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A GAS JET BEAM PROFILE MONITOR FOR BEAM HALO MEASUREMENT

O. Stringer†, H. Zhang[1], N. Kumar[1], C. Welsch[1]
University of Liverpool, Liverpool, United Kingdom
[1]also at Cockcroft Institute, Warrington, United Kingdom

Abstract

The gas jet beam profile monitor is a non-invasive beam monitor that is currently being commissioned at Cockcroft Institute. It utilises a supersonic gas curtain which transverses the beam at an angle of 45 degrees and measures beam-induced ionisation interactions of the gas to produce a 2D transverse beam profile image. 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 storage rings 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 storage rings.

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. Differing machines and the perspectives between instrumentation specialists and accelerator physicists give a range of definitions. 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 this paper, beam halo shall be defined simply by a low-density region surrounding the central beam core. Further expansion upon this definition is not required due to the proof of concept diagnostics device utilised, and a low energy, 5 keV electron beam used to demonstrate the available imaging region intended on capturing the halo.

Typical diagnostics methods for beam halo include wire scanners, scrapers and screens [1]. These are all inherently destructive in nature, especially when one regards their cumulative effects in storage rings. As such, non-invasive techniques are required for halo monitoring, such as coronagraphing synchrotron radiation with optical masks [2,3]. The Beam Gas Curtain (BGC) aims to provide an alternative method of non-invasive beam diagnostics that may be more suited to specific beam conditions.

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

The gas used is accelerated to a supersonic speed in the continuum flow regime and propagates through three

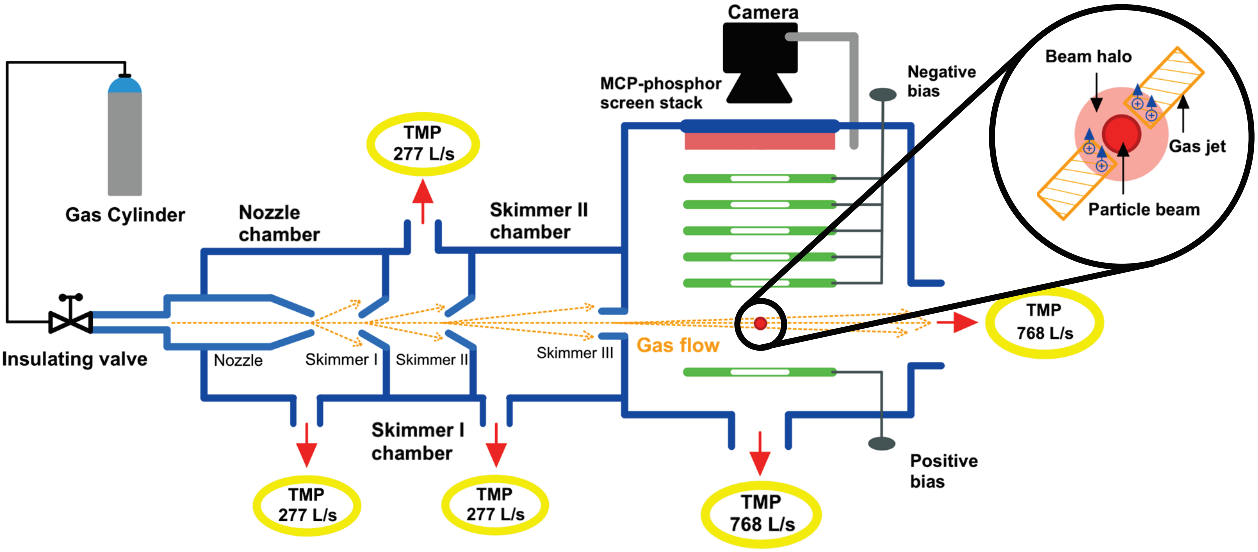

Figure 1: The layout of the Beam Gas Curtain setup configurated as an Ionization Profile Monitor for halo monitoring.

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† O.Stringer@liverpool.ac.uk

skimmers to form a desired curtain shape and density. The skimmers separate the vacuum system into isolated pumping stages and remove off-momentum particles from the jet such that the jet is highly directionalised 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, used for the experiments described. The electron beam propagates perpendicular to the jet flow such that in the figure it is illustrated propagating out of the page.

The setup uses a 30 µm diameter nozzle, a 400 µm diameter conical first skimmer, a 2 mm diameter pinhole second skimmer. For the third skimmer, it includes two $0.4 \times 10\ \mathrm{mm}^2$ rectangular slits, both offset 2 mm from the centre as shown in Fig. 2 (a). This double slit 3rd skimmer will shape the gas curtain into two smaller curtains offset from the central mask, as shown in Fig. 2 (b). In measurement, these two curtains will interact with the halo structure of the beam in one dimension displaying the ionisation distribution as in Fig. 1.

For ease of visualisation of the gas jet and proof of principle purpose, the 3rd skimmer was orientated 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. All results shown use an N_2 gas jet, pressured to 5 bar at the inlet.

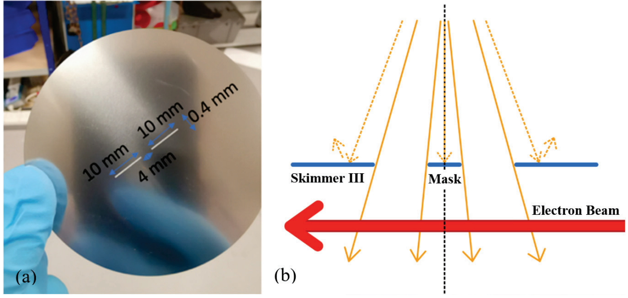

Figure 2: (a) Double slit third skimmer used to form the gas distribution; (b) Gas curtain propagation representation.

SIMULATION RESULTS

A custom simulation code was created to model the gas jet density and its distribution in the BGC system, using analytical predictions for the continuum flow regime and particle tracking for the molecular flow regime [7]. The simulation uses the Monte-Carlo method to statistically predict the shape of the gas curtain at the interaction point. To minimise the computational power required, the jet undergoes several regions where off-momentum particles are discarded, emulating each skimmer. Previously, the effectiveness of this simulation code is tested with experimental results [7].

Figure 3 displays the simulated density variation along the curtain's length with the current nozzle-skimmers geometry. The effectiveness of the mask and the high-density gradient shows a potential to image beam halo by using this gas jet curtain.

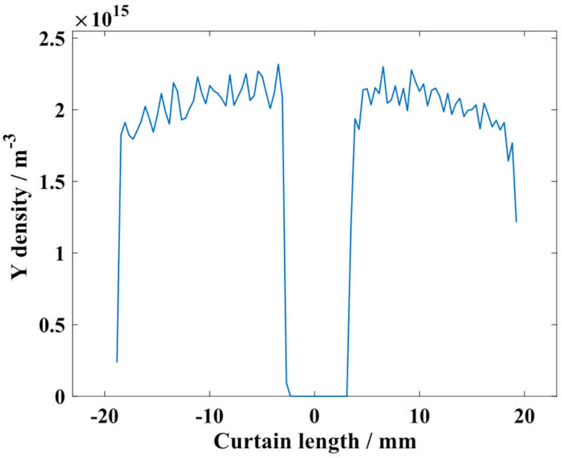

Figure 3: Simulated jet density profile along the curtain length at interaction point.

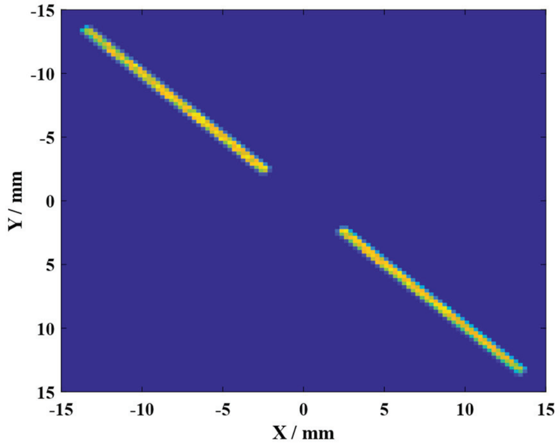

Figure 4: Simulated jet distribution in 2D at interaction point.

Figure 4 depicts a 2D slice of the gas jet at the interaction point. Again, a large density gradient is observed around the jet, providing a clean cut-off between jet and background pressure. Note for these simulations, as a result of discarding the off-momentum particles, background pressure is not simulated and diffusion effects from chamber pressure differentials are also ignored. The simulated dimensions of the gas jet are shown in Table 1. Note the width dimension refers to the thickness visible in Fig. 4.

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

The IPM setup uses electrical bias plates to generate an electric field to accelerate the ions produced from the gas-beam interactions towards the MCP and phosphor screen imaging system. The electrical field from the bias plates causes the low-energy (5 keV) electron beam to be deflected as the beam propagates through the system. As such, one cannot ionise the entire area of the jet curtain with a single measurement as 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. 5 (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 does not possess a sharp edge and instead has a visually noticeable density gradient. It is expected that the incomplete curtain occurs from a misaligned skimmer. Instead of the idealised setup shown in Fig. 2 (b), the centre of the skimmer plate is misaligned from the centre of the gas jet such that one of the slits overlap 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, instead of the idealised flat-top distribution. The alignment of the skimmers can be adjusted to correct this in later experiments.

Figure 5 (b) demonstrates a case where majority of the electron beam passing through the masked area of the jet. The one-dimensional tails are captured by the two small gas curtains. Note that the vertical 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 a ~2.0x10^{8} mbar pressure. The jet ions are created with an initial momentum due to the supersonic jet, which is depicted in Fig. 5 with a transversely displaced jet in the negative x direction, relative to the zero-momentum residual gas.

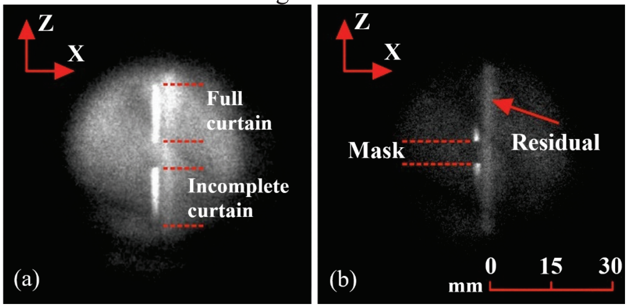

Figure 5: Gas-Beam interaction captured on the phosphor screen. (a) Full gas jet ionisation, a composition of multiple measurements to highlight the full jet, and (b) Central mask image to represent a beam halo measurement.

Table 2 describes the measured values of the jet using 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 also have focus or defocus component which causes distortion of the image. Therefore, the image profile does not match the exact jet distribution profile. These effects need further study, but it is beyond the discussion of this paper.

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 measures the width of the electron beam, rather than the width of the jet. The width of the jet is effectively infinite as this is the direction of propagation.

The discrepancy in curtain height and width between Tables 1 & 2 is a result of the electromagnetic fields and preexisting momentum as previously discussed, which seems a focusing effect was applied to the ions being collected to form the image. This ion collection process in the external electrical field can be simulated, which will be done in the future.

CONCLUSIONS

In this contribution, a beam halo monitor using a masked supersonic gas jet curtain generated by a double slit skimmer has been proposed. Simulation suggests that a masked gas jet curtain can be created. The experimental results prove the generation of such gas jet curtain and demonstrate a proof-of-concept measurement for this halo imaging diagnostics tool.

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. 4 and further validate the simulation as an accurate representation of the true jet. Further steps could 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.

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