SIMULATIONS OF THE ION SPATIAL DISTRIBUTION IN A GAS-CURTAIN BASED BEAM PROFILE MONITOR*

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Abstract

A gas-jet monitor has been developed and commissioned by the QUASAR Group at the Cockcroft Institute, UK. It is designed to measure the transverse profile of a beam by crossing it with a neutral supersonic gas-jet. An array of high voltage electrodes is used to extract ions from the region where the beam and gas-jet interact. These ions first hit a micro-channel plate (MCP) and are then imaged through a phosphor screen and a CCD camera. It is important to understand and characterise the measured ion distribution in order to extract the beam profile. Therefore, numerical investigations using the commercial COMSOL and OPERA codes were carried out benchmarking profile measurements obtained from a low energy electron beam. This paper presents results from these studies. It compares measurements based on the interaction of the primary beam with the residual gas or the ultra-cold gas curtain, and discusses the comparisons of simulated profiles and extraction field configurations on the measured profile.

INTRODUCTION

At the Facility for Low Energy Antiproton and Ion Research (FLAIR), two novel storage rings, the magnetic low energy storage ring (LSR) and an electrostatic ultra-low energy storage ring (USR) shall provide low energy antiproton beams at energies down to 20 keV/q [1, 2]. Cooled beams of antiprotons in this energy range would enable e.g. hitherto impossible investigations into antiproton-atom collisions [3]. At intensities of $\sim 10^7$ antiprotons per cycle new diagnostic methods are required to monitor the beam's properties as most of the existing techniques are no longer suitable – either because they are destructive (e.g. screens) or since the low operating pressure in the ring of 10^{-10}-10^{-11} mbar makes them not usable (ionization beam profile monitor or beam induced fluorescence monitor [4, 5]). A candidate for non-invasive beam profiling is a gas jet based beam profile monitor, suitable for online measuring of the transverse profile of a particle beam with minimum disturbance to the vacuum conditions. A system of collimators allows the geometry of the gas-jet to be shaped. In this case, a nozzle-skimmer system is used to form a thin supersonic neutral gas-jet into a curtain [6].

The ion formation of a cold gas jet curtain in the interaction region with the primary beam is critical to the function of the monitor. In order to better understand the impact of different parameters on the final performance of the monitor, numerical studies were undertaken to characterise the monitor operation and benchmark the simulated transverse profiles with experimental measurements. Commercial simulation codes were used to track the ions which enter the detector and compare their distributions with existing measurements.

BEAM PROFILE MONITOR

The gas-jet monitor operates by shaping a supersonic gas made up of neutral molecules, such as molecular Nitrogen (N_2), into a thin curtain. This gas is differentially pumped through a complex vacuum system [6] and then sprayed across the beam line at a 45° angle, perpendicular to the beam path as depicted in Fig. 1. In an initial prototype setup the gas-jet (blue) crosses an experimental chamber and is ionized by a low energy electron beam (red).
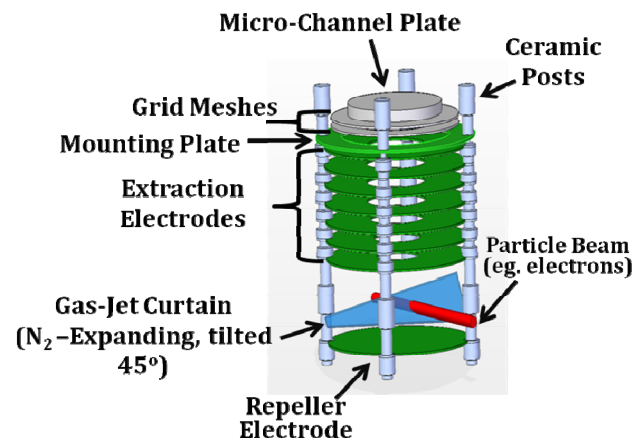

Figure 1: Illustration of the extraction system of the gas-curtain monitor with the extraction electrodes (green), the MCP detector with meshes and mounting plate (grey).

SIMULATION MODEL

To test the design of the extraction system and optimise the voltages for the array of electrodes and the detector, a 3D model was constructed with the commercial codes COMSOL and OPERA [7, 8] as shown in Fig. 2. In the model the residual gas is simulated using a Maxwellian

distribution with T~300K for the momentum in the v_x, v_y and v_z -directions. In contrast, for the initial velocity distribution of the gas-jet ions, a temperature of T=20K in the v_x and v_z directions was used, while the velocity in the direction of propagation of the jet was $v_y \sim 500\text{-}1{,}000 m/s$ depending on the gas species.
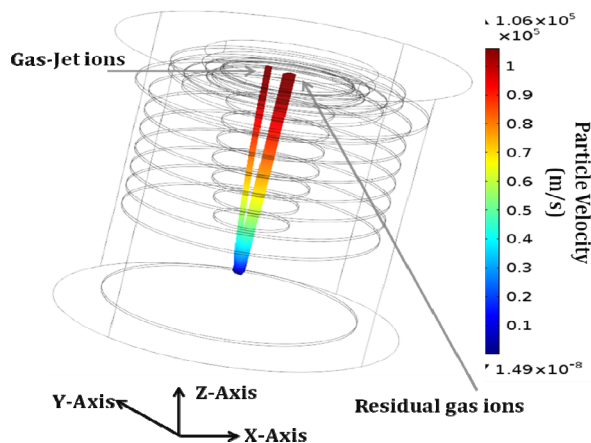

Figure 2: The model for the simulation of the operation of the gas-jet monitor with the predicted trajectory of the particles ionised by the electron beam.

The simulation approximates the interaction zone of the particle beam and gas-curtain to a 1 mm^3 volume, which essentially contains ions as shown in Fig. 2. By modelling the charged extraction plates with varying voltages, the code simulates the acceleration of the ions along the plates. Fig. 3 shows the contour plot for the extraction electric field produced with the nominal operating voltages. The linear voltage progression generates a homogeneous electric field. The large potential difference enables the ions to be directed to the MCP with minimum travelling time and thus small transverse movement.
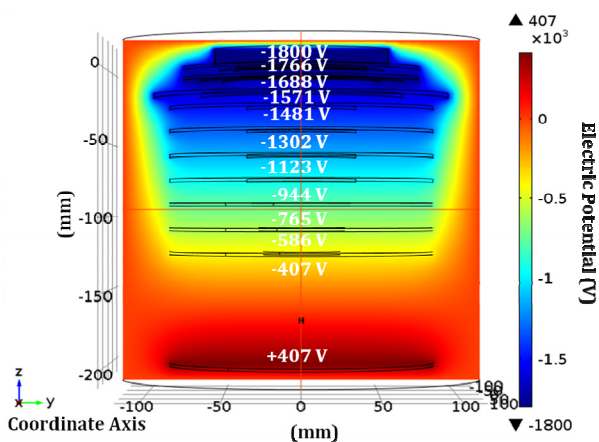

Figure 3: The contour plot of the extraction field distribution for nominal operation of the monitor, with the electric potential (V) indicated for each electrode.

The selected voltages produce a uniform electric field across the extraction chamber. In order to allow a calibration screen to be inserted, an asymmetry exists in the lower half of the array, which produces some

distortions in the components of the extraction field along the z-direction. These distortions are less significant in the upper half of the array as the high extraction fields mask these effects.

BEAM PROFILE MEASUREMENTS

A CCD camera is used with the gas-jet monitor to record profiles of the primary beam based on both the gas-jet and residual gas ions. These are depicted in Fig. 4, with the x and y- profiles of the two populations of ions. The profiles were filtered and background subtracted. The y and z profiles of the electron beam can be extracted from the y and x profiles of the gas jet ions, respectively, while the residual gas ions allow only the measurement of the beam's y profile.
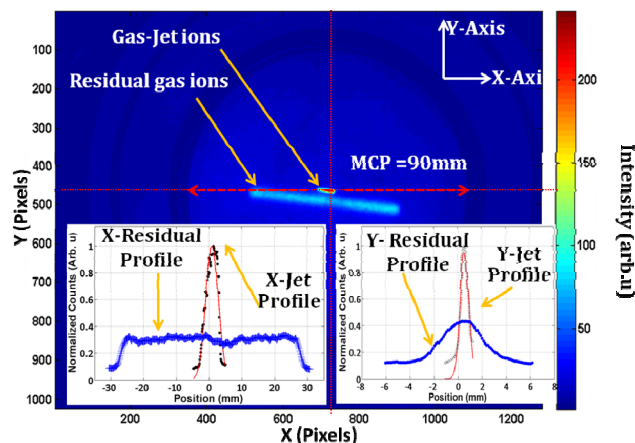

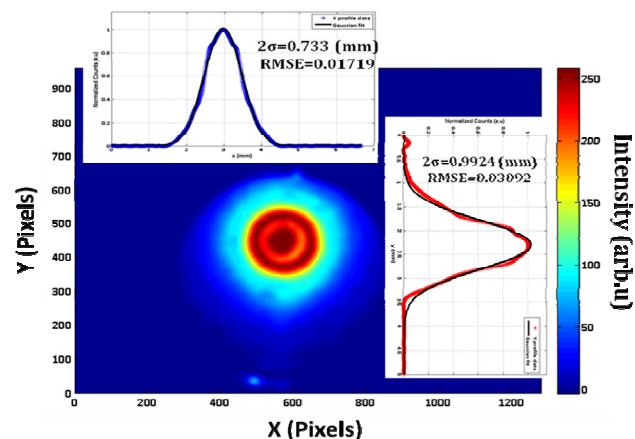Figure 4: Measured profiles based on the gas-curtain and residual gas.

Figure 5: The electron beam profile measurements with a phosphor calibration screen and imaged with a CCD sensor (in units of pixels).

The profile measured from the MCP depends on the extraction field configuration and primary beam conditions. A calibration factor of approx. ~8 pixels/mm was used to convert the pixels to mm and estimate the profile width (FWHM) and beam size. The transverse profile of the electron beam is depicted in the Fig. 5, with the x and y profiles fitted with a Gaussian curve, estimating the beam size at approx. 1mm.

RESULTS

Figure 6 shows the ion spatial distribution on the micro-channel plate detector for both the gas-jet and rest-gas ions as predicted by the simulation model.
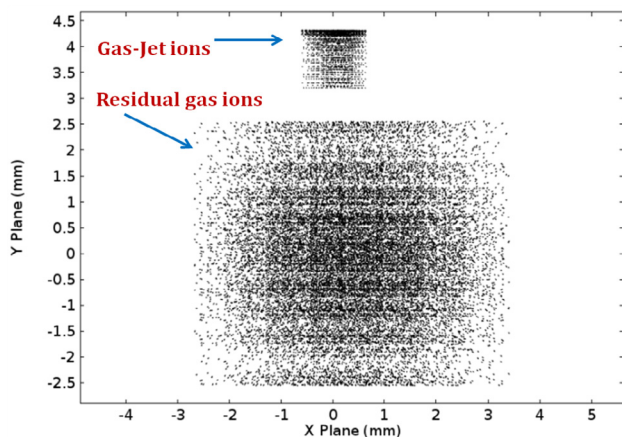

Figure 6: *x* and *y* spatial ion distribution for the gas-jet and residual gas ions at the bottom of the MCP detector as predicted by simulations.
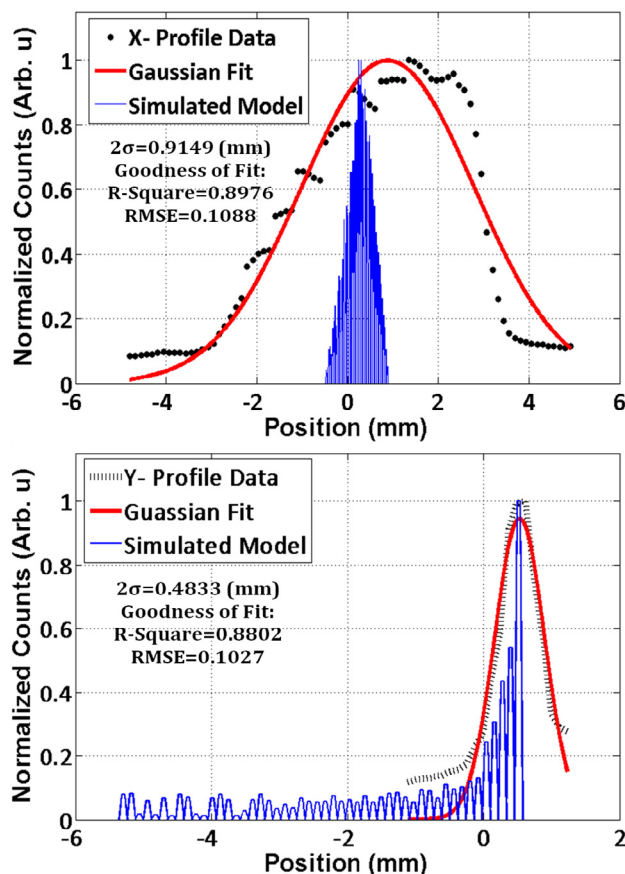

Figure 7: Measured *x* (top) and *y* (bottom) profile of the gas-jet ions (dotted line) fitted with a Gaussian-curve (solid line) and compared to the simulated gas jet ion profile from the numerical model (histogram).

The simulated results from Fig. 6 indicate similarities to the measured distribution seen in Fig. 4. The separation distance between the residual gas ions and gas-jet ions is estimated at ~3.5 mm from the measured distribution and about 4 mm from the simulation. This is within the uncertainty of the pixel to mm conversion factor for the measured image. The difference in the simulated distributions as compared to the measured distributions may be due to the choice of aperture in which the simulated ions are created. By adjusting the initial ion distribution until the simulated distribution at the MCP matches the measured one, the spatial extent of the gas jet can be estimated. In addition, the results can help explaining any distortions or physical effects associated with the imaged beam profile.

The *x* and *y* profiles of the simulated distributions are shown in Fig. 7 for the gas-jet ions. The strong asymmetry in the simulated *y* profile of the gas jet ions is not yet fully understood.

SUMMARY

This paper has presented the results from simulations of a gas-jet curtain beam profile monitor. Using nominal extraction field configurations the model allowed the ion distribution at the sensor to be obtained. This was compared with profile images obtained during the gas-jet operation. Finally, numerical tracking of the ion spatial distributions at the location of the MCP has reproduced some of the monitor characteristics for specific operational settings. The model shall be used for numerical optimization studies of the monitor and a range of parameter studies in the future.

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