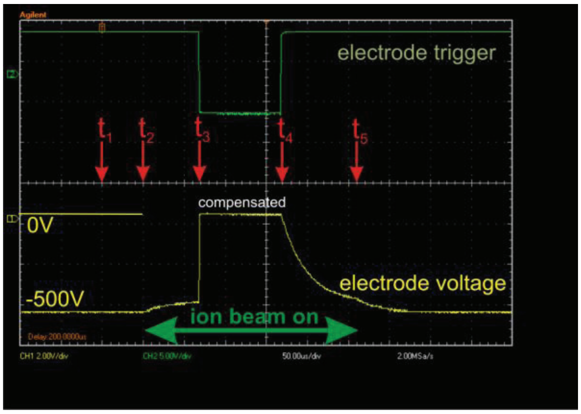

Figure 4: Overview of timing signals. Time t_1 is defined by the master clock and starts the plasma formation in the ion source. At t_2 the beam extraction starts. At t_3 the decompensation voltage is switched off and at t_4 switched on again. Beam extraction is finished at t_5.

EXPERIMENTAL RESULTS

The first measurements were performed using a 65 kV H^- 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. The decompensated beam (time A to B and after D) shows larger angular distribution due to the decompensation compared with the compensated transport. 50 µs after the compensation process started (C) 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. 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. As the rise time of space charge compensation (~50 µs) is shorter than the time required for the ion source to deliver a stabile beam (~150 µs) a higher residual gas pressure in the LEBT will not reduce beam wastage at the pulse front.

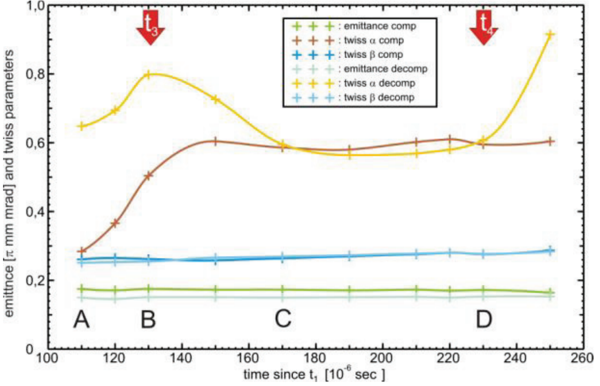

Figure 5: Development of emittance and twiss parameters as a function of time for the nominal beam (=comp.) and pulsed decompensated beam.

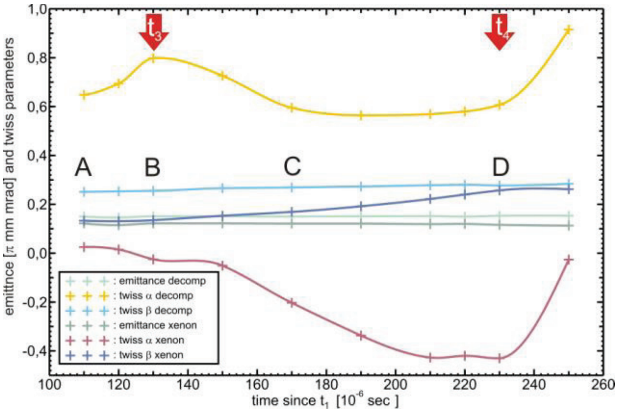

Figure 6: Development of emittance and twiss parameters as a function of time for the beam at nominal pressure and with increased residual gas pressure (= xenon).

A further set of experiments was performed at increased residual gas pressure. In general this should lead to a reduction in the rise time of compensation. The nominal residual gas pressure in the drift vessel is in the range of $2*10^{-6}$ hPa mainly consisting of Hydrogen and Nitrogen. The pressure was increased to $7*10^{-6}$ hPa by injecting Xenon gas into the vessel. From the results of the measurements shown in Figure 6 it is obvious that the beam at increased pressure has a different twiss α 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 to reach equilibrium compensation is ~ 30 µs longer than for the nominal pressure which is in contradiction to theory except overcompensation is assumed.

RESIDUAL GAS ION ENERGY SPECTROMETER

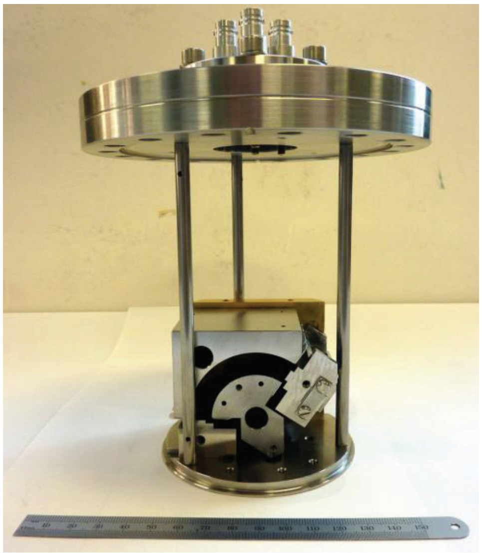

Figure 7: RGIE spectrometer to determine the potential distribution within the ion beam.

To directly measure the potential distribution of the beam and therefore resolve the question of overcompensation, a Residual Gas Ion Energy (RGIE) spectrometer (see Figure 7) [5, 6] has been built and installed in the drift vessel. The basic layout of the detector front end electronics and one of the energy spectra measured with this setup is shown in Figure 8.

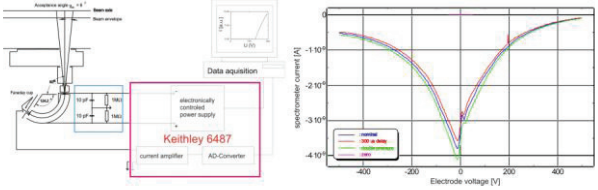

Figure 8: RGIE spectrometer first electronics setup and experimental results (for details see text).

The results gained with that setup show clearly that the maximum time resolution achievable with this technology is not sufficient for the proposed experiments. As this result was not fully unexpected an alternative electronics front end was installed and tested. The Keithley 6487 ammeter of the previous setup was replaced by a combination of power supply, fast current amplifier and a high bandwidth oscilloscope, as shown in Figure 9 (left hand side)

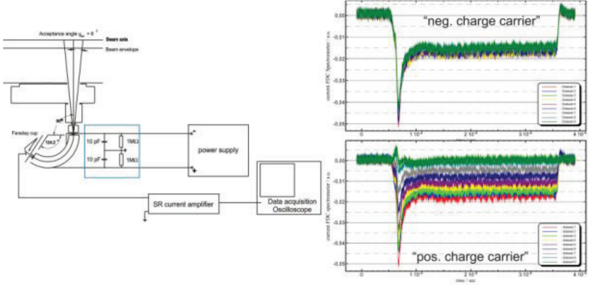

Figure 9: RGIE spectrometer second data acquisition setup and experimental results (for details see text).

This setup does not record the spectrum directly, but the spectrum has to be reproduced from measurements in time for fixed electrode voltages, as shown in Figure 9 right hand side. While the results achieved show good progress on the data acquisition side with peaks of positive charge carriers at some times visible as expected, but the measurements also indicate a problem with the influx of negative charge carrier on the detector when non should be detected. This subject has been address with an additional suppression electrode installed at the entrance of the spectrometer. This improved setup is under test and further measurements are expected as soon as the collimation electrode installed for alignment purposes at the entrance of the LEBT is removed and full beam current available. Preliminary data shown in figure 10 for the case of Xenon added to the residual gas indicate a very interesting dynamic when comparing the fully compensated and decompensated transport (DC -70 V). The pronounced positive current for compensated transport at the end of the beam pulse indicate that ions have been stored in the beam potential in this case.

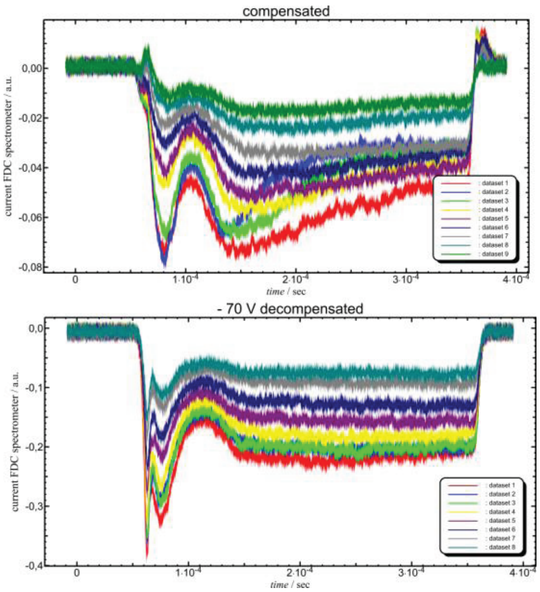

Figure 10: Preliminary spectrometer data with Xenon gas for compensated and uncompensated transport.

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. Further measurements planned for autumn 2013 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 beam line.

ACKNOWLEDGMENTS

We would like to thank Dr. Rudolf Dölling (PSI) for making the technical drawings of the RGIES available to the FETS collaboration.

REFERENCES

[1] A. Letchford et. al., "Status of the RAL Front End Test Stand" IPAC'12, Sitges, May 2012, THPPP051; http://www.JACoW.org
[2] C. Gabor et. al., "Experimental and Theortical studies of a Low Energy H^- beam" IPAC'12, New Orleans, May 2012, THPPP051; http://www.JACoW.org
[3] J. Pozimski et. al., "Investigation of space charge compensation at FETS" IPAC'12, New Orleans, May 2012, MOPPD037; http://www.JACoW.org
[4] P. Savage et. al., "Investigation of space charge compensation at FETS" IPAC'12, New Orleans, May 2012, MOPPD037; http://www.JACoW.org
[5] K. Reidelbach et. al., "Investigation of space charge compensation of Pulsed Ion beams," EPAC'94, London, June 1994; http://www.JACoW.org
[6] R. Döllinget. al., "Diagnostic of the compensation process of pulsed Ion beams with a time-resolving ion energy spectrometer", EPAC'96, Sitges, June 1996; http://www.JACoW.org