A GAS JET BEAM HALO MONITOR FOR LINACS

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Abstract

The gas jet beam profile monitor is a non-invasive beam monitor that is currently being commissioned at the Cockcroft Institute. It utilises a supersonic gas curtain which traverses the beam perpendicular to its propagation and measures beam-induced ionisation interactions of the gas. A 2D transverse beam profile image is created by orientating the gas jet 45 degrees to obtain both X and Y distributions of the beam. This paper builds upon previously used single-slit skimmers and improves their ability to form the gas jet into a desired distribution for imaging beam halo. A skimmer device removes off-momentum gas particles and forms the jet into a dense thin curtain, suitable for transverse imaging of the beam. The use of a novel double-slit skimmer is shown to provide a mask-like void of gas over the beam core, increasing the relative intensity of the halo interactions for measurement. Such a non-invasive monitor would be beneficial to linacs by providing real time beam characteristic measurements without affecting the beam. More specifically, beam halo behaviour is a key characteristic associated with beam losses within linacs.

INTRODUCTION

Beam halo is typically regarded as a region of particles outside the beam core but the distinction of the boundary between beam profile and beam halo is highly dependent on the application. A geometric perspective could be chosen, describing it as density distributions beyond n sigma or from a formation perspective, as a function of the space charge or parametric resonance [1]. In linar accelerators, beam halo froms due to factors such as dark current in the cathode, emittance mismatch or skewness. In this paper, beam halo shall be defined simply by a low-density region surrounding the higher density central beam core. Further clarification of this definition is not required due to the proof of concept demonstration in this contribution. A low energy, 5 keV electron beam is used to demonstrate the available imaging region intended on capturing the halo, however it is unable to produce a measurable halo itself.

Typical diagnostics methods for beam halo include wire scanners, scrapers and screens [1]. These are all inherently destructive in nature to the beam. As such, non-invasive techniques are preferred for halo monitoring, such as coronagraphing synchrotron radiation with optical masks [2, 3]. However, this method also has drawbacks due to the energy requirements of generating synchrotron radiation suitable for imaging. The Beam Gas Curtain (BGC) aims to provide an alternative method of non-invasive beam diagnostics that may be more suited to specific beamlines.

The BGC diagnostics tool utilises a thin, supersonic gas curtain, inclined at a 45-degree angle which produces ionisation and fluorescent interactions between the working gas and beam [4-6]. The setup used in this contribution was configured as an Ionisation Profile Monitor (IPM). The gas ions created are collected upon a Micro Plate Channel (MCP) and imaged on a phosphor screen above the interaction point. This provides a real-time recreated 2D image of the beam at the location of interaction.

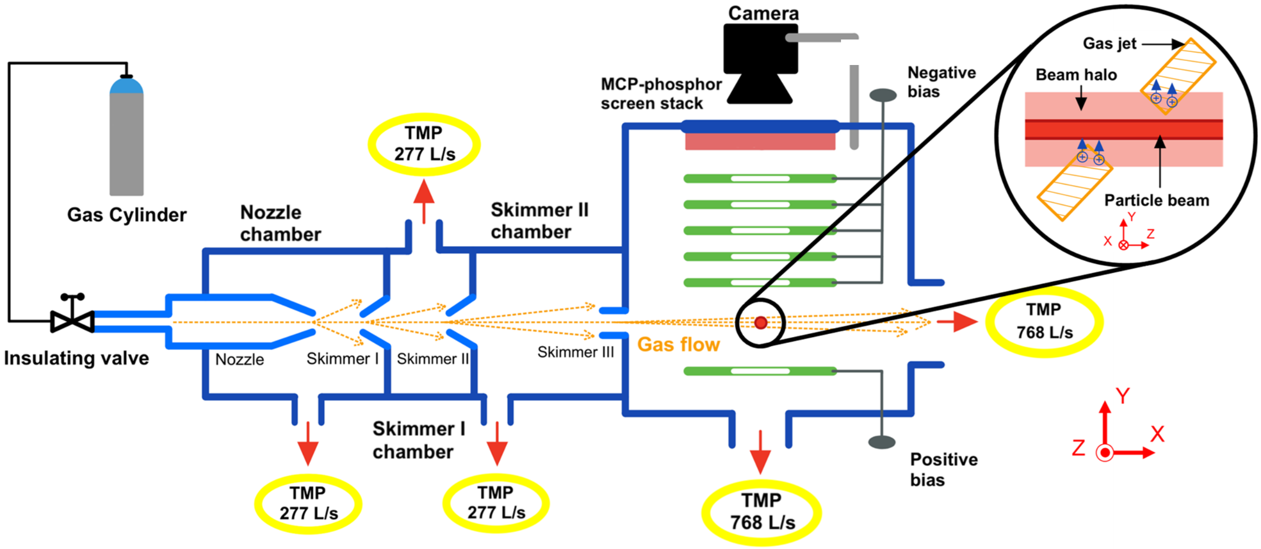

Figure 1: The layout of the Beam Gas Curtain setup configurated as an Ionization Profile Monitor for halo monitoring.

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The gas used is accelerated to a supersonic speed in the continuum flow regime and propagates through three skimmers to form a curtain of the desired shape and density. The skimmers separate the vacuum system into isolated pumping stages and remove off-momentum particles from the jet. This causes the jet to be highly directional and does not compromise the background vacuum pressure in the interaction chamber.

EXPERIMENTAL SETUP

Figure 1 shows a schematic for the BGC setup configurated as an IPM, which is used for the experiments described. The electron beam propagates perpendicular to the direction of gas jet flow such that in Fig. 1 it is propagating out of the page in the positive Z direction.

The setup uses a 30 µm diameter nozzle, a 400 µm diameter conical first skimmer, a 2 mm diameter pinhole second skimmer. The third skimmer includes two 0.4×10 mm^2 rectangular slits, both offset 2 mm from the centre point as shown in Fig. 2 (a). This double slit skimmer will shape the gas into two small curtains offset from the central masked region, as shown in Fig. 2 (b). During measurement, these two curtains will interact with the beam halo displaying the one-dimension ionisation distribution.

For ease of visualisation of the gas jet and proof of principle purpose, the 3rd skimmer was orientated such that the generated curtain is parallel to the beam propagation, as seen in Fig. 2 (b). This was intended to provide full gas curtain ionisation from the beam to demonstrate the curtain size, conventional measurements would be performed at a 45-degree orientation. The results presented in this contribution use an N_2 gas jet, pressured to 5 bar at the inlet.

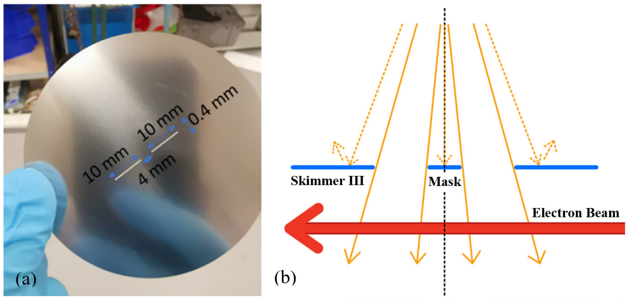

Figure 2: (a) Double slit third skimmer used to shape the gas distribution; (b) Gas curtain propagation representation.

GAS JET FORMATION SIMULATION

A custom simulation code was created to model the gas jet density and distribution in the BGC system, using analytical predictions for the continuum flow regime and Monte-Carlo particle tracking for the molecular flow regime [7].

Figure 3 depicts a 2D image of the gas jet at the interaction point in the Y-Z plane. A large density gradient is observed around the jet, visualised by a sharp density drop at the edges of the jet. The simulation removes particles outside each skimmer orifice, therefore background pressure is not simulated. The simulated dimensions of the gas jet are shown in Table 1, note that the width dimension refers to the thickness visible in Fig. 3.

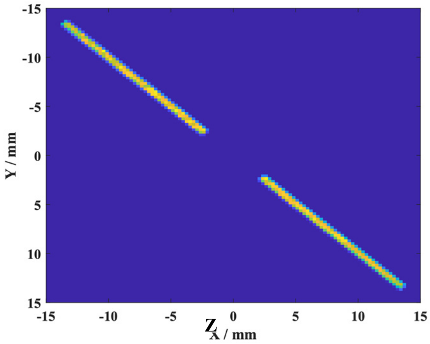

Figure 3: Simulated jet distribution in 2D at interaction point.

Table 1: Simulated Dimensions of the Jet

Dimension	Upper Slit	Mask	Lower Slit
Height	15.36 mm	6.92 mm	15.36 mm
Width	0.808 mm	0.808 mm	0.808 mm

EXPERIMENTAL RESULTS

As the low-energy (5 keV) electron beam passes through the system, it is subject to the electric field generated by the ion extraction system for imaging. This causes the beam to be deflected. As such, the entire curtain cannot be ionised with a single measurement as is idealised in Fig. 2 (b).

Instead, a composition of multiple measurements with different deflection angles of the electron beam gives a representation of the entire jet curtain as shown in Fig. 4 (a). The edges of the gas jet seen in this figure have clear cutoffs, which describe a large density gradient between the jet and the surrounding background gas. However, the lowest edge of the jet does not possess a sharp edge and instead has a visually noticeable density gradient. It is anticipated that the incomplete curtain was caused by a misaligned skimmer. The centres of the skimmer plate and gas jet are misaligned such that one of the slits overlaps the edge of the jet. This causes the Gaussian edge of the jet to pass through the skimmer and to be present in the interaction chamber, rather than producing the idealised flat-top distribution. The alignment of the skimmers will be adjusted to correct this in later experiments.

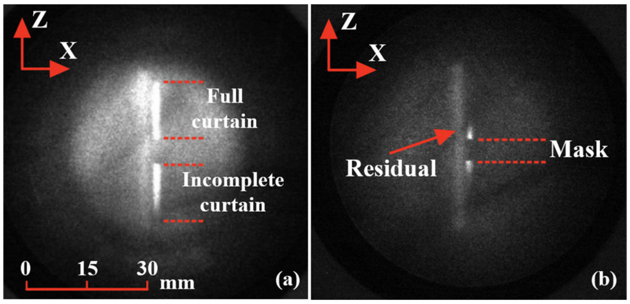

Figure 4: Gas-Beam interaction captured on the phosphor screen. (a) Full gas jet ionisation, a composition of multiple measurements to highlight the full jet, and (b) Central mask image to represent a beam halo measurement.

Figure 4 (b) demonstrates a case where majority of the electron beam is passing through the masked area of the jet. The one-dimensional tails are captured by the two small gas curtains. Note that the region labelled as residual is the interactions between the beam propagating along the z direction and the residual background gas present within the chamber, at $2.0\text{x}10^{-8}$ mbar pressure. The jet ions are created with an initial momentum due to the supersonic jet which is depicted in Fig. 4. The jet is transversely displaced in the negative x direction, relative to the near-zero momentum residual gas.

Table 2 provides the measured values of the jet from the imaging system of the IPM. The pixel resolution is calibrated to provide a measured jet size in mm. As a result of the MCP-phosphor screen stack being located a non-zero distance away from the interaction point, the ions that create the image are subject to drift. The extraction electric field will also have focus or defocus component which causes distortion of the image. A result of this is an image profile that is distorted from the jet distribution profile at the point of interaction.

Table 2: Measured Dimensions of the Jet

Dimension	Upper Slit	Mask	Lower Slit
Height	13.59 mm	5.46 mm	13.59 mm
Width	1.53 mm	1.44 mm	1.48 mm

Table 2 shows the width of the electron beam, rather than the width of the jet as in Table 1. The width of the jet is effectively infinite as this is the direction of jet propagation. The variation in width occurs as a result of beam deflection caused by the electrical field generated by the ion extraction system.

ELECTRIC FIELDS SIMULATIONS

As previously discussed, the discrepancy in curtain height and width between Tables 1 & 2 is a result of the electromagnetic fields and pre-existing momentum. This results in a focusing effect applied to the ions being collected to form the image. This ion collection process in the external electrical field was simulated using WARP code [8], with the initial and final extraction profiles shown in Fig. 5.

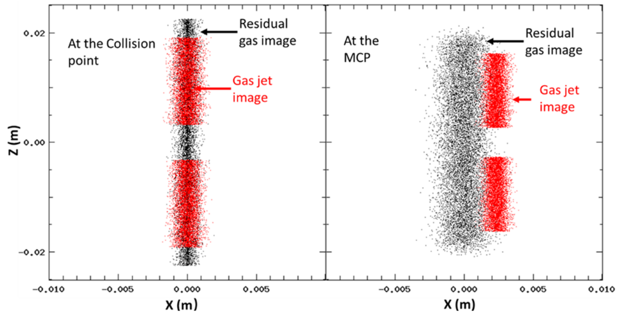

Figure 5: Simulation of ions propagation from the interaction point (left) to the MCP (right) for both residual gas and the gas jet with the mask feature.

In the simulation, ions from the gas jet are regarded as the product of interaction with the electron beam. The beam is simulated as a Gaussian distribution with an RMS radius 0.5 mm. Each ion possesses location and velocity parameters extracted from the output of the jet formation simulation. As shown in Fig. 5 and 6, there is a clear focusing effect on the height of the jet ions as a result of the external extraction field. This can be corrected by tuning the external field. The separation of the gas jet ions and residual gas ions is a result of the gas jet velocity in the direction of its propagation. The residual gas has a temperature of approximately 300K, thereby possessing a significantly higher temperature than the jet which results in a greater broadening effect from thermal velocities.

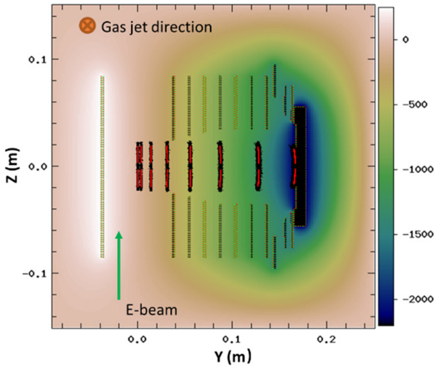

Figure 6: Simulation of ion collecting process under the external field for ions from the gas jet and the residual gas.

CONCLUSIONS

In this contribution, a beam halo monitor using a masked supersonic gas jet curtain generated by a novel double slit skimmer has been proposed and presented. Simulation suggests that a masked gas jet curtain can be created. The experimental results prove the generation of such gas jet curtain is obtainable and match the expected result of the external fields focusing effects.

Future work that could be considered includes using a movable pressure gauge situated at the Cockcroft Institute to create a 2D density map of the gas curtain. This would replicate the density distribution in Fig. 3 and further validate the simulation as an accurate representation of the true jet. Further steps will also be taken to realign the system and ensure the skimmer devices are positioned such that the flat-top density profile is provided at the interaction point.

ACKNOWLEDGEMENTS

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