DEVELOPMENT OF AN ONLINE EMITTANCE MONITOR FOR LOW ENERGY HEAVY ION BEAMS*

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Abstract

RIKEN's 18 GHz ECR [1] (electron cyclotron resonance) ion source supplies the AVF cyclotron with beams ranging from protons to heavy ions as xenon. From comparison with the use of the RILAC (RIKEN Linear Accelerator) and beam transport simulations it was found that the transport efficiency is much lower. To this extend and with the aim to understand the ECR beam production, beam dynamics and optimize the beam transfer we have developed an emittance monitor based on the pepperpot method. The device is composed of a perforated copper plate, transparent scintillator and a CMOS camera for image capturing. Parameters of interest for scintillator's performance are the light yield and radiation hardness. Quartz was found to be resilient to damage and having linear light emission. A real time algorithm written in LabVIEW manages the data acquisition and the 4D phase space distribution calculation. Provided this information, we can investigate parameters such as inter-plane correlation and emittance dependence on extraction specifications, beam current and the magnetic field in the ion source. In this contribution we are presenting the emittance meter design, algorithm description and a set of typical measurements.

INTRODUCTION

For efficient beam transport in LEBT (low energy beam transfer) lines, the understanding of the beam production and beam dynamics is of very high importance. Beam transverse emittances are key parameters to quantify the beam quality and for an improved beam transfer, emittance matching between the ion source and the LEBT's acceptance is required.

For the case of RIKEN's 18 GHz superconducting ECR ion source, user experience has shown that the transport efficiency is much lower compared to the use of RIKEN's linear accelerator as injector. It has been confirmed experimentally with use of a scintillating screen at the entrance of the LEBT, that the beam size is larger than the LEBT aperture while the beam diameter at the extraction is around 1 cm. Moreover, preliminary beam dynamics studies suggested that the transport efficiency is about 16% and the beam emittance blows up in the area between the ion source and LEBT (~ 1m).

Studies by L. Groening et al and C. Xiao et al [2–4] on the concept of emittance reduction and emittance exchange have shown that it is possible to improve ion beam quality transport efficiency by exchange between the 2 transverse emittances.

With those considerations in mind and the goal to better understand beam transfer and improve beam quality we have developed an emittance monitor that allows for real time beam emittance measurements. The device is based on the pepperpot method which has been well studied and applied in multiple beam sources of electrons and ions..

EMITTANCE MONITOR

ECR Ion Source

The 18 GHz ECR ion source is used to provide various ion beams to the RIKEN AVF cyclotron. From there they are either further accelerated for RIBF or used for RI production and nuclear physics experiments. The ion source design is based on 4 superconducting solenoid magnets and a permanent hexapole magnet that generate a mirror magnetic field for plasma confinement. Different gases depending on the desired ions are injected in the ion source and heated up by microwaves produced by an 18 GHz reference source and amplified by a TWTA (traveling wave tube amplifier).

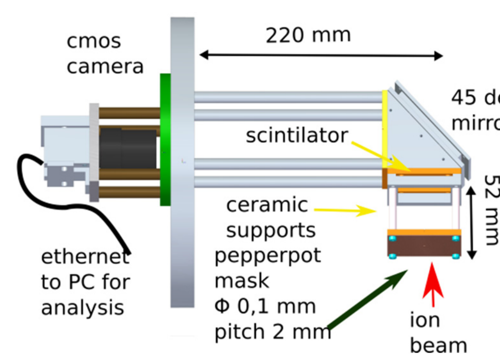

Figure 1: Emittance monitor schematic.

Pepperpot Device

The pepperpot device used here, Figure 1, is mounted on an ICF203 flange about 3m from the beginning of the LEBT. A 70x70 mm perforated copper plate with hole diameter of 0,1mm and pitch 2 mm intercepts the ion beam and splits it in small beamlets. The plate is electrically isolated so it can be used for direct beam current measurements for a measure of beam stability. Absolute current measurements are not possible as there is no secondary electrons suppression. The ion beamlets

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imping on a transparent scintillator 52mm downstream that produces visible light. Scintillators tested include CaF2 (Eu), CsI (Th), KBr and SiO2 (quartz) with quartz being the most suitable. Light produced by the ion-scintillator interaction is then recorded from the back side of the scintillator after being reflected by a 45^0 tilted mirror. The image captured device used here is a CMOS based (BFLY-PGE-13E4M-CS) Ethernet camera sitting behind a transparent glass viewport. The camera is water cooled for improved performance in high gain and high exposure time operation mode. A windows 7 operated PC running Labview is used for data acquisition and camera control.

Algorithm Description

A labview custom written algorithm acquires the images and calculates the 4D phase space distribution. It starts with an offline calibration for a fixed pepperpot position and size. This input provides the pixel to mm ratio and compensates for any rotation due to alignment tolerances of the device.

In the real time operation the software acquires images and isolates the beamlets while removing noise based on intensity and size thresholds. Every beamlet location corresponds to a pepperpot hole location with a known X and Y coordinate. From the difference between the hole's location and the actual beamlet location the beam divergence X′ and Y′are calculated and later used for the transverse rms emittances calculation E_x and E_y as given in literature [5]. Furthermore and to investigate interplane correlation the E_{4D} is calculated as described by Groeningen [2–4] that results in the coupling parameter t as:

$$t = \frac{E_x E_y}{E_{4D}}. \tag{1}$$

If this parameter is larger than 1 it indicates emittance interplane coupling that can be used to reduce the one of the 2 transverse emittances by emittance exchange.

The algorithm also plots the 6 combinations among X,Y, X′ and Y′ of the 4D phase space projections (Figure 2 top left) and the same plots after applying a different colour in groups or particle every 10 mm (Figure 2 top right). These plots provide a better visualization of any interplane correlations. Other parameters visualized depend on the performed measurements and they can be beam current, extraction voltage, etc.

It has to be stated that the user can highlight an area of the beam (Figure 2 bottom left) and plot the phase space distribution of it. This selection takes place on a binary image for better performance in real time. The usual operation speed of the algorithm is a few fps (1-5).

EXPERIMENTAL

For the current contribution, experimental results obtained by a 6.5 keV proton beam will be discussed. The beam current varied from a few euA to around 800 as measured from the pepperpot plate and not the absolute value. For the different beam currents, transverse emittances and the coupling factors were calculated (Figure *3*).

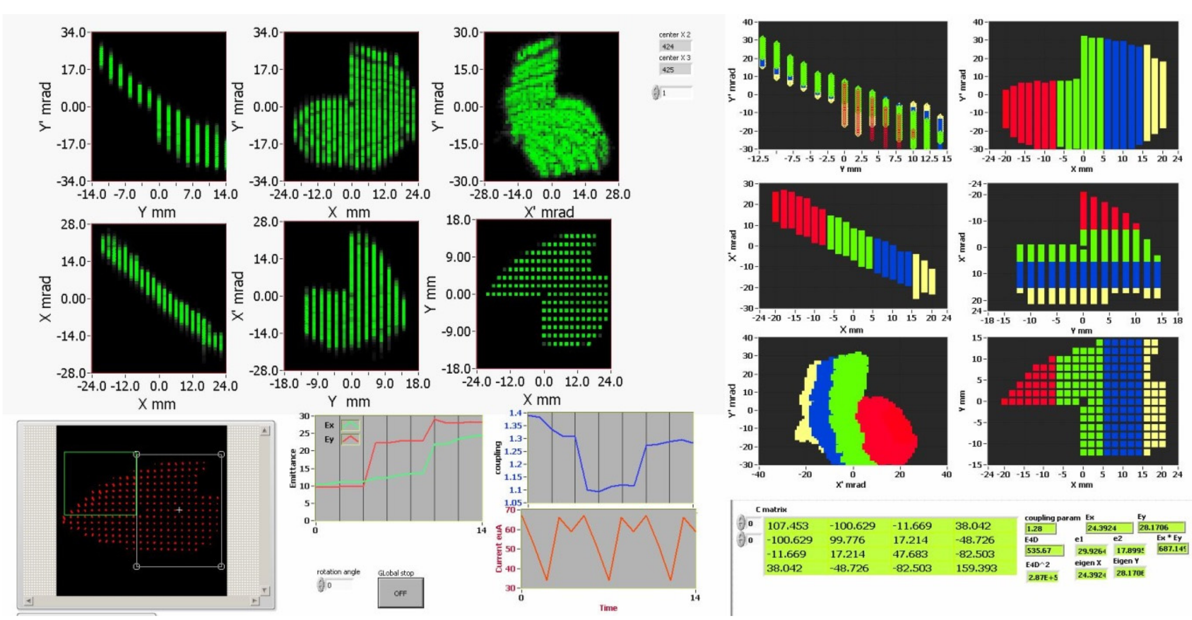

Figure 2: Sample image of the emittance meter algorithm. Various visualizations of phase space projections are shown as well as a binary beam image for selection of only a subset to plot.

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Secondly we measured the emittance while varying the position of the extraction electrode from 25 mm to 55 mm from the end of the ion source chamber, Figure 4. Final measurement is the emittance as a function of the mirror magnetic field by adjusting the solenoid current, Figure 5. For the last case the current values were such that the magnetic fields changed only locally around the 3rd solenoid downstream in the ion source. This only affects the beam near the extraction point as the fringe field decays past the ion source chamber.

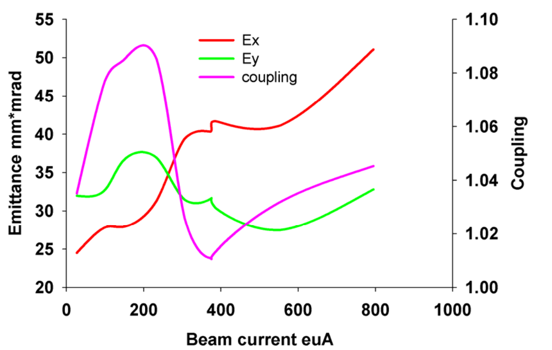

Figure 3: Emittance and coupling factor against beam current.

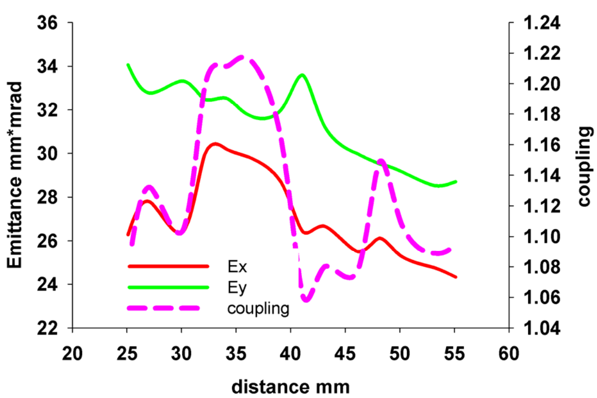

Figure 4: Emittances versus extraction electrode location.

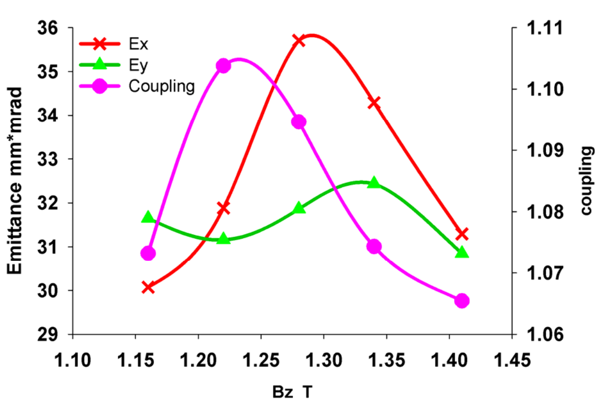

Figure 5: Emittances versus solenoid magnetic field.

RESULTS

As it can be seen here, variation in operating parameters of the ion source affects the beam emittance. The aim of this study is to investigate the operation of the ion source and find optimized value of the all the parameters for more efficient beam transport. The interplane coupling is small in all the measurements and reduces the possibility of emittance reduction by exchange between the 2 planes.

The beam emittance changes by up to 50% with beam current variations as *seen in Figure 3*. For the specific case the beam current was increased by increasing the microwave power that heats up the plasma. Nevertheless the beam current can be increased by other factors too such as the injected gas flow-rate. The very high values of current do not represent reality because of the lack of secondary electron suppression by the pepperpot plate.

The position of the extraction electrode affects the emittance too but it has a much smaller contribution. Variation of the solenoid magnetic field seems to have a greater effect and on the E_x than the E_y component.

SUMMARY

A real time emittance monitor is valuable tool for beam transport optimization and tuning. It will assist to the more efficient operation of the ion source when it will be completed. In the current state is can provide emittance measurements and plot in real time all the phase space components as shown here.

Further developments include better noise immunity, automatic parameters scans and. A new prototype is being prepared that includes retractable emittance monitor and a movable pepperpot plate to better fit the very tight space constrains.

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