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COMMISSIONING OF THE PROTOTYPE FOR A NEW GAS CURTAIN BEAM PROFILE MONITOR USING BEAM INDUCED FLUORESCENCE FOR HL-LHC

A. Salehilashkajani*, C.P. Welsch, H.D. Zhang
Cockcroft Institute and University of Liverpool, Warrington, UK
M. Ady, N. S. Chritin, J. Glutting, O. R. Jones,R. Kersevan T. Marriott-Dodington,
S. Mazzoni, A. Rossi, G. Schneider, R. Veness, CERN, Geneva, Switzerland
P. Forck, S. Udrea, GSI, Darmstadt, Germany

Abstract

A new supersonic gas-jet curtain based beam profile monitor is under development for minimally invasive simultaneous transverse profile diagnostics of proton and electron beams, at pressures compatible with LHC. The monitor makes use of a thin gas-jet curtain angled at 45° with respect to the charged particle beams. The fluorescence caused by the interaction between the curtain and the beam can then be detected using a dedicated imaging system to determine its transverse profile. This contribution details design features of the monitor, discusses the gas-jet curtain formation and presents various experimental tests, including profile measurements of an electron beam using nitrogen and neon curtains. The gas-jet density was estimated by correlating it with the number of photons detected by the camera. These measurements are then compared with results obtained using a movable pressure gauge. This monitor has been commissioned in collaboration with CERN, GSI and the University of Liverpool. It serves as a first prototype of a final design that will be placed in the LHC beam line to measure the profile of the proton beam.

INTRODUCTION

A hollow electron lens system [1] is currently under development as a key part of the collimation upgrade for the High Luminosity Large Hadron Collider (HL-LHC) [2]. It is crucial for the proton beam and its surrounding electron beam to be aligned. In order to meet this challenge and monitor the two beams simultaneously, a new, minimally invasive supersonic gas curtain beam profile monitor is under development within a collaboration between CERN, GSI and the Cockcroft Institute (CI). A supersonic gas curtain ionisation profile monitor has already been developed and tested extensively at the CI [3–6].This old monitor was also tested in fluorescence mode as a proof of principle [7].

In this type of monitor, a supersonic gas curtain is created as a high-pressure gas flows through a nozzle and a series of three skimmers. This gas curtain enters the interaction chamber, where a beam of charged particles pass through the curtain in perpendicular to its flow. The fluorescence induced by the excitation of the gas molecules by the charged particles beam is detected via a dedicated imaging system to produce a 2D image of the beam's transverse profile. Details on the imaging system can be found in [8].

This contribution summarises the findings from the proto-type monitor, where neon and nitrogen are used as working gases [8, 9]. The results from this monitor ultimately con-tribute to the design of the final system to be deployed at the LHC.

SYSTEM OUTLINE

A supersonic gas jet is generated as a high pressure gas flows through a 30 μm nozzle into a vacuum chamber with an ambient pressure of 3×10^{-3} mbar. This jet of high density, high velocity gas then flows through two conical skimmers with diameters of 180 μm and 400 μm respectively and a third pyramid shaped one with 4× 0.4 μm slit opening. The third skimmer is tilted by 45° to allow a 2D measurement of the profile.

The schematics of the new gas-curtain based beam profile monitor and a picture of the setup installed at the Cockcroft Institute are displayed in Fig. 1. The operating pressure of each chamber is given in Table 1.

Table 1: Background Gas Pressure in Each Chamber with the Electron Gun on and the Inlet Pressure for the Jet Set to 5 bar

Chamber	Pressure
Nozzle Chamber	2.90×10^{-3} mbar
Skimmer Chamber 1	5.90×10^{-6} mbar
Skimmer Chamber 2	6.10×10^{-7} mbar
Interaction Chamber	1.38×10^{-8} mbar
Dump Chamber	4.30×10^{-9} mbar

The skimmer assembly that contains the nozzle holder, the first and the second skimmer is placed in the skimmer chamber. The third skimmer is placed 325 mm downstream from the nozzle. There is a gas separator placed in the skimmer chamber that divides the volume between the first and the second skimmers, and the second and the third skimmers. This separator is designed to reduce the gas load entering the interaction chamber. Off-line alignment of the nozzle and the skimmer assembly is possible with the setup as described in [10].

The gas curtain, angled at 45°, is formed after the third skimmer and enters the interaction chamber. An electron gun (EGG-3103A), which produces a Gaussian electron

* amir.salehilashkajani@cockcroft.ac.uk

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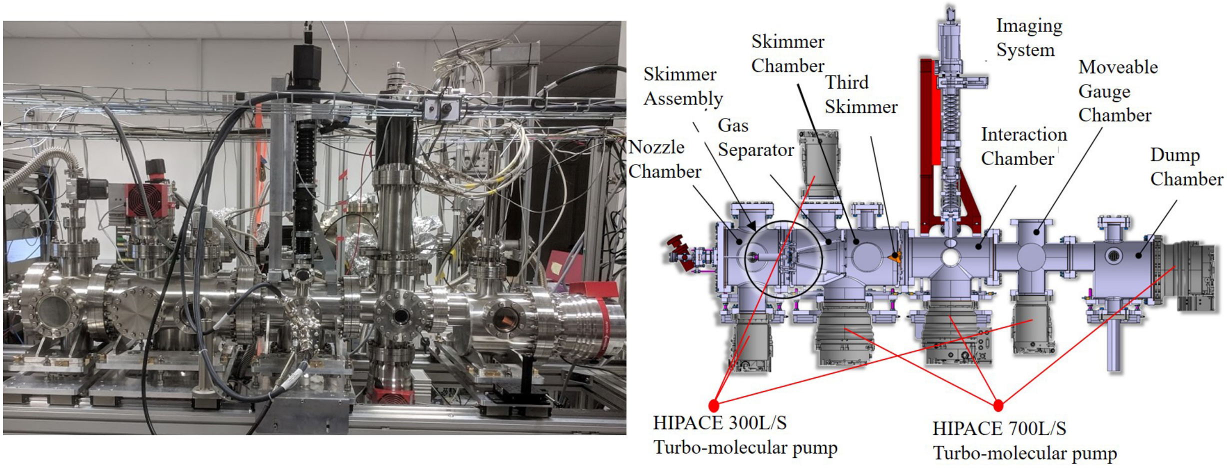

Figure 1: Schematic of a prototype gas curtain based beam profile monitor using beam induced fluorescence. The turbo-pumps are connected to three nXDS15i scroll pumps.

beam, fired perpendicularly to the direction of the gas-jet, and the imaging system are placed at the interaction chamber. The imaging system contains an apochromatic lens, a filter wheel, an image intensifier and a CMOS camera. Also attached to the interaction chamber is an insertable assembly with a resolution target and a phosphor screen connected by a linear bellow drive. This is used to adjust the focusing of the imaging system and characterise the electron beam for comparison. The current of the electron beam is measured at the emission point by the gun controller and once again by a Faraday Cup placed on the other side of the interaction chamber, opposite to the gun.

The gas jet leaving the interaction chamber enters the diagnostic chamber. There, a moveable, enclosed pressure gauge having a slit opening is used to measure the density profile of the gas jet. In the last chamber the gas jet will directly enter a turbo-pump to avoid back scattering.

PROFILE MEASUREMENTS USING THE GAS CURTAIN

In order to measure a clear profile of the electron beam with relatively low integration times, a dense, localized gas curtain is needed. The gas species taken under consideration were nitrogen and neon with strong fluorescence at 391.4 nm and 585.4 nm respectively [8, 9]. The cross section for the nitrogen emission at 391.4 nm is about 100 times that of neon at 585.4 nm, but neon is more favorable to the LHC vacuum environment. A nitrogen gas curtain was used to commission the imaging system and to optimise the setup for a maximum density jet. The electron beam profile was then measured using both neon and nitrogen.

For the aligned system under optimum conditions, using nitrogen, an integration time of only 2 s is enough to measure the 1D profile of a 5 KeV electron beam carrying a current of 0.69 mA. The transverse profile of the beam along the y-direction is displayed in Fig. 2. More time is needed (e.g. 200 s) for a clear 2D image such as shown in Fig. 3.

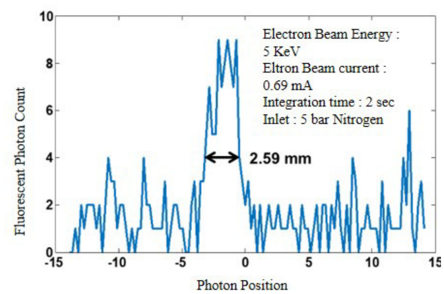

Figure 2: Profile of an electron beam measured from the fluorescence of a nitrogen gas curtain.

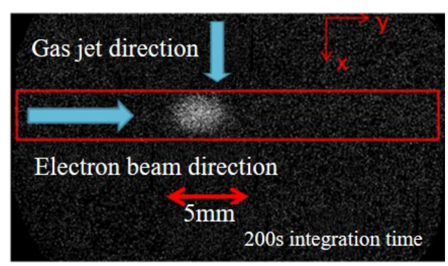

Figure 3: Image produced over 200 s from the fluorescence of a nitrogen gas curtain.

Neon florescence line at 585.4 nm, corresponds to the yellow region of the optical spectrum. Here, the light released from the filament of the electron gun by the black-body radiation of the thermionic cathode and the filament gives rise to a background found to be too strong for observing the signal from the gas curtain. To reduce the background, the electron gun and Faraday cup have been placed further away from the centre of the interaction chamber, which increased the diameter of the beam. Also, a small black aperture was placed in front of the electron gun with a 4 mm opening to block the filament light. The normalised profiles from nitrogen and neon are displayed in Fig. 4, and show a good

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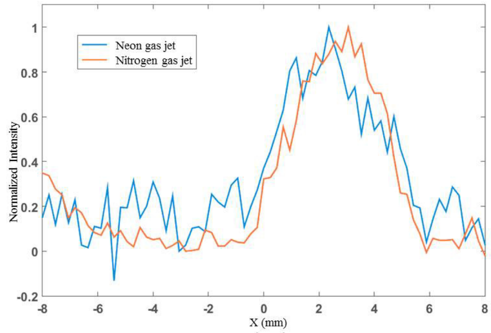

Figure 4: Profile measurements of a 3 KeV electron beam using neon and nitrogen gas curtains. Beam current: 0.50 mA, Integration time: 200 s for nitrogen, 4000 s for neon, inlet pressure: 5 bar.

agreement. The intensity of the signal from the nitrogen gas curtain was observed to be approximately 20 times higher than neon for the same inlet pressure at the nozzle. The density of the nitrogen curtain is higher than the neon one due to the different heat conductivity between the two gas species [11].

DENSITY MEASUREMENTS OF THE GAS JET

To measure the density of the gas jet, a moveable pressure gauge was placed in the diagnostic chamber 265mm downstream from the interaction point. The actual density of the jet at the interaction point is expected to be higher as the gas jet will continue a linear expansion after the third skimmer. A detailed density distribution of the jet, measured at the diagnostics chamber and corrected to the estimated value at the interaction point (assuming a linear expansion) is detailed in Fig 5. It is suggested by this measurement that the gas curtain remains at an angle of 45° with a quasi-uniform distribution and an average density of 9×10^{14} molecules/m^{-3}.

As an alternative, the photon gauge method was used to verify the density measurements taken by the moveable pressure gauge. The number of photons detected by the camera from the gas jet is directly proportional to the integration time, the current and energy of the electron beam, and the density and thickness of the curtain. By establishing a calibration between the density of the background gas and the number of photons detected, assuming all other relevant parameters remain constant, one can estimate the density of the jet. A series of residual gas measurements were taken at different background pressures in the interaction chamber. The observed photon number per pixel per second was then plotted against the pressure inside the interaction chamber as displayed in Fig. 6. The number of photons per pixel per second from the gas jet was then transferred into a corresponding pressure using this linear fit. The equivalent pressure of the nitrogen jet measured at the centre of the interaction chamber, with an inlet pressure of 5bar, was calculated to be 4.6×10^{-8} mbar which is equivalent to a density of 1.1×10^{15} molecules/m^{-3}.

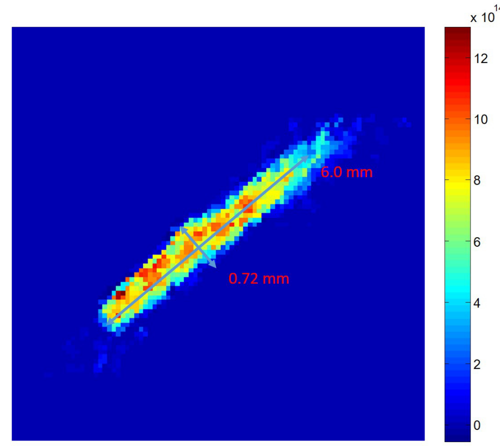

Figure 5: Nitrogen gas curtain density distribution (molecules/m^{-3}) measured by the moveable gauge system. The dimensions of the jet are measured to be 0.72×6 mm [11].

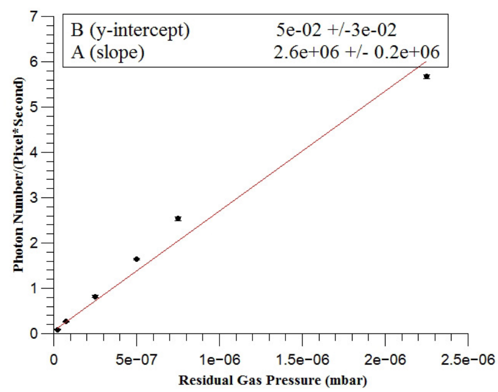

Figure 6: Calibration of the photon gauge.

CONCLUSION

In this contribution, the progress on the development of a supersonic gas-curtain based profile monitor has been presented. It has been demonstrated that this device can be used as a viable profile monitor that utilises the beam induced florescence in the gas curtain. The use of nitrogen and neon as working gases was demonstrated and it was observed that nitrogen may offer a better signal to noise ratio. The density of the jet was measured using two different methods. A value of about 1×10^{15} molecules/m^{-3} has been observed. This experimental program is ongoing, and it aims to produce a final design in collaboration with CI, CERN and GSI, which will be installed in the LHC tunnel [12].

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