ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-TUPLE06

SKIMMER–NOZZLE CONFIGURATION MEASUREMENTS FOR A GAS SHEET BEAM PROFILE MONITOR*

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Abstract

Understanding the characteristics of the gas sheet being produced and optimal configuration of the gas injection system is essential to the the performance of a gas sheet beam profile monitor. A gas injection system test stand has been built at Fermilab to test various nozzle and slit configurations. The distance between the nozzle and slit can be changed to find an optimal configuration. Using a moveable cold cathode gauge the gas profile is measured.

INTRODUCTION

Various diagnostic systems are desired in the accelerator community. Traditional transverse profile monitors are destructive to the beam, such as multiwires and scintillator screens. Residual gas monitors only measure one dimension of the beam and have a slow read back. If the gas is forced into a sheet and injected at an angle with respect to the beam direction, then a two-dimensional transverse profile can be measured.

The premise of a gas sheet beam profile monitor is as follows. A compressed gas is forced through a nozzle. As the gas travels downstream, it exhibits molecular flow due to a high Knudsen number [1]. It then reaches a skimmer, which removes any gas molecules with significant divergence and provides the final shape. The resulting sheet is then injected at an angle transversely to the direction of the particle beam. The beam ionizes the gas, after which the ions are extracted by a series of annular electrodes. A single or series of microchannel plates (MCPs) convert the ions to electrons and allow for an amplification factor of 10^3–10^6, typically. The electrons impinge on a scintillator screen, and the image is recorded by a high speed CCD camera. This allows the transverse beam distribution to be reconstructed. The amplification provided by the MCP allows for single pass readback, or the sparsely-populated tails of the beam to be imaged.

Understanding the injection system is crucial in order to have an appropriate sheet thickness and uniform distribution, as these two parameters directly impact the measured signal [2]. Simulations have also shown that if the distance between the nozzle and skimmer decreases, the distribution of the gas sheet tails become more prominent [3]. A test stand will give insight into the optimal configuration of the injection system, as well as a direct measurement of the sheet thickness and uniformity.

APPARATUS

Figure 1 depicts how the internal layout of the test stand. Figure 2 shows the test stand located at Fermi National Accelerator Laboratory. The test stand footprint is 4×8 ft.

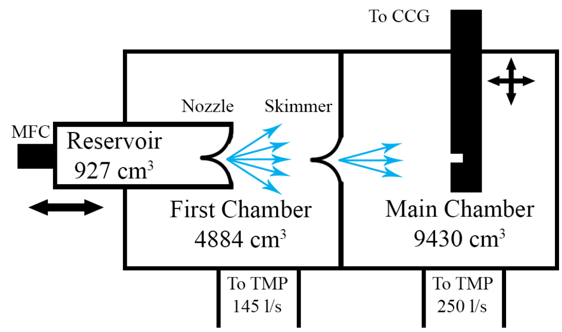

Figure 1: Sketch of apparatus setup.

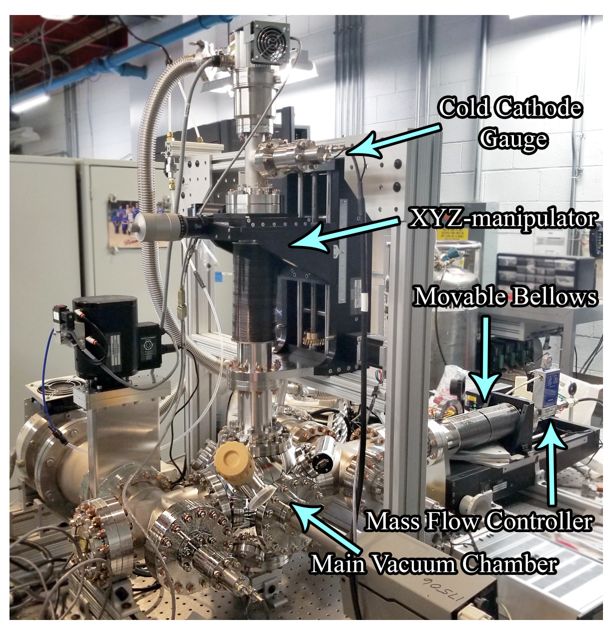

Figure 2: Gas Sheet Profile Monitor Test Stand.

The test stand is constructed as follows. A compressed nitrogen gas bottle is connected to a mass flow controller that can vary the flow up to 10,000 sccm. The gas is injected into a cylindrical reservoir of 927 cm^3. The reservoir is

* Fermilab is operated by the Fermi Research Alliance, LLC, under Contract No. DE-AC0207CH11359 with the US Department of Energy. This work is supported by the Office of High Energy Physics General Accelerator Research and Development (GARD) Program.
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ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-TUPLE06

on a bellows, which can be used to change the distance between the nozzle and the skimmer. At one end of the reservoir a nozzle is attached. The first vacuum chamber that is between the nozzle and skimmer has a volume of 4884 cm^3. Connected to it is a turbomolecular pump (TMP) with a pumping speed of 145 l/s. A skimmer is fixed in a holder between the first vacuum chamber and the main vacuum chamber. The main vacuum chamber has a volume of 9430 cm^3, with a TMP of pumping speed 250 l/s.

The system by which the gas distribution is measured in the main vacuum chamber is as follows. Attached to the chamber is an XYZ manipulator. The manipulator moves a cylindrical tube of volume 695 cm^3 with a small hole of diameter 0.24 cm facing toward the exit of the skimmer. Attached to this tube is a cold cathode gauge used to read back the pressure in this volume, as well as a 77 l/s TMP. Since the tube is movable, a full three-dimensional profile of the injected gas can be measured. The apparatus itself is fully modular and other nozzles and skimmers can be swapped out and tested. The test stand can achieve a pressure of 2.0×10^{-10} torr without gas injection.

METHOD

The standard operating procedure for measuring the gas distribution of a skimmer–nozzle configuration in the test stand is as follows:

1. Establish background pressure.
2. Move the detector to the first position of the scan.
3. Inject 150 sccm of nitrogen gas until cold cathode gauge read back plateaus.
4. Turn off injection, and wait until background pressure is reestablished.
5. Move to next vertical position.
6. Repeat steps 3–5 until a full vertical scan is complete.
7. Move to next horizontal position and repeat steps 3–6 until a full horizontal scan is complete.
8. Move to next longitudinal position and repeat steps 3–7 until a full longitudinal scan is complete.

The typical time it takes to do a full transverse scan in steps of 2 mm for a 20 mm by 20 mm grid is approximately 3.5 hours.

RESULTS

The full-width-half-maximum (FWHM) is determined by using the maximum peak center-line, with a function that uses a spline interpolation. The systematic uncertainty of the position of the gas distribution transversely, which includes the size of the detector hole and stepper motor resolution, is ±0.711 mm. The uncertainty of the distance between the nozzle and the skimmer is ±0.114 mm.

Figure 3 shows the gas distribution produced by a single nozzle, using a 1 mm step size scan. The FWHM of this figure is 14.56 mm at a location 4.52 mm away from the nozzle.

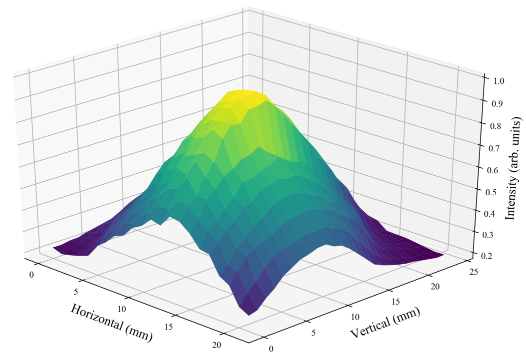

Figure 3: 2D scan of a single nozzle located 4.52 mm away.

The following are preliminary results of using two conical nozzles of length 6.99 mm, base diameter of 12.70 mm, and orifice diameter of 0.20 mm. Figure 4 is a transverse profile scan at three different detector planes of 4.52, 9.60, and 14.68 mm away from the skimmer, with a transverse step size of 2 mm. The skimmer–nozzle (S-N) distance is 31.35 mm. The intensity is normalized to the maximum peak located, which is located at the plane of Fig. 4c (4.52 mm). This peak intensity is four times greater than the peak at plane Fig. 4a (14.68 mm).

The center-line intensity can be compared at different skimmer–nozzle distances, as shown in Fig. 5 with the detector located 4.52 mm from the skimmer. The highest intensity is when the S-N distance is at 31.75 mm, were it is two times higher than the intensity of distance 47.62 mm. There is also a much more significant peak at S-N = 31.75 mm, indicating the skimmer is closer to sampling the correct subset of gas molecules coming from the nozzle than the other two S-N distances measured. The current smallest FWHM achieved was 8.88 mm vertically, and 3.32 mm horizontally, at skimmer–nozzle distance of 31.75 mm, measured 4.52 mm from the skimmer. Table 1 is the FWHM at various skimmer–nozzle distances and detector locations.

CONCLUSION AND OUTLOOK

A gas injection system test stand has been built and successfully tested two conical nozzles at Fermilab. FWHM values of 8.88 mm vertically and 3.32 mm horizontally were achieved. Optimization of the nozzle and skimmer geometry, as well as the nozzle-skimmer distance is ongoing.

A rectangular slit, shown in Fig. 6, with dimensions of length 50.75 mm, depth 0.2 mm, and width 12.75 mm, has been manufactured. Having a larger length to depth ratio than the length to diameter ratio of the conical nozzles, the smallest FWHM is predicted to be 0.22 mm. A design for aligning the conical nozzle and slit skimmer is being

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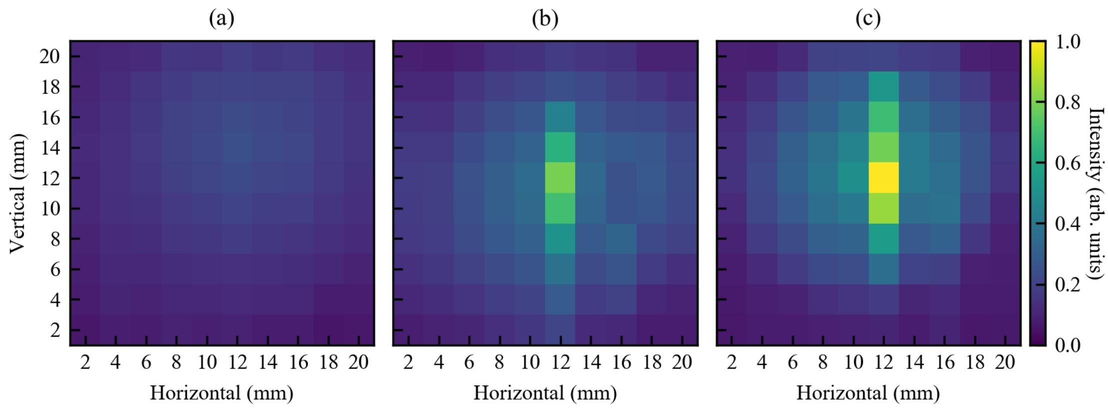

Figure 4: Slices of the transverse plane at distances of 14.68 mm (a), 9.60 mm (b) and 4.52 mm (c) from the skimmer. The skimmer–nozzle distance was 31.75 mm.

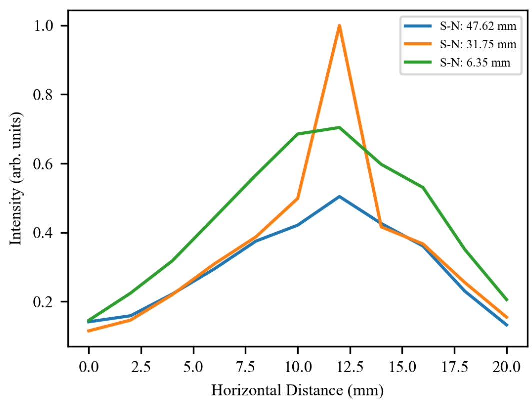

Figure 5: Horizontal profile at different skimmer–nozzle distances, measured 4.52 mm from the skimmer.

Table 1: Horizontal and Vertical FWHM at Various S-N Distance and Detector Location

Detector Location	FWHM (mm)	
S-N Distance = 6.35 mm	**Vert.**	**Horiz.**
z = 4.52 mm	15.69	11.65
z = 9.60 mm	20.78	12.83
z = 14.68 mm	23.18	19.24
S-N Distance = 31.75 mm		
z = 4.52 mm	8.88	3.32
z = 9.60 mm	9.72	4.27
z = 14.68 mm	23.9	18.77
S-N Distance = 47.62 mm		
z = 4.52 mm	11.65	12.40
z = 9.60 mm	14.93	15.51
z = 14.68 mm	24.51	18.42

explored. Once complete, the profile of the sheet produced will be characterized.

Figure 6: Rectangular Slit.

ACKNOWLEDGEMENTS

The authors would like to thank the Fermilab Accelerator Science and Technology (FAST) Facility team for their tremendous help and support, especially the vacuum technicians David Franck and Elias Lopez.

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