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H^- beam emittance analysis in a multicusp ion source

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H^- beam emittance analysis in a multicusp ion source

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Abstract. Emittance of the ion beam extracted from an ion source is dependent on the initial focusing action at the plasma sheath. The properties of the plasma sheath is further dependent on the local electric fields and charge densities around the sheath. Experiments are conducted for creating different sets of conditions around the plasma sheath in an H^- multicusp filament ion source and the resulting emittance of the extracted H^- ion beam is measured. Variation of beam emittance under different plasma densities, electrode voltages and gas flows are analysed.

1. INTRODUCTION

Emittance is one of the most important quality parameters representing the extent of the spread of particles in an ion beam in phase space. Emittance of the ion beam, soon after the beam formation from the plasma, is determined by the initial focusing action at the plasma sheath. This plasma sheath is the boundary layer between the quasi neutral plasma and the extraction region where mostly negative charges are present. The shape and location of the plasma sheath is determined by properties of the plasma, geometry of the electrodes around the plasma and electric potential on the electrodes. At optimal shape of the plasma sheath, the produced beam emittance has a minimum value. Depending on the properties of the extraction system and beam transport, there might be other effects which contribute to the emittance. For example, the beam might suffer from aberrations in the extraction resulting in emittance growth or collimation which can decrease both the emittance and the measured current. Nevertheless, in a suitable extraction system, the emittance minimum should be observable in conditions where these other effects are avoided or at least minimized. In the current paper, different factors affecting the H^- beam emittance from D-Pace's TRIUMF licensed multicusp ion source are presented [1].

2. DETAILS OF THE ION SOURCE AND EXTRACTION SYSTEM

Section view of the filament ion source is presented in Fig. 1. Plasma is sustained inside the plasma chamber via thermionic emission from electrically heated Ta filaments. The filaments are biased at -120 V with respect to the plasma chamber and the corresponding current measured on the filament power supply is the arc current. H^- ions are generated inside the plasma mostly through volume production methods [2]. The plasma chamber is surrounded by Sm_2Co_{17} permanent magnets that form cusp fields, which confines the electrons in the plasma. The extraction system consists of the plasma electrode, the extraction electrode and the ground electrode [3]. The plasma and extraction electrodes are biased positive with respect to the plasma chamber for negative ion extraction. The co-extracted electrons are deflected on to the extraction electrode, before reaching the ground electrode, by the perpendicular magnetic field created by permanent magnets in the extraction electrode and is measured as the electron

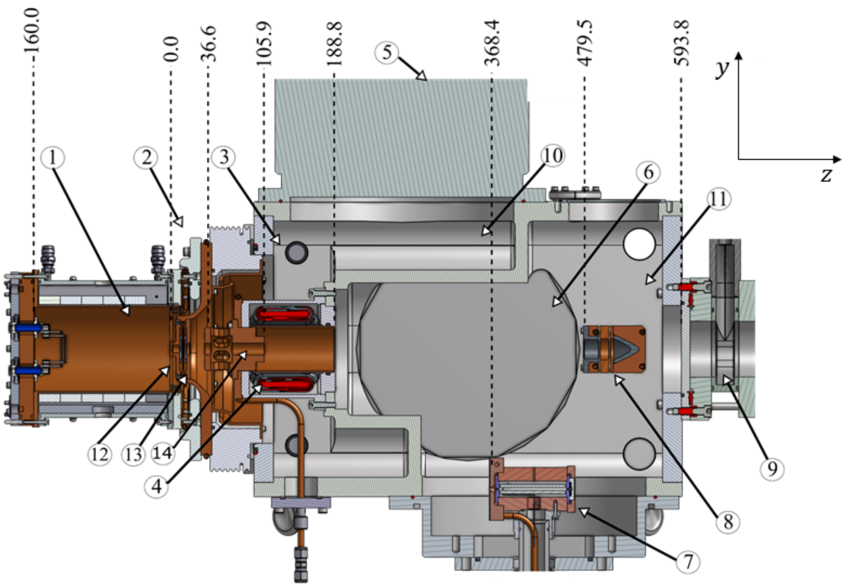

Figure 1: Section view of D-Pace's TRIUMF licensed multicusp filament ion source and extraction system. Ion beam is extracted in the z direction.

current, I_e. The plasma chamber and the plasma and extraction electrodes are biased at a negative potential (−30 kV) with respect to the ground electrode by the bias power supply. The current measured on the bias power supply, I_{bias}, represents the net charge flow from the ion source to the ground electrode region. Beam emittance is measured at about 368 mm downstream from plasma electrode, by D-Pace ES4 emittance scanner. This is an Allison-type emittance scanner which measures the beam intensity as a function of position (y) and angle (y′) simultaneously. Background electronic noise in the emittance data measurement is eliminated by discarding the beam intensity values below 4% of the maximum value. The Faraday cup is located at about 480 mm from the plasma electrode and can measure current (I_{FC}) in a beam of size up to 55 mm diameter. Since I_{FC} values are affected by the beam emittance, I_{bias} variable is used for characterizing the emittance variation in the current set of experiments. I_{FC} values are having a linear dependence on the measured I_{bias} values in the ion source.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1. Effect of gas flow on beam emittance

A set of experiments were performed at 30 keV beam energy to study the influence of H_2 gas flows on the beam emittance values from the filament ion source. In order to isolate the influence of the gas flows, the experiments were conducted at constant values of electrode potentials (V_{plasma} = 5 V, V_{ext} = 3.5 kV). Gas flows were varied from 8 sccm (standard cubic centimeter per minute) to 17 sccm for constant arc currents. This corresponds to about 10 mTorr to 20 mTorr of pressure inside the plasma chamber. The increase in H^- bias current (I_{bias}) extracted from the plasma is obtained by increasing the arc current and hence the plasma density, as shown in Fig 2(A). The beam emittance values obtained for the different conditions created in the experiment are shown in Fig. 2(B). As can be seen from the figure, the curve passes through an emittance minimum value at a certain I_{bias} value, for all gas flows. The minimum corresponds to an optimum plasma sheath shape [4]. The emittance grows to either side of the minimum,

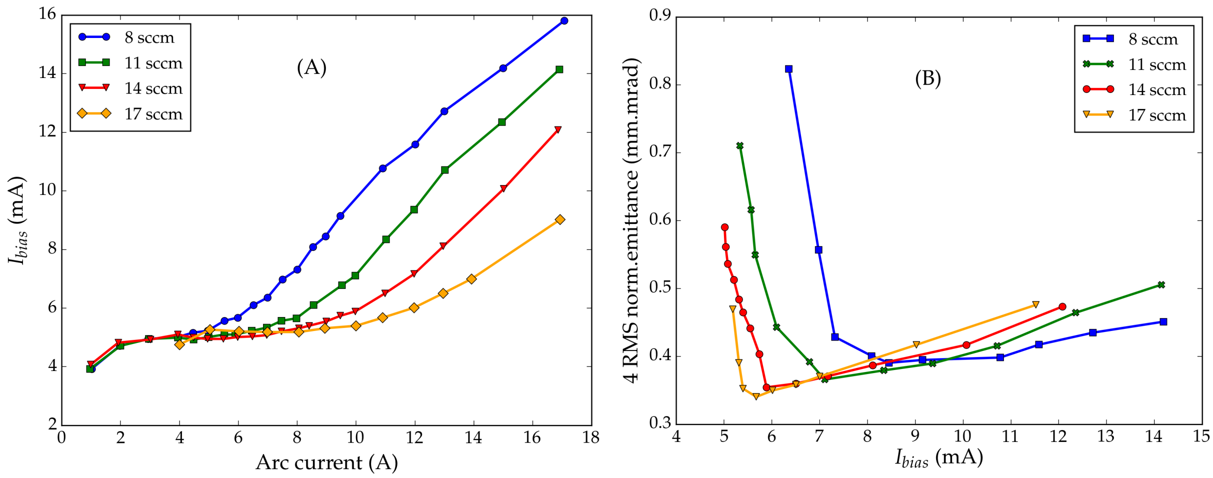

Figure 2: (A) Variation in I_{bias} and (B) beam emittance values at different arc currents and gas flows.

indicating the plasma sheath becoming more convex or concave from the optimum shape. The emittance minimum drifts to lower bias current values as the gas flow increases. This is contrary to the behaviour observed in some other filament ion sources, as mentioned in [4]. It can also be seen that the shift in emittance minimum decreases as gas flow values increases. The variation in the co-extracted electron current (I_e) obtained at the extraction electrode for the different arc currents and gas flows is shown in Fig. 3(A). As can be seen from this figure and Fig 2(A), both I_{bias} and I_e decrease as the gas flow increases. These currents correspond to the charged particle density in the regions close to the plasma sheath. The decrease in the extracted currents with higher gas flows suggests a decrease in the electron and negative ion charge densities near the plasma sheath. This could lead to the observed variations in the beam emittance values. The dependence of the emittance on gas flow points to the fact that the plasma sheath dynamics is influenced by the electron and negative ion charge densities near the sheath. Fig 2(B) considers only the negative ion charge density through the I_{bias} values. In order to include the effect of electron densities, we can define an effective current at the plasma sheath, I_{eff}, which corresponds to the sum of currents due to H^- ions and electrons [4].

$$I_{\text{eff}} = R_{ic} I_{\text{bias}} + R_{ec} I_e \sqrt{m_e/m_H}, \tag{1}$$

where m_e and m_H represent the mass of electron and H^- ion. Here R_{ic} and R_{ec} represents the negative ion density correction factor and electron density correction factor. These correction factors represent the transport properties of negative ions and electrons from the plasma sheath to the electrodes. A value of 1 for the correction factors means that the charge densities measured on the electrodes are equal to the charge densities near the sheath. The $R_{ic} = R_{ec}$ scenario suggests that the electrons and ions behave in the same manner in the plasma sheath and there are no factors that affect only the ions or electrons. The emittance values in Fig. 2(B) can now be plotted in terms of the effective current, I_{eff} in (1), such that the emittance minimum occurs at the same value in x-axis by choosing the appropriate correction factor values. This is shown in Fig. 3(B). The values used for the correction factors are $R_{ic} = 1$ and $R_{ec} = 1, 6, 11$ and 14, for the different gas flows. $R_{ec} > 1$ values suggest that the electron density in the plasma sheath region is higher than the observed current density corresponding to the co-extracted electron current at the extraction electrode. This is an anticipated result, as part of the electrons near the sheath will never get extracted. These electrons would get accelerated from the sheath, but they bend due to the magnetic fields and hit the plasma electrode. Hence the real electron to ion ratio at the sheath would be different from the values obtained by measuring currents at the electrodes in the experiments. It can also be seen that the value of R_{ec} increases with gas flow. This can be understood in terms of the

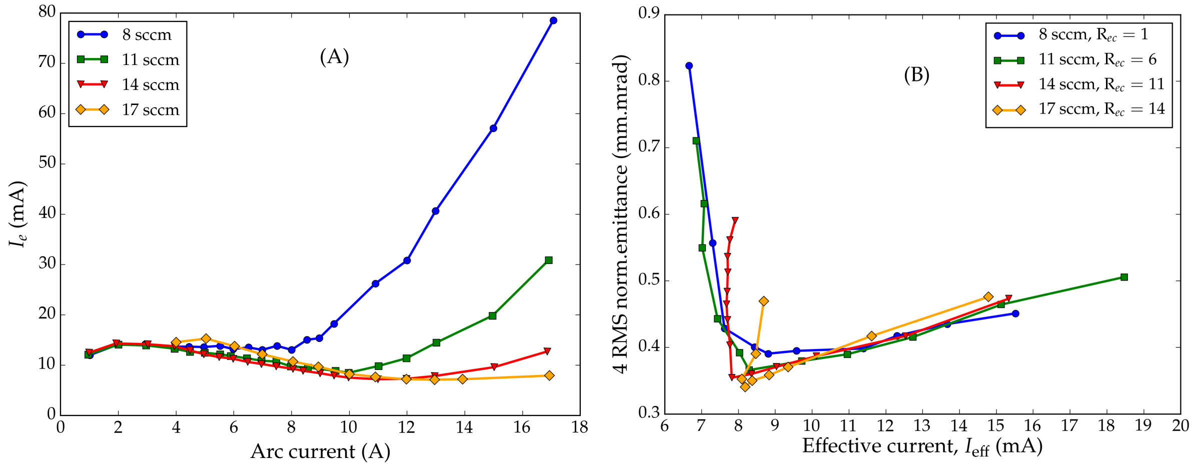

Figure 3: (A) Variation in co-extracted electron current (I_e) for different arc currents and gas flows. (B) Emittance values (as in Fig 2(B)) in terms of the effective current, using correction factors.

effect of pressure on electron transport and collisions in the plasma [4]. But such high R_{ec} values are difficult to comprehend as it represents very high electron density at the plasma sheath. Another set of correction factors which can produce similar results is when $R_{ec} = 1$ and the ion density correction factor R_{ic} =0.65, 0.8, 0.95 and 1.0 for the different gas flows. This indicates that the bias currents recorded at lower gas flows consist of charges other than the negative ions. In all cases, $R_{ec} \neq R_{ic}$ for different gas flows indicate that the emittance is dependent on the density of the type of particle species, ions or electrons, near the plasma sheath and not only on the total charge density.

3.2. Effect of extraction electrode voltage on beam emittance.

The variation in beam emittance values for 3 different extraction electrode voltages is shown in Fig. 4(A), for fixed values of gas flow (15 sccm) and plasma electrode voltage (5 V). This ensures that the variation in emittance values along a curve is only due to the variation in plasma densities from changes in arc currents. These graphs also reveal an emittance minimum for all the experiments. Fig. 4(A) also shows a decrease of emittance at higher bias currents (> 13 mA) for 3 kV extraction electrode voltage curve. The current at the Faraday cup (I_{FC}) was also found to be decreasing at this point even though I_{bias} continued to increase. The emittance scanner scans a region of about 50 mm length in the direction perpendicular to the beam propagation. Simulations reveal that the beam is more divergent due to space charge effects, leading to the loss of charged particles to regions outside the emittance measurement and hence a decrease in emittance values [3]. Also, there are more particles hitting the extraction electrodes, leading to beam collimation. Furthermore the emittance curve drifts to slightly lower values as the extraction electrode voltage increases. This is mostly seen when the plasma density increases from the emittance minimum. The curvature of the plasma sheath might play a role in this behaviour. Increase in the extraction voltage causes higher positive electric field near the plasma electrode, pushing the positive ions towards the plasma in the ion source. This causes the boundary of the quasi neutral plasma also to be shifted further towards the plasma, resulting in a more concave plasma sheath and this could lead to lower emittance values. Another factor that could contribute to the lower emittance values at high extraction voltages is the reduced space charge effects. Higher beam velocities experience reduced space charge forces and this could reduce the beam spread.

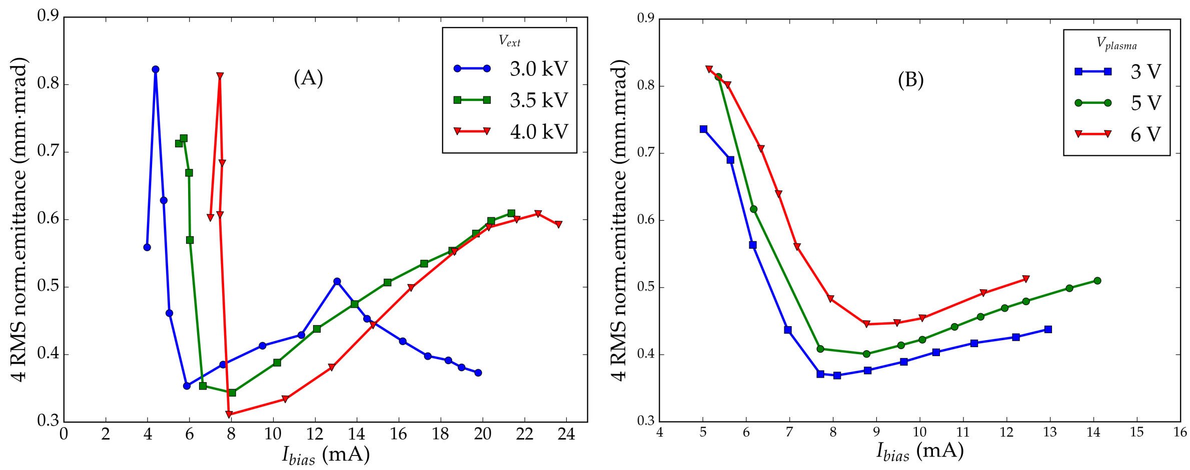

Figure 4: Beam emittance values for (A) different extraction and (B) plasma electrode voltages.

3.3. Effect of plasma electrode voltage on beam emittance
Experiments were performed to understand the influence of plasma electrode voltages on the beam emittance, using a fixed H_2 gas flow (8 sccm) and extraction electrode voltage (3.5 kV). The plasma electrode current increased proportional to the electrode voltage for fixed arc currents. This was accompanied by a decrease in the I_{bias} and I_e values. It suggests that increasing plasma electrode voltage depletes the corresponding charge densities at the plasma sheath, since the gas flow is constant. The effect of plasma electrode voltages on the beam emittance is shown in Fig. 4(B). As seen in the figure, the beam emittance minimum does not shift appreciably in terms of bias current. But, in general, the beam emittance values increase as the plasma voltage increase, for a fixed bias current. This could be attributed to the higher total charge densities needed for attaining a particular I_{bias} at high plasma electrode voltages. Furthermore, variations in the plasma electrode voltage could also affect the electric fields in the plasma sheath, leading to the trends in the figure.

4. CONCLUSIONS
The current paper reports the results of the experiments conducted to study the influence of different factors on the H^- beam emittance from D-Pace's TRIUMF licensed filament ion source. Different conditions of gas flows, extraction and plasma electrode potentials and arc currents were studied. The possible relation between the emittance results and the plasma sheath behaviour is also discussed. The results indicate that the H^- and co-extracted electron currents measured at the electrodes might not be a true representation of the charge densities at the plasma sheath, and the dependency between these parameters needs to be established. The study also suggests differences between the transport of negative ions and electrons from the plasma sheath to extraction.

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