EMITTANCE MEASUREMENTS FOR STABLE AND RADIOACTIVE ION BEAMS*

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Abstract

An emittance meter based on a pepper-pot coupled to a CsI(Tl) scintillator has been developed over the last several years [1] at Argonne National Laboratory. A compact version of such a probe for on-line emittance measurements has been designed, built and installed into the low energy beam transport (LEBT) line of the Argonne Tandem Linac Accelerator System (ATLAS) and also downstream of the gas catcher of the recently commissioned Californium Rare Isotope Breeder Upgrade (CARIBU). The probe has demonstrated the capability to measure emittance of ion beams with a current density as low as 10 nA/cm^2. Systematic emittance measurements in the ATLAS LEBT for different ion species have been done and results are presented. The probe, based on a pepper-pot coupled to an MCP viewing system, has been designed and built to measure the emittance of low intensity (10^2-10^6 ions/s) radioactive CARIBU ion beams.

INTRODUCTION

A pepper pot emittance probe has significant advantages in comparison with slits or Alison type emittance scanners providing on-line 4-D emittance data for both cw and pulsed ion beams. The intensity of the ion beams to be measured can vary by many orders of magnitude – from 10^3 – 10^4 ions/s in the case of rare isotope ions up to 10^{14} – 10^{15} ions/s in the case of the most intense ion species coming out of modern ECR ion sources. As it was shown in [1], a pepper pot coupled to a CsI(Tl) crystal is an effective tool to measure the emittance of ion beams with current densities above 100 nA/cm^2 (above 10^{11} ions/(s·cm^2)). Such an emittance probe is relatively simple and cost effective. No saturation of the Cs(Tl) scintillator was found for ion energies and current densities typical for ECR ion sources. For much lower ion beam intensities, the sensitivity of any scintillator is not high enough, thus implementation of microchannel plates (MCP) for ion registration can not be avoided. Having a very high (up to 10^7 in chevron configuration) gain, an MCP-based probe should be sensitive enough to measure the emittance of low intensity rare isotope ion beams. CsI(Tl)- and MCP-based on-line pepper pot emittance probes have been designed, built and installed into the LEBT line of the ATLAS, and also downstream of the gas catcher of the recently commissioned CARIBU. Systematic emittance measurements in the ATLAS LEBT for different ion species have been performed.

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PROBE DESIGN

The emittance probe design is similar to the design of BNL probe [2] in that the design of CsI(Tl)- and MCP-based probes are the same, except that 5 kV and 10 kV vacuum feedthroughs with spring loaded wires were added for the MCP based version to bring potentials to the MCP and phosphor screen. A photograph of the MCP-based emittance probe is presented in Fig. 1.

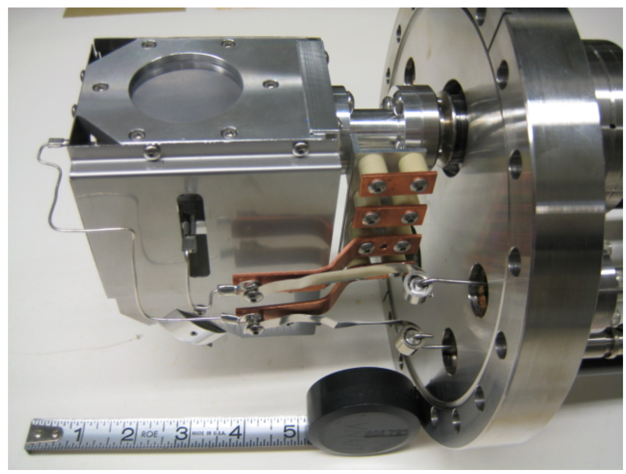

Figure 1: Photograph of the MCP-based emittance probe (scale is in inches).

A compressed air cylinder drives the probe between two positions: in and out of the beam pipe axis. The tantalum pepper pot plate with a diameter of 50 mm and thickness of 25 μm has a laser drilled aperture array (20 μm diameter holes with 500 μm spacing) over the whole area. The distance between the pepper pot plate and the CsI(Tl) scintillator (or MCP in chevron configuration coupled to P46 phosphor) is adjustable from 13.7 to 50 mm. A grounded fine nickel mesh with 88.6% transparency was attached to CsI(Tl) scintillator surface to prevent charge build-up caused by the ion beam. A plane mirror mounted downstream of the scintillator (or MCP coupled to phosphor) reflects the ion beam image through the vacuum window to the CCD camera. The CsI(Tl) scintillator (or MCP assembly) is shielded from secondary particles and scattered light by placing them inside a grounded metal box. A PC connected IMI TECH IMB-147FT 12-bit Firewire Monochrome [www.imi-tech.com] digital CCD camera with shutter speed variable in the range of 1 μs to 65 s and adjustable gain was used to acquire and save pepper pot images. On-line emittance measurements were performed by an application code developed on LabVIEW [www.ni.com] platform [1].

EMITTANCE MEASUREMENTS AT ATLAS

A description of the ANL ATLAS facility can be found elsewhere [3]. The CsI(Tl)-based emittance probe was installed in the ATLAS LEBT downstream of the second bending magnet. Emittance was measured for the following ion species generated by a 14 GHz ECR ion source: $^{55}Mn^{13+}$, $^{58}Ni^{14+}$, $^{40}Ar^{9+}$, $^{48}Ca^{11+}$, and $^{48}Ti^{13+}$. Currents and energies per charge state (q) of those ion beams are listed in Table 1.

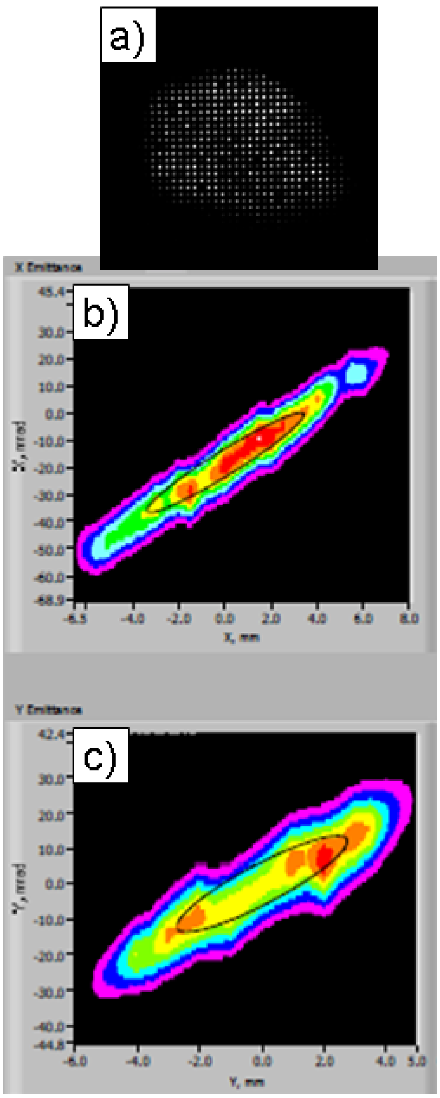

Figure 2 (a, b, c): Emittance data for a 151 keV/q $^{40}Ar^{9+}$ ion beam (a – pepper pot image, b and c – xx' and yy' trace spaces, rms emittance ellipses are plotted in black color) with an intensity of 3 eμA.

13.7 mm pepper pot – viewing screen distance was used for both ATLAS and CARIBU emittance measurements. The pepper pot image, together with xx' and yy' trace spaces for an $^{40}Ar^{9+}$ ion beam, are presented in Fig. 2 (a, b, c). All measured emittance data are summarized in Fig. 3.

Table 1: Currents and Energies of Ion Beams

Ion species	Current, enA	Energy, keV/q
$^{55}Mn^{13+}$	200	147
$^{58}Ni^{14+}$	100	143
$^{40}Ar^{9+}$	3000	151
$^{48}Ca^{11+}$	50	160
$^{48}Ti^{13+}$	900	166

The CCD camera gain and integration time were varied for all ion species to find the saturation threshold of the CCD camera. A criterion for the number of CCD saturated pixels to be between 1 and 10 was used for all emittance measurements. Such approach provides the most accurate emittance values [1, 4].

The emittances (4 rms xx' and yy' normalized) vary in the range of 0.2 – 0.9 π mm·mrad for all ion species. Normally, ATLAS runs for nuclear physics experiments with selected ion specie for about one week. Emittance data for $^{58}Ni^{14+}$ and $^{48}Ca^{11+}$ ion beams were taken at the beginning and end of the 5 day run cycles. As one can see from Fig. 3, the emittance became smaller at the end of the run cycles for both ion species. This is probably a result of ECR ion source conditioning over several days. In the case of $^{48}Ti^{13+}$ ion beam, the emittance was measured for radial and axial sputter rod insertion into ECR ion source chamber. Smaller emittance was found for the radial sputter rod insertion (Fig. 3).

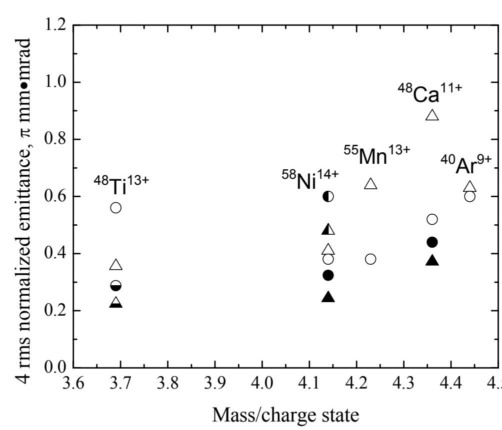

Figure 3: Emittance data for ion beams of different elements in ATLAS LEBT (transparent triangular and circle (symbols) – xx' and yy' emittance in the beginning of 5 days run (axial Ti sputter insertion), filled symbols – xx' and yy' emittance in the end of 5 days run, left-filled symbols - xx' and yy' emittance in the beginning of the second Ni run, bottom-filled symbols - xx' and yy' emittance for radial Ti sputter insertion).

EMITTANCE MEASUREMENTS AT CARIBU

The construction of the Californium Rare Ion Breeder Upgrade (CARIBU) [5], a new radioactive beam facility for the Argonne Tandem Linac Accelerator System (ATLAS), is complete. The facility will use fission fragments, with charge states of 1+ or 2+, from a 1 Ci ^{252}Cf source; thermalized and collected into a low-energy particle beam by a helium gas catcher [6].

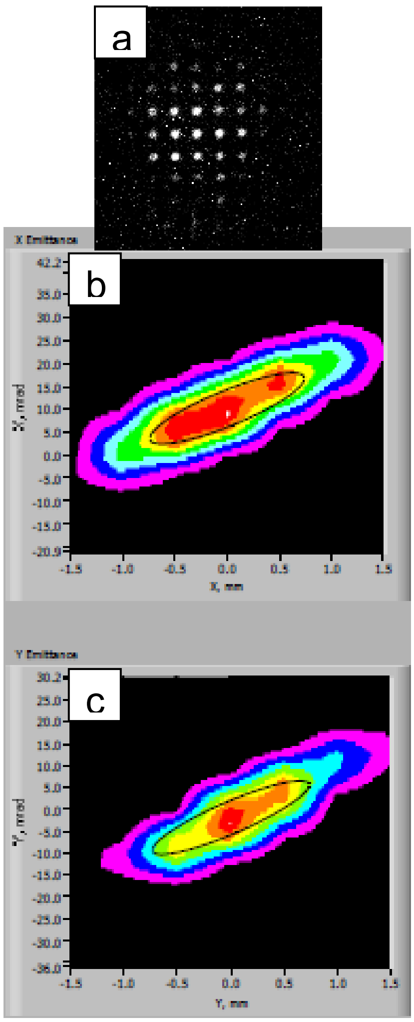

Figure 4 (a, b, c): Emittance data for a 25 keV/1.5 nA ^{40}Ar^{+} ion beam (a – pepper pot image, b and c – xx' and yy' trace spaces, rms emittance ellipses are plotted in black color).

The CsI(Tl)-based emittance probe was installed 50 cm downstream of the gas catcher output. Emittance measurements were performed with the gas catcher operating with an external source of ^{40}Ar ions. A ^{40}Ar^{+} ion beam with a current of 1.5 nA and an energy of 25 keV was extracted from the gas catcher. The diameter of the beam was about 3 mm and the ion current density about 20 nA/cm^2. The gain and integration time of the CCD camera were set to maximum values, so these measurements indicate the CsI(Tl)-based emittance probe's sensitivity limit. The results of the emittance measurements are presented in Fig. 4 (a, b, c). The emittances (xx' and yy' 4 rms normalized) averaged by three images are found to be 0.014 π mm·mrad both.

The sensitivity of the CsI(Tl)-based emittance probe is sufficient (up to about 10 nA/cm^2 for ion beam energy about 30 keV) to cover the entire range of stable ion beams generated by modern ion sources. However, higher sensitivity is required in the case of the CARIBU rare isotope ion beams which will have an intensity below 10^7 ions/s. An MCP-based emittance probe with gain up to 10^7 in chevron configuration is the right choice for those beams. As it was mentioned above, such a probe has been designed, built and will be used for on-line emittance measurements at CARIBU.

CONCLUSION

Two versions of a pepper pot emittance probe have been designed and built for on-line emittance measurements: a CsI(Tl)-based probe for stable ion beams and a MCP-based probe for low intensity rare isotope ion beams. The CsI(Tl)-based probe was installed into the ATLAS LEBT and downstream of the CARIBU gas catcher. The probe has demonstrated the capability to measure the emittance of ion beams with a current density as low as 10 nA/cm^2. Emittances (4 rms xx' and yy' normalized) have been measured in the ATLAS LEBT and are in the range of 0.2 – 0.9 π mm·mrad for all ion species.

ACKNOWELEDGEMENT

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