EMITTANCE MEASUREMENTS OF THE HIGH INTENSITY POLARIZED ION SOURCE AT IUCF

V. Derenchuk, R. Brown, H. Petri, E. Stephenson, M. Wedekind
Indiana University Cyclotron Facility, Bloomington, IN 47408

Abstract

The IUCF high intensity polarized ion source (HIPIOS) is now being routinely used to deliver beam to experiments. Recent efforts have been focussed on measuring beam properties in order to improve beam transmission through the cyclotrons and maximize P^2I, the product of the polarization and current delivered to the user. The results of measurements using a pepperpot beam emittance apparatus is presented relative to several source parameters.

I. INTRODUCTION

The IUCF high intensity polarized ion source (HIPIOS) has been used to deliver beam to users for over a year. Neutron time of flight and polarimetry measurements with the recently completed Indiana Neutron Polarimeter (INPOL) facility require polarized proton beam intensities of up to 500 nA at 200 MeV, with a microscopic time structure of ≈400 ps and a period of ≈340 ns. Both INPOL and internal polarized target experiments in the Cooler ring requiring high circulating beam intensities have recently benefitted from the use of HIPIOS. Development of HIPIOS and the 600 keV beam transport line have been described elsewhere[1,2], but to summarize the latest operating parameters, HIPIOS is currently able to deliver 170µA DC of mass analyzed $\vec{H}^+$, $p_z \geq .76$, with an emittance of 0.5 π-mm-mrad normalized, for 80% of the beam to the entrance of the 600 kV electrostatic accelerator column. While recent operating experience has been promising, HIPIOS beam characteristics continue to be studied in order to improve transmission through the cyclotrons and the P^2I delivered to the user.

II. TRANSMISSION AND POLARIZATION

Emittance matching to the 600 keV accelerator column is critical because of the tight focus and high divergence required at the first accelerating segment. If these conditions are not met, the column will introduce aberrations that will lead to emittance growth. Measurements in the 600 keV beam line (described elsewhere in these proceedings[3]) indicate that the normalized beam emittance decreases with terminal potential. At 400 keV, the emittance for 75% of the beam is less than 1/2 that at 600 keV. Transmission through the length of the beam line is improved at these lower energies.

The source has delivered $p_z \geq .75$ in both states with close to the highest ion beam intensity, but it appears that the beam, polarization may vary through its cross-section. It was concluded that a knowledge of how the beam emittance varied as a function of source parameters would help in understanding this phenomena.

III. IONIZER OPERATION

The ECR ionizer for this polarized source is unique in several ways. The beam is extracted from the source at an energy of 15 keV by biasing the plasma using the first electrode of the extraction system. This poses the primary problem of beam extracted toward the grounded atomic beam section of the source. We have experienced damage to the surfaces of and melting of insulators in the transition units immediately upstream of the ionizer. Beam extraction in this direction would also cause sparking, general instability of the plasma and a large energy spread. The solution has been to carefully isolate the plasma from ground potential by using quartz glass liners and a glass ECR buffer gas feed tube.

The ECR operates at 4.0 GHz, with a resulting higher average ionizer field strength than is used with the standard 2.45 GHz generator. The axial magnetic field strength in the valley of HIPIOS is greater than 1.30 kG at 4.0 Ghz.

The buffer gas used in the ECR, for operation with atomic hydrogen beam, is D_2 gas. To avoid hydrogen gas loading of the cryo-pumps, they are regenerated during dissociator maintenance periods. Operation and beam intensity using N2 gas is degraded due to a higher sputtering rate of the gridded extraction system and a decrease in plasma stability. A beam intensity increase of about 30% was observed when using D_2 buffer gas. This effect was predicted by A.Belov[4] as a result of his experience with the deuterium plasma charge exchange ionizer.

The accel-accel extraction system is a gridded design with a high transparency for atomic hydrogen that passes through the ECR without being ionized. There are two well aligned grids with a transmission of 95% followed by a tube lens. The beam emittance has been measured as a function of the voltage difference between the two gridded elements for several ECR parameters.

IV. EMITTANCE MEASURING APPARATUS

Emittance measurements in the beam transport line between the ion source and accelerator column are made using a pepperpot apparatus. A 0.05 mm foil with a matrix of 0.5 mm holes on a 3 mm center is placed 137 mm upstream of a wire scanner. The beamlets that pass through the foil are easily seen on a wire scanner trace (Figure 1).

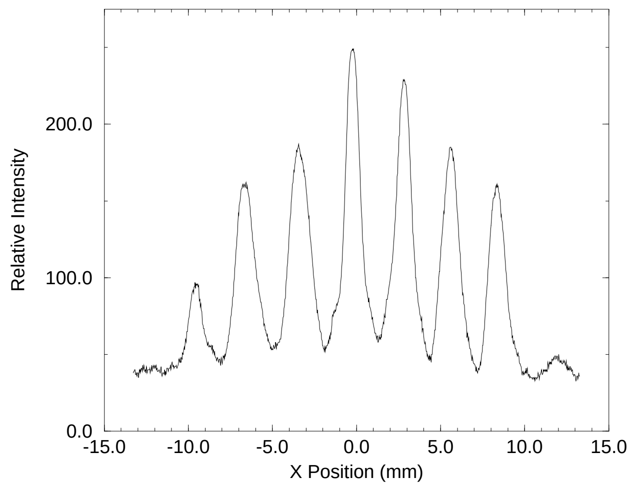

Figure 1: The horizontal part of a wire scanner oscillogram for an approximately parallel beam with few aberrations. The beam has passed through a foil with a 3 mm matrix of 0.5 mm holes.

Scans were stored on a HP digital scope and downloaded to a PC. Each peak was ascribed to one row or column of holes in the foil. An RMS analysis of the data points was made to give a rough estimate of a phase space ellipse that would best contain the beam. The Courant-Snyder parameters α, β and γ were calculated and used to evaluate the fraction of beam that fell within the boundary of a phase space ellipse of fixed size according to the following boundary condition;

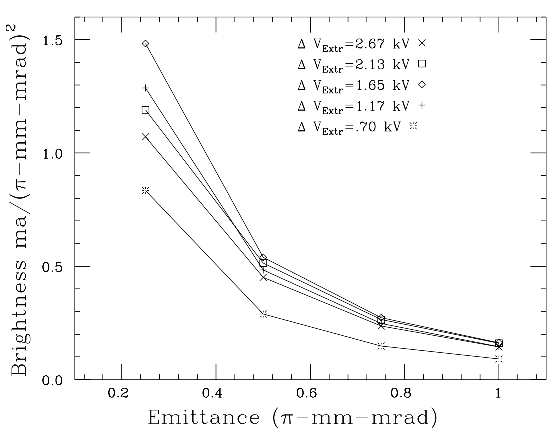

Figure 2: Brightness versus emittance for several values of the voltage difference between the two extraction grids.

$$\gamma(x-x_0)^2+2\alpha(x-x_0)(x'-x_0')+\beta(x'-x_0')^2 \le \varepsilon_x$$

where x and x' are position and divergence, x_0 and x_0' are the ellipse centroid and ε_x is the unnormalized emittance.

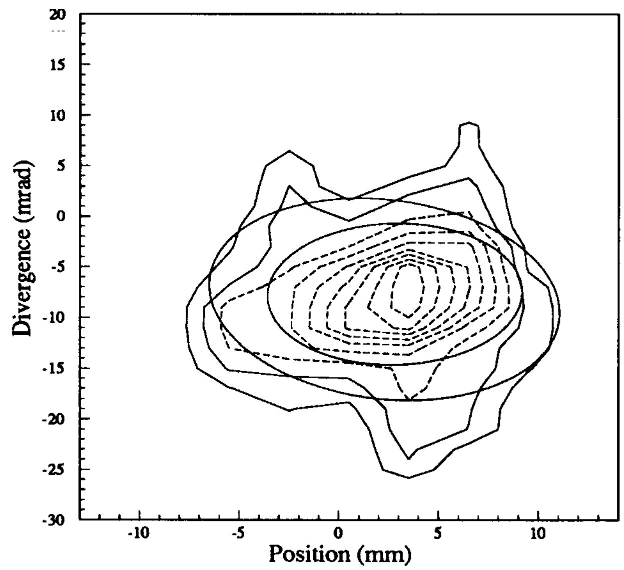

Figure 3: Emittance contour of a 170μA beam. An ellipse of 0.5 and 0.25 π-mm-mrad contain 80% and 55% of the total beam. The ellipses are superimposed on the real data.

Brightness was calculated for various values of the elliptical phase space area (Figure 2) using the total beam current on a stop downstream from the apparatus. All values of the phase space and the brightness are normalized to βγ.

In Figure 3, emittance contours of a 170 μA beam with good transmission are compared against a 0.5 π-mm-mrad and a 0.25 π-mm-mrad phase space ellipse calculated as described above.

IV. EMITTANCE MEASUREMENTS

The emittance as a function of several source parameters has been measured using the pepperpot emittance apparatus. The voltage between the two extraction grids, ΔV_{Ext}, was varied for different extraction energies, buffer gas pressures, and ECR RF power levels. The data for 4 different ECR pressures, adjusted by regulating the amount of D_2 buffer gas, and for 4 different values of the ECR power levels are plotted against ΔV_{Ext} in Figures 4 and 5 respectively. The optimum operating condition for the buffer gas variable is clearly indicated in the sharp peak in brightness at ΔV_{Ext} = 1.7 kV at a pressure of 5.3 x 10^{-7}T. Higher and lower pressures require a larger voltage difference to extract highest brightness beam. A similar but less obvious effect is seen for the ECR power level. During operation, it is clearly important to maintain the pressure at the optimum value. The normalized brightness for 80% of an optimized 170 μA beam is 0.54 (π-mm-mrad)^2.

Tuning of the beam is very sensitive to this voltage difference. Best transmission through the accelerator column occurs in a very narrow range of ΔV_{Ext} . One explanation of the variation in the peak brightness with respect to the ΔV_{Ext} could be that the shape of the ECR plasma surface near the grids is affected by the electric field strength. Variation in the pressure of the buffer gas and the ECR power level also affect the plasma density which would subsequently change the shape of the plasma surface near the grids due to space charge effects. Aberrations in the shape of the electric field between the grids cannot totally account for this behaviour.

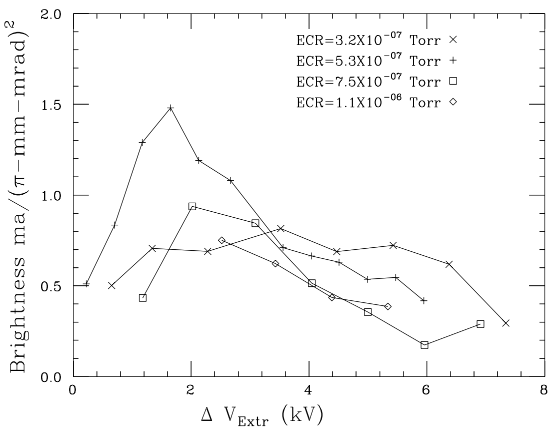

Figure 4: Plot of the beam brightness in a 0.25 π-mm-mrad ellipse as a function of ΔV_{Ext} for different pressures. The peak in the brightness varies with pressure.

Beam brightness is also related to the atomic beam density. Transmission of proton beam ionized from a deuterium hydrogen gas mixture leaked into the ECR is significantly less than beam produced from the atomic beam with a deuterium buffer gas. Emittance of the leaked gas beam will be measured and compared against the total emittance of the polarized beam to determine what contribution an unpolarized background gas will have on the final beam polarization. This is currently under study.

V. CONCLUSIONS

Beam emittance from a two gridded extraction system in the IUCF high intensity polarized ion source has been measured for several different parameters. The optimum voltage difference between the two extraction grids for best beam transmission and brightness varies with the ECR pressure and power. This could be explained by the change in the plasma density in the ECR.

The optimum tune results in a beam current of 170 μA at the entrance to the 600 keV accelerator column. The emittance of 80% of this beam is 0.50 π-mm-mrad has a brightness of 0.54 (π-mm-mrad)^2. This beam was measured to have a polarization of p_z=0.75 in both states.

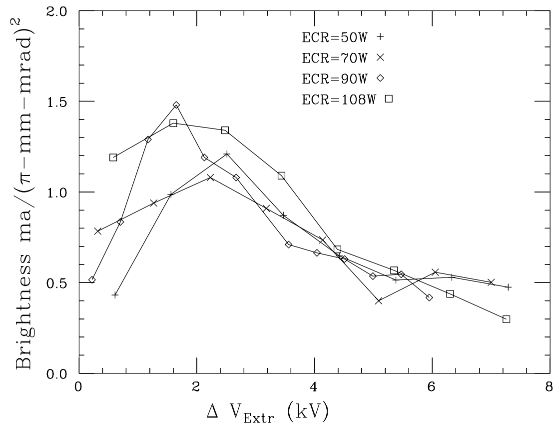

Figure 5: Plot of the beam brightness in a 0.25 π-mm-mrad ellipse as a function of ΔV_{Ext} for different ECR RF power levels. As in Figure 4, the peak varies with power.

VI. ACKNOWLEDGEMENTS

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VII. REFERENCES

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