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# GAS-MIXING TO IMPROVE THE RESOLUTION OF NON-INVASIVE GAS JET-BASED IONIZATION PROFILE MONITORS

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*Abstract*

Ionization beam profile monitor using a supersonic gas jet is an attractive option for the characterization of low and medium energy beams. In this scheme, a primary beam crosses a 45-degree tilted thin gas curtain which causes ionization of gas molecules in the jet. The generated ions are then collected using an electrostatic extraction system to determine the 2D transverse profile of the primary beam. The most commonly used gases for the jet are neon and nitrogen. The signal from the gas jet is always super-imposed with the signal resulting from residual gases in the interaction chamber. CST simulations indicate that the gas jet speed is a key factor for the separation of the jet and the residual gas signals. To obtain a good signal separation, one can increase the velocity of the gas jet. This can be accomplished by generating a gas jet that mixes heavier and lighter gases. This contribution gives a general overview of the monitor design, discusses the effects of gas mixing and CST simulations results. It also presents experimental results obtained with Helium, and Nitrogen, as well as a mixture of them using different percentages and the impact on measurement resolution.

## INTRODUCTION

The working principle of ionization profile monitors (IPMs) can be summarized as detection of ionization products (gas ions or electrons) generated due to the Coulomb interaction between the primary beam particles and residual gas molecules, with the help of a strong external electrostatic field applied perpendicular to the beam propagation direction. These profile monitors are categorized as non-invasive or minimally invasive beam profile monitors that can operate in real-time and are highly desirable for any particle accelerator. In order to generate both transverse profiles of the primary beam, two IPMs oriented at right angles with respect to each other are recommended [1], however both cannot be placed at same location. In high vacuum accelerators, these devices are limited in both acquisition speed as well as resolution due to signal reduction. At the Cockcroft Institute (CI), V. Tzoganis *et al.* [2] developed a supersonic gas jet based beam profile monitor which works on the principles of IPM, but the charged species are generated by an interaction between a 45° tilted thin gas jet curtain and an electron beam [2]. The additional advantage of this monitor over the residual gas IPMs is the measurement of both transverse profiles or even 2D profile can be performed by a single monitor in the same way as an interceptive screen.

In medical accelerators, especially in Hadron Therapy machines, the particle beam is extracted from vacuum to ambient environment to treat patients. The particle beam has to pass through thin foil which provides passage to the beam without causing much perturbation. Due to the presence of these foils, the ultra-high vacuum is difficult to maintain towards the extraction point of the medical accelerators. Under these circumstances, the signal from the gas jet is always super-imposed with the signal resulting from residual gases in the interaction chamber. In order to improve resolution for these monitors operating in moderate vacuum conditions (~$10^{-7}$-$10^{-8}$ mbar), the signal from the gas jet and residual gas should be distinguished sufficiently. CST simulations were performed to determine the major factor contributing towards the signal separation and it was found that gas jet speed is a key parameter that defines the location of the peak originated from the gas jet curtain. For the same species of gas jet, jets with higher velocity can have a more distinguishable peak as compared to jets with lower velocities. Literature suggests that a gas jet generated after mixing heavier and lighter gases, can not only lead to higher velocity for heavier gas but can also increase the areal density of the heavier gas along the direction of motion [3]. This contribution includes the experimental results obtained with Helium, and Nitrogen, as well as a mixture of them using different percentages. The effect of gas mixing on the resolution of the monitor was compared with the CST simulation results.

## OVERVIEW OF THE MONITOR DESIGN

The monitor used for gas mixing studies is the same non-invasive IPM design and developed at CI for high-intensity beams such as the ones for the CLIC Drive and the European Spallation Source. [2, 4, 5]. The schematic of the whole setup is shown in Fig. 1. A nozzle -skimmers assembly with differential pumping stages is used to generate the supersonic gas jet curtain. The technique of gas-curtain generation can be found in our previous work [2]. The Interaction chamber was coupled with an electron gun which can generate an electron beam of energy up to 10 keV and this beam propagates perpendicular to the direction of the flow of the gas jet curtain. When the electron beam and the supersonic gas-curtain interact, it leads to ionization of the gas molecules and these ions will be extracted using an external electrostatic field generated by a series of hollow metallic electrodes. The ion signal is amplified using a micro-channel plate (MCP) which is converted into scintillating light with a phosphor screen and finally viewed by a CCD camera.

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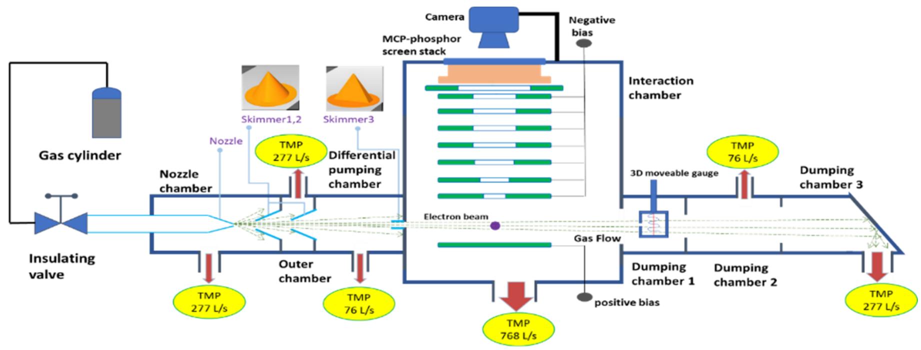


Figure 1: Schematic of the gas jet curtain based Ionization profile monitor.

## GAS MIXING STUDIES

The gas species taken under consideration were nitrogen, helium and a mixture of both. The initial measurements were performed for the aligned system under optimum conditions, using nitrogen and helium (at various stagnation pressures), to measure the 1D profile of a 5 keV electron beam carrying with a filament current of 2.60 A. One of the measured beam image using a helium gas jet curtain with a stagnation pressure of 5 bar are shown in Fig. 2, along with the line plot in the centre of the beam in the x direction. The left side peak indicates the signal obtained from the gas jet curtain and the right one indicates the signal obtained from background/residual gas available in the interaction chamber.

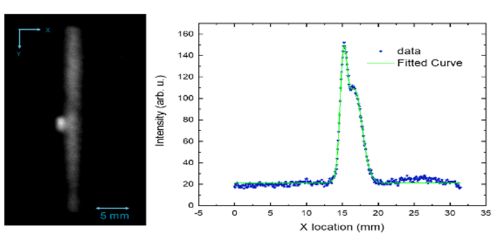


Figure 2: Transverse profile of an electron beam measured from the ionization of a helium gas curtain [6].

For gas mixing studies, the nitrogen and helium were mixed in a separate vacuum enclosed chamber with a ratio of 5:1 and then, this chamber is used as an input for gas jet curtain generation with the stagnation pressure of 2 bar. The schematic of the gas mixing setup is shown in Fig 3. The gases were allowed to mix for 30 minutes before the measurements were started.

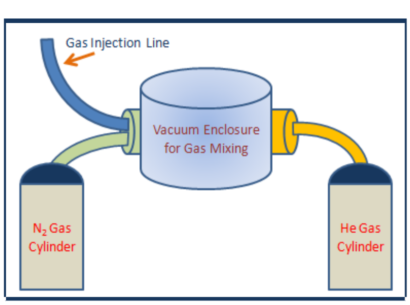


Figure 3: Schematic of the gas mixing setup at CI.

The measurements using the mixture gas were carried out in a regular interval. Then, they are compared with the ones with gas jet using nitrogen alone at various stagnation pressures.

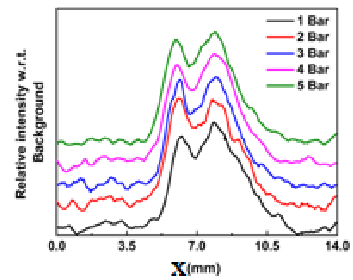


Figure 4: Transverse profile of an electron beam measured from the ionization of a nitrogen gas curtain (at different injection pressures). Each curve is offset by a value of 0.2 w.r.t. previous curve.

Figure 4 shows the transverse profile of the electron beam with the same parameters, generated using nitrogen gas injected at pressures varying from 1 to 5 bars. By increasing injection pressure and keeping all the other parameters the same, the signal from the gas jet curtain is increasing and then gets saturated in the range of 3-4 bar of injection pressure and eventually, starts falling again. The results are in agreement with the predication suggested by J. P. Valleau *et al.* [3], which is variation in density of the gas jet for a given system of nozzle-skimmers assembly with changing injection pressure.

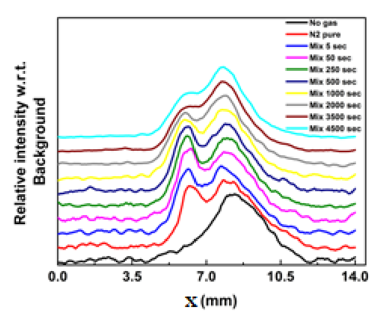


Figure 5: Transverse profile of an electron beam measured from the ionization of a mixture gas curtain of nitrogen and helium (5:1) gases (at 2bar injection pressure). Each curve is offset by a value of 0.2 w.r.t. previous curve.

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Figure 5 shows the transverse profile of the electron beam with same properties using mixed gas jet curtain generated at injection pressure of 2 bars. With increasing time, keeping all the other parameters same, the signal from the gas jet curtain is increasing as predicted by J.P. Valleau et al. [3], the density of the heavier gas would increase due to the introduction of the lighter gas. After 500 seconds, signal gets saturated and then starts falling again. The reason for this behaviour is the change in the composition of the gas over the period of time, since we currently don't have a dedicated system which can mix the two gases in desired composition and maintain the same ratio throughout the measurements.

We are assuming that since the mixed gases were extracted from the nitrogen injection end, for initial measurements, the composition is slowly changing from pure nitrogen to a mixture of nitrogen and helium gas with nitrogen as a major constituent, leading to increase in signal strength and resolution. With time, the helium concentration started to increase in the mixture beyond a certain limit, and leads to fall in intensity of the signal. This reduction in intensity with time is to be further studied in terms of up to what mixing percentage; there would be an increase in the intensity of the signal. Some of the detailed analyses of the results obtained for both measurements are shown in Figs. 6 and 7.

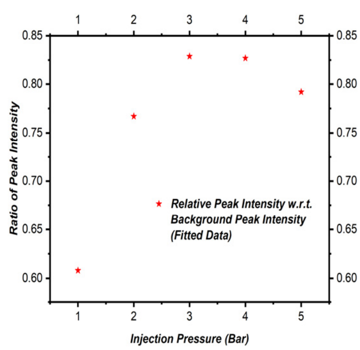


Figure 6: Relative signal peak intensity w.r.t background peak intensity obtained from the Gaussian fitted data; for nitrogen gas curtain at different injection pressures.

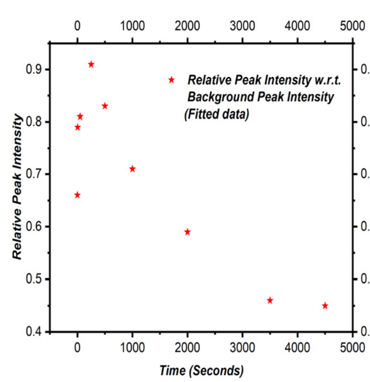


Figure 7: Relative signal peak intensity w.r.t background peak intensity obtained from the Gaussian fitted data; for mixture of nitrogen and helium in 5:1 ratio respectively.

Similar trends were observed for the ratio of areas under both peaks, separation between centroid locations for both peaks and relative signal FWHM w.r.t. background FWHM. The separation between the signal from gas jet curtain and background was slightly increased due to gas mixing as compares to pure gas, but there is some scope for further improvement. The gas mixing studies at higher injection pressures will provide further clarification on these studies.

CST simulations were carried out to check the effect of the velocity of gas species on the signal's centroid location. For the same extraction system, CST simulations indicate, for heavier masses with the same velocity, the separation from the background signal would be higher and similarly, for the same masses with higher velocity, the separation would be higher. One of the CST simulations result is shown in the Fig. 8 [6].

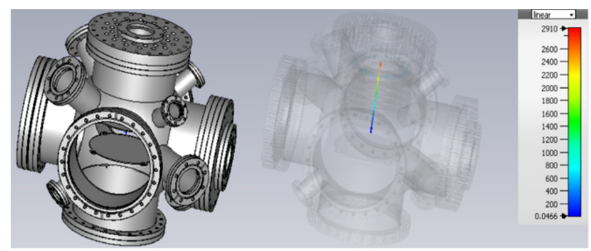

Figure 8: CST PIC solver simulations of supersonic $He^+$ jet trajectory under the influence of electrostatic field.

## CONCLUSION

The progress on the development of a supersonic gas-curtain based profile monitor has been presented here. It has been demonstrated that this device can be used as a viable profile monitor that utilises the beam-induced ionization in the gas curtain. The use of nitrogen, helium and their mixture as working gases was demonstrated and observed that mixture may offer a better signal to noise ratio for similar injection pressure. For a given injection system, the resolution obtained for 2 bar of injection pressure of mixed gas is similar to the resolution obtained for 4 bar of injection pressure of nitrogen gas. The time variation of signal for the mixed gas curtain is due to the changing composition of the mixture. This device would be highly desirable for non-invasive beam profiling for accelerators operating in moderate vacuum conditions.

## ACKNOWLEDGEMENT

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