EXPERIMENTAL RESULTS OF A GAS JET BASED BEAM PROFILE MONITOR*

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Abstract

A novel, least invasive beam profile monitor based on a supersonic gas jet has been developed by the QUASAR Group at the Cockcroft Institute, UK. It allows the measurement of beam profiles for various particle beams across a range of energies and vacuum levels.

A finely collimated neutral gas jet, produced by a nozzle and several skimmers, is injected into the vacuum chamber perpendicular to the main particle beam. Ionisation by the primary beam produces ions which are extracted from the interaction region and directed towards an imaging detector.

This contribution presents the design of the monitor and first experimental results obtained with a low energy electron beam. It also discusses solutions of previous alignment problems and challenges in the realization of a versatile control and data acquisition system.

INTRODUCTION

Beam diagnostics are indispensable parts of any particle accelerator ranging from high energy colliders to low energy and low intensity machines for precision experiments. They are required for beam operation, beam dynamics studies and also for machine optimization. In the high power regime, well established diagnostics methods such as interceptive foils and scintillating screens are not applicable or if they are they usually operate on a small fraction of the nominal beam intensity. For the low energy low intensity applications, for instance storage rings and radioactive ion beams, the challenge is posed by the need to preserve these fragile beams.

Non-interceptive instrumentation is highly desirable as an online monitoring method. It can operate in parallel with the accelerator without interfering and altering the beam's properties and with a minimum footprint on the preservation of the required vacuum levels. The non-invasive methods include Ionization Profile Monitors (IPM) and Beam Induced Fluorescence (BIF) monitors. The first are based on detecting the ions produced as the main beam ionizes the residual gas and the latter on detecting the light emitted during the de-excitation of the same residual gas [1–4].

Even though these methods are by nature non-invasive and well-accepted they are mostly used in high energy machines and vacuum pressures of 10^{-8} mbar and higher.

The gas jet based beam profile monitor that is presented here fulfils the requirements for non-destructive beam profile measurements and vacuum preservation for a broad range of beam types, energies and pressure levels.

DESCRIPTION OF THE MONITOR

The beam monitor presented here is based on the Reaction Microscope (ReMi) that was initially designed and developed by the Ullrich group at the Max Plank Institute for Nuclear Physics [5,6] for Atomic Physics experiments. It relies on the generation of a cold (<20 K), supersonic (Mach 7 or 800 m/s) gas jet shaped to a thin sheet or a cylinder. The same principle for the generation of supersonic molecular beams has been implemented at KSU-CRYEBIS facility for energy measurements of impact ionization [7] and at JPARC for beam instrumentation purposes [8–11]. However, Hashimoto's work on gas jet generation for beam profile measurements included a magnetically focused oxygen molecular beam and a mechanically skimmed nitrogen beam.

The working principle of the gas jet based beam profile monitor and the optimized dimensions of the skimmers have been reported elsewhere [12–14].The production of the supersonic gas jet starts with allowing a neutral gas (N_2 here) sourcing from a high pressure reservoir (1-10 bar), to expand in the vacuum. Gas can be injected using a pulsed valve or a manual valve if pulsed mode is not required. The expansion takes place through a 30 μm orifice and with the given operating conditions it leads to a shockwave formation and a supersonic gas jet travelling inside the vacuum chamber.

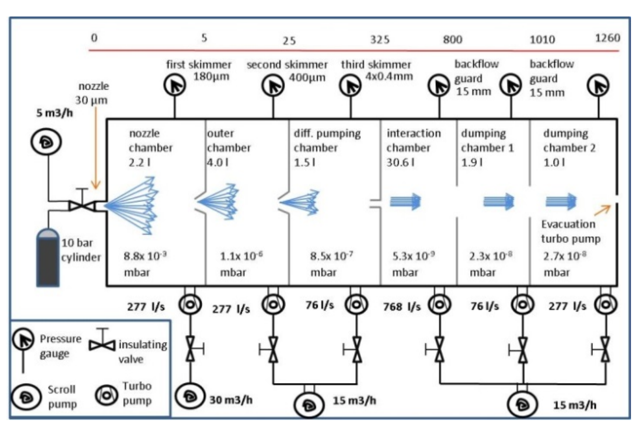

Figure 1:Overview of the setup.

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A series of skimmers separates the vacuum chamber in differentially pumped sub-chambers, see Fig. 1. As the gas jet passes through them it collimates and shapes into a thin sheet inclined at 45^0 with density in the range of 10^{10}-10^{13} particles/cm^3. This angle is what gives the capability of 2-dimentional beam profile imaging, see Fig. 2.

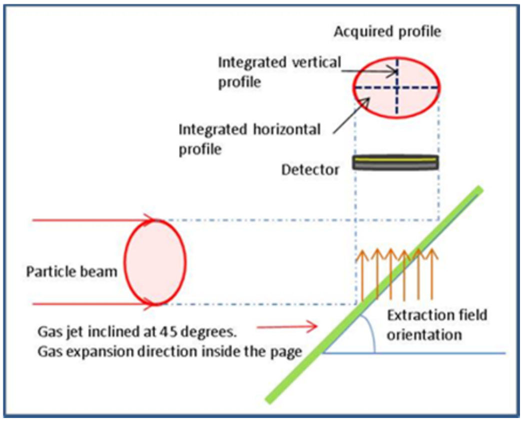

Figure 2: 2-dimensional profile imaging.

The gas jet is travelling perpendicular to the particle beam to be measured and at the point of interaction ionization occurs. The produced ions are extracted by an external electric field of 12 kV/m and directed towards a MicroChannel Plate detector (MCP).Inside the MCP a shower of electrons is produced for every impinging ion offering an amplification of 10^6 electrons/ion. The MCP is stacked with a phosphor screen which yields visible light upon the impact of the electrons. The light is then recorded by a CCD camera placed outside of the vacuum chamber. After the interaction the gas jet exits the chamber through a specially designed dumping chamber leaving the vacuum environment practically unaffected. In the current setup a 5 keV electron beam produced by a PSP vacuum electron gun was used. An overall view of the experimental setup is depicted in Fig. 3.

The monitor can be used even without the gas jet by simply imaging the particle beam from the interaction of the residual gas that is present in the chamber. For pressure down to 10^{-8} mbar this method is valuable for commissioning of the diagnostics and troubleshooting or verification.

A supersonic gas jet based beam profile monitor is highly flexible and can be adjusted for different applications and particle beams. Impact ionization, which the monitor relies on, has been studied by many groups and experimental values can be found for a large variety of gas species, projectile energy and type[15–17]. A few examples are shown in Table 1.

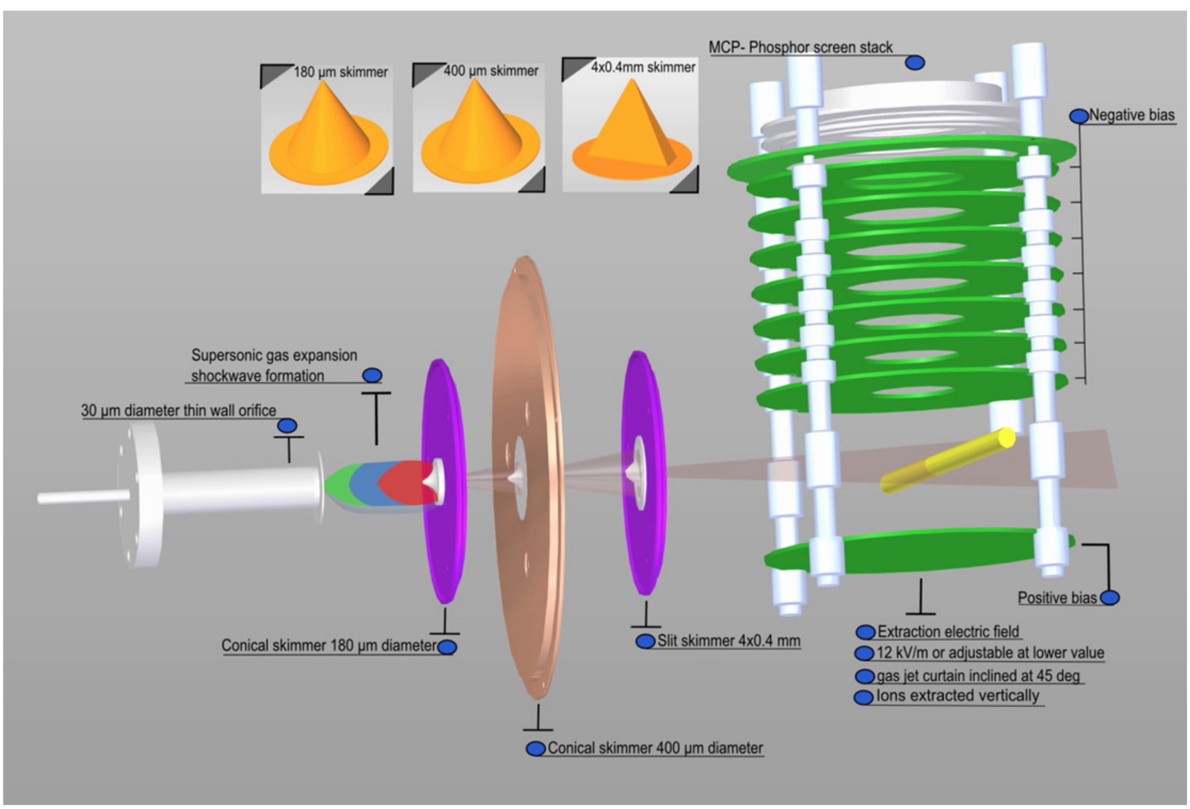

Figure 3: 3D schematic of the skimming section and the extraction field scheme. The distances between skimmers have been scaled for better visual representation. Top left: shockwave formation, top centre: conical skimmers and rectangular slit skimmer.

Table 1: Ionization Cross Section Values

projectile	Energy (keV)	Target (a.n.)	Cross section (Å^2)
electron	5	Nitrogen(7)	0.181
electron	10	Argon(18)	0.155
proton	50	Helium(2)	0.743
antiproton	100	Nitrogen(7)	2.86

MEASUREMENTS

During the measurements shown here the stagnation pressure was fixed at 5 bars and the electron beam at 3.8 kV and filament current at 2.51 A. The bottom repeller plate was biased at 130 V and the voltage distributed among the top rings was -1300V, see Fig. 3. The MCP voltage was at -1300 V and the phosphor screen at 3300 V. The camera that was used to capture the beam profile's image was a uEYE 1024x768 CCD siting 110 mm from the phosphor screen.

The acquired image was then smoothed and filtered for noise suppression in Labview and the beam profile imaged by the gas jet and by the residual gas was calculated by integration along a straight path. The dimensions of the profile are not calibrated in real coordinates thus the axis scale is in pixels. The result is shown in Fig. 4.

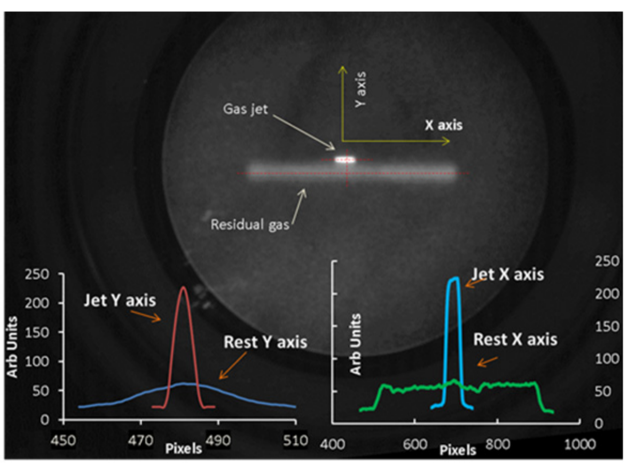

Figure 4: Electron beam profile imaged by the gas jet and the residual gas [18].

As shown in Fig. 4 the monitor can measure residual gas induced profile together with the gas jet induced profile for relatively high background pressures (10^{-8} mbar). The bright track in the centre of the picture corresponds to the beam's profile imaged by the gas jet and the longer and fade track comes from the residual gas. The intensity ratio is about 5 as the gas jet density is much higher that the residual gas density and as a result more ions are produced hence more light from the phosphor screen. Numerous alignment issues have prevented the proper operation of the monitor in the past. Those problems arose from the small nozzle-skimmer dimensions, tight tolerances and small deformations of parts of the setup due to pressure differentials. As the exact sources of the issues were unknown, the most critical parts of the setup were monitored in real time with cameras placed in selected locations recording displacements in the order of a few µm.In addition, a laser shined through the circular orifice propagating along the jet's expansion path and image with another camera at the dumping chamber provided another verification of the correct alignment [19].

The use of multiple cameras and the need for real time acquisition for both alignment purposes and beam profile imaging poses several challenges. Labview was chosen as an application with real time capabilities and compatibility with usb controlled cameras. Different algorithms have been developed for the control and data acquisition aiming for the integration of all the devices (cameras, power supplies, gas supply, vacuum gauges, and electron gun) in a single control program which can be operated by a local or remote user.

CONCLUSION

The first results of a supersonic gas jet based beam profile monitor have been presented in this contribution. As a flexible beam monitor it can be used in different machines for various types of particle beams and vacuum conditions. Here the first experimental results are presented which were obtained from a laboratory electron gun.

Future measurements have been scheduled in order to explore the gas jet properties in depth and also study the interaction with the main beam for different operating parameters, namely beam energy and current, stagnation pressure and extraction field strength.

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