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EXPERIMENTAL CHARACTERIZATION OF GAS SHEET TRANSVERSE PROFILE DIAGNOSTIC

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Abstract

The non-invasive characterization of high intensity charged particle beams is necessary in modern accelerators. Here, we present an update on a diagnostic that operates on the principle of beam-induced ionization across a spatially localized gas distribution. As the beam traverses through the gas sheet, the ionization cloud is transported and imaged on a detector to reveal beam transverse distributions. A modular gas jet transport allows for tunability of gas sheet parameters, while a tunable array of electrostatic lenses allows for the imaging of a variety of ion species. The benchtop results of gas sheet characterization using an insertable periscope probe are presented. In addition, preliminary results on the ion imaging system, including focusing with electrostatic lenses and detection on a micro-channel plate are shown for a low energy test case.

BACKGROUND

Non-invasive and non-destructive beam diagnostics are necessary for applications where beam quality is important and where high intensity beams preclude operation of standard techniques. In this paper, we present the development of a transverse beam profile monitor that operates on the principle of gas ionization. A supersonic gas jet is tailored, using an array of precision skimmers, into a thin curtain-shaped sheet (approximately 150 µm thick) oriented at 45° with respect to the beam axis. The localized gas density is introduced in the center of a diagnostic chamber orthogonal to the main beam. The charged particle beam passes through the gas sheet, and ionizes the neutral gas particles in its path; depending on the beam intensity, different ionization regimes may be considered. The ionization cloud is then imaged on a spatial detector, revealing information encoded by the passing particle beam. Reconstruction algorithms trained on simulation data provide further details in a rapid feedback system. A rendering of the complete gas sheet monitor is shown in Fig. 1.

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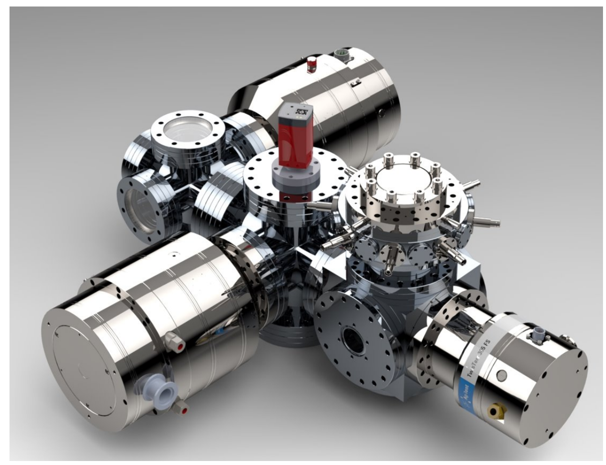

Figure 1: Rendering of gas sheet ionization monitor. The overall footprint of the monitor is < 1 m in the transverse direction, and < 200 mm in the longitudinal direction (i.e beam axis).

GAS SHEET MONITOR

The gas sheet ionization monitor is based on a successful design used prior for low energy beams [1]. The monitor incorporates a number of distinct engineering developments for complete operation. First, the gas delivery system includes multiple nozzles and skimmers and a fast-piezo valve. The shaped nozzles serve to first collimate the supersonic gas jet, and the second skimmer is used to shape the gas jet profile at the interaction region. The fast valve is used to decrease the gas load on the turbo-molecular pumps of the main chamber. Using a scheme that incorporates differential pumping, UHV levels of 1×10^{-9} mbar are maintained outside the localized density region of the interaction point. Using the gas delivery system, a local gas sheet of density ~ 10^{12}–10^{16} cm^{-3} is able to achieved, with a pulse duration variable from 40 µs - 400 µs [2], up to 1 kHz repetition rate.

In order to characterize the gas density, a diagnostic method was developed for bench top tests to compare against simulation results using the code MolFlow [3]. Figure 2 shows a sample measurment of the gas sheet density at the interaction region. In place of the ion microscope at the inter-

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action chamber, a diagnostic probe is situated on a shaft. The probe incorporates a slotted hole in a cylindrical tube that terminates in an ion gauge for pressure measurements. As the probe is translated vertically, it samples various portions of the gas jet propagating across the interaction chamber. The final skimmer in the gas delivery is a rectangular aperture with dimensions of 8 mm × 150 µm. The diagnostic probe measurements show a density distribution that is approximately 8 mm in length.

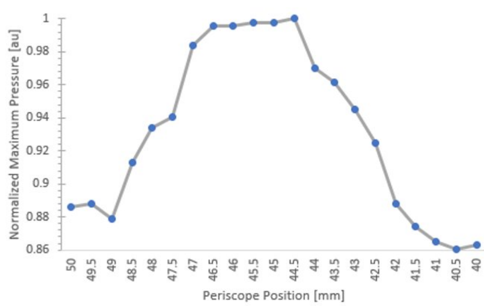

Figure 2: Measurement of gas density showing ~ 8 mm length, equivalent to long dimension of slotted skimmer.

The array of nozzles and skimmers also serves a dual purpose beyond gas jet generation. The small apertures allow segregation of each part of the chamber, and the use of independent control of pumping. The differential pumping scheme employed allows a rapid evacuation of the directional gas jet, and mainting high levels of vacuum near the interaction chamber along the beam direction. Figure 3 shows an example of the gas jet operation and the recovery of UHV in a timescale of ~ ms. In this specific case the gas pulse is approximately 40 µs in duration.

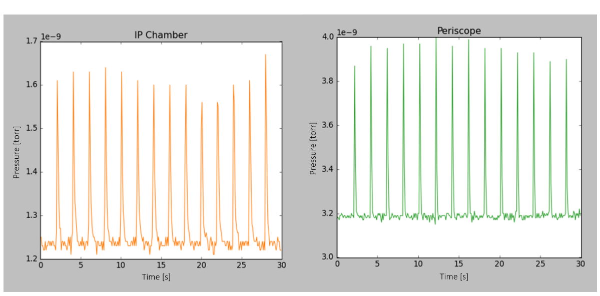

Figure 3: Measurement of vacuum levels during gas jet operation (0.5 Hz), attaining 1E-9 torr rapidly after pulse is evacuated.

The other main component of the gas sheet monitor is termed the ion microscope because its purpose is the direct imaging of ionized particles after the interaction. The microscope consists of an array of nine electrostatic lenses and is described in Ref. [4], and shown in Fig. 4. A repeller plate is held at positive bias on one side of the beam-gas interaction, and the focusing lens array is located on the other side. In the case of impact ionization, the electron beam leaves a correlated footprint of its transverse profile on the ionization cloud, so the electrostatic lens is designed to operate in an imaging condition, allowing for straightforward interpretation of the data. For the parameters of the available lenses and repeller ring, a magnification factor of ~ 8× is achievable. The ion microscope uses a micro-channel plate and phosphor screen as the detector. High voltage power supplies are used to individually control each of the lenses, as well as the bias on the micro-channel plate and the gain on the phosphor screen.

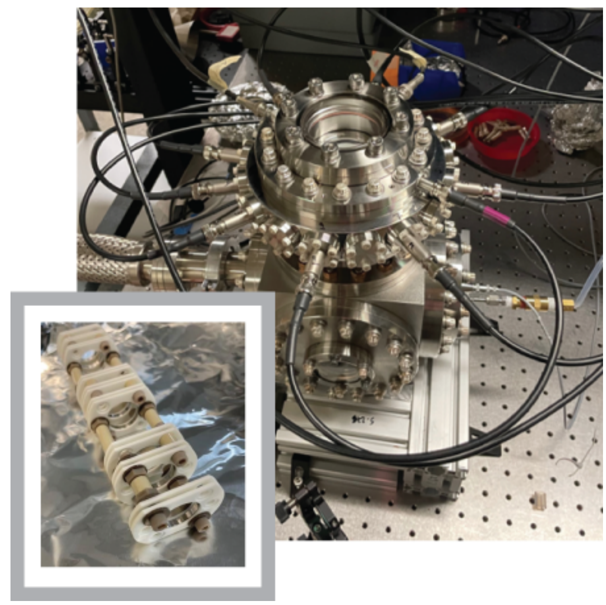

Figure 4: Photograph of the ion microscope chamber undergoing testing on the benchtop. The phosphor screen is visible at the top through a fused silica vacuum window. Inset: photograph of the electrostatic lens array during assembly.

COMMISSIONING

Although the gas sheet monitor is designed for utility at high intensity beam sources, initial commissioning of the device takes place with lower intensity beams. Testing with low-moderate energy beams, at moderate charge, allows characterization of the diagnostic and calibration with other well-established techniques. In this case, the gas sheet monitor initial commissioning stage takes place at the UCLA Pegasus photoinjector beamline [5]. The UCLA Pegasus facility provides electron beams with charge in the ~ 100 pC range, and spot sizes < 40 µm. Pulse lengths on the order of 200 µm are available with higher intensity achievable through compression. Initial simulations using the code WARP [6, 7] with the UCLA Pegasus beam parameters and a nitrogen gas sheet density of $n_0 = 1 \times 10^{14}\,\mathrm{cm}^{-3}$, and thickness 150 µm, were performed and summarized in Fig. 5. Impact ionization dominates in this regime and the expected ion charge is approximately 9 fC. The transmission for this case is > 95 %, indicating minimal space charge effects.

Although the ion count is lower than for higher charge beams, the ions are still readily resolvable by the detection

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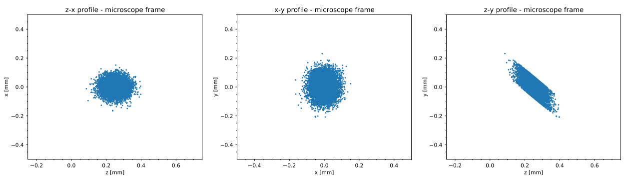

Figure 5: Simulations of the ion beam distribution after passage of a beam with Pegasus parameters showing x-y, x-z and y-z transverse dimension plots respectively.

system. In commissioning the ion microscope system, initial tests use a high power laser for ionization. Using a laser removes uncertainty with beamline operations, and provides a reliable and repeatable method to test the electrostatic lens array and imaging screen. In this case, a λ=800 nm laser, with 40 µm spot size and 50 fs pulse duration is propagated to the interaction chamber. Pulse energy is variable and initial tests used 1 mJ per pulse. The first image from laser-based ionization of gas in the ion microscope is shown in Fig. 6. The image shows a streak that corresponds to the direction of the laser axis, and is formed by manipulating the voltages on the electrostatic lenses in the column. Further tests are currently ongoing to calibrate the signal strength as a function of laser intensity and gas density, or pressurse as measured by ion gauges near the interaction point.

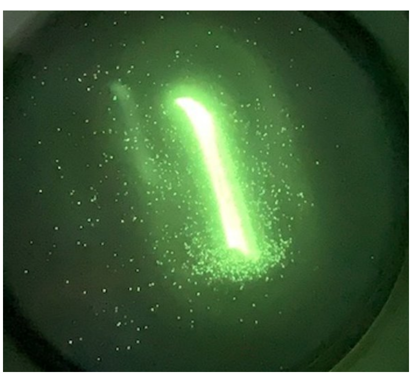

Figure 6: Raw measurement of first ions detected on ion microscope at the Pegasus lab, using laser-based ionization for commissioning.

CONCLUSION

The gas sheet ionization monitor is instrumentation developed for beam profiling of high intensity beams, and is adaptable for a wide range of applications, including ion detection and time-of-flight measurements [8]. Initial commissioning of the device has commenced with first results on gas jet delivery, vacuum recovery, and electrostatic lens array operations. Tests at the UCLA Pegasus laboratory continue with the goals of device calibration and exploration of ionization cross-sections for low energy beams. Successful utilization of the gas jet monitor would lead to other avenues, include electron beam streaking for high-resolution and gaseous sample delivery for pump-probe experiments [9].

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