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COMMISSIONING OF A GAS JET BEAM PROFILE MONITOR FOR EBTS AND LHC

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Abstract

A gas jet beam profile monitor was designed for measuring the electron beam at the electron beam test stand (EBTS) for the Hollow electron lens (HEL) and the proton beam in the large hadron collider (LHC). It is partially installed in the LHC during the second long shutdown. The current monitor is tailored to the accelerator environment including vacuum, geometry, and magnetic field for both the EBTS and the LHC. It features a compact design, a higher gas jet density, and a wider curtain size for a better integration time and a larger detecting range. In this contribution, the commissioning of this monitor at the Cockcroft Institute will be discussed.

INTRODUCTION

A Beam Gas Curtain (BGC) instrument is currently under development in the framework of the HL-LHC beam diagnostic upgrade. This instrument aims to develop a versatile beam profile monitor for the LHC and an overlap monitor for the Hollow Electron Lens (HEL)[1]. The HEL will be used to actively scatter the halo particles of the LHC beams by letting them interact with a hollow electron beam confined in an high magnetic field superconducting solenoid. Therefore, the homogeneity and the position of the hollow electron beam will be crucial for the successful operation of the HEL and is intended to be measured by the BGC instrument.

For the LHC and HEL, the destructive power of the beams makes all intercepting instruments fragile and thus not applicable. The widely used ionisation profile monitors (IPM)[2–4] and beam-induced fluorescence monitors (BIFs)[5, 6] based on the interaction of charged particle with the residual gas in the vacuum vessel would also be perturbed by space charge effect and the high external magnetic field. In addition, the ultrahigh vacuum environment in the LHC would also limit the sensitivity of such instruments.

To increase the signal level for IPMs and BIFs, one idea is to introduce the gas into the diagnostics chamber with needle valves[7]. More efficiently, one can use a gas jet [8–10] which is more controllable, with higher local density and easier to pump out. The latter feature will help maintain an ultrahigh vacuum environment.

Previously, an IPM based on the supersonic gas jet [11, 12], was demonstrated for detecting a two-dimensional beam profile and the vacuum feature [13] was proved. Recently, a BIF monitor based on a similar supersonic gas jet [14, 15] showed that by using a short-lived or neutral light emitters, the distortion due to the space charge effect and external magnetic field can be minimized. In both applications, the supersonic gas jet was generated by letting the working gas, usually, nitrogen or neon with a stagnation pressure of 5 bar from the gas bottle, flow through a 30 µm flat nozzle continuously into a nozzle chamber where the background pressure is maintained at $\sim 5\times10^{-3}$ mbar. Then the generated jet will be collimated through 2 conical skimmers with opening diameters of 180 µm and 400 µm and shaped into a curtain-like jet with either a pyramid or flat third skimmer which has a slit opening with a size of 0.4 mm×4 mm tilted at 45°. As shown in Fig. 1, the charged particle beam will interact with the molecules in the jet and generate secondaries such as electrons, ions and fluorescent photons which can be detected to represent the original beam profile with two-dimensional information. The gas jet density at the interaction point can reach $\sim 1\times10^{16}$ m^{-3}[16], which gives an estimation of the integration time of ~1 s for both the LHC and HEL applications. These discoveries pave the way for designing beam profile monitors for the LHC and the Electron Beam Test Stand (EBTS) for the HEL.

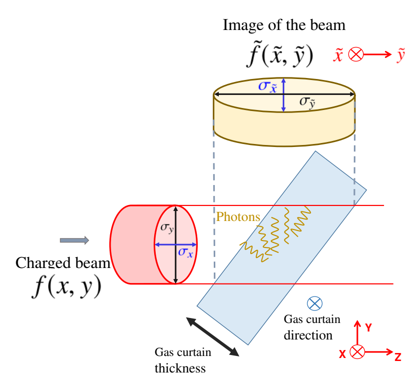

Figure 1: The principle of the gas jet curtain beam profile monitor[15].

To satisfy the LHC installation requirement, the device is redesigned to fit into the tunnel and the design principle has been discussed in [14]. Compared with the previous version [15, 17] developed in the Cockcroft Institute (CI), it features a compact overall structure with a modified geometry of the

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nozzle-skimmer assembly to provide a larger uniform gas jet curtain which can tolerate the beam jitters of the LHC beam and the hollow electron beam in the EBTS. Although the interaction chambers are designed differently for the LHC installation and the EBTS, they are both attached with three gate valves and the blackened copper liner. The gate valves are used to isolate the interaction chamber from either the gas injection line or the turbo-molecular pump (TMP) in case of a malfunction. The copper liner is used to reduce the resistance due to the introduction of extra ports. In this contribution, we will focus on the commissioning of such a gas jet beam profile monitor.

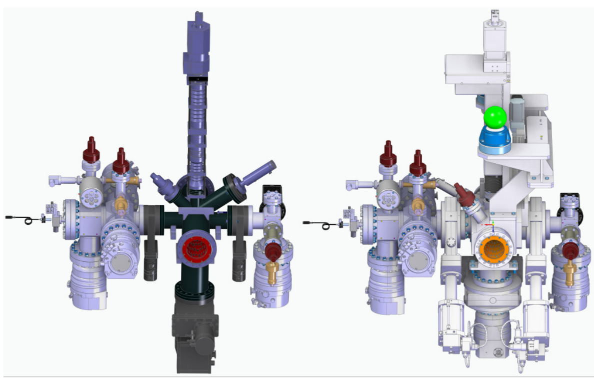

Figure 2: Drawing of the gas jet monitor for (a) EBTS and (b) LHC.

MONITOR DESIGN FOR THE EBTS AND LHC

As shown in Fig. 2 of the design, the gas jet monitors designed for the EBTS and the LHC share the same gas injection section and the dump section. The differences are the interaction chamber where the one for the EBTS is slimmer due to the space limitation of the magnet around. As mentioned previously [14], the interaction chamber of the monitor for the LHC is already installed into the tunnel during the long shutdown 2 of the LHC and is intended to monitor the beam profile by using the residual gas for the Run 3 [18]. The gas jet monitor for the EBTS was assembled in the CI as shown in Fig. 3. According to the simulation, the nozzle-skimmers assembly described in the introduction can achieve a beam size of 0.97 mm×6.5 mm in the current design, which is not sufficient for either electron beam in the EBTS or the LHC beam if there is a large centroid offset of the beam. The desired jet size would be larger than 20 mm. To achieve that, different combinations of skimmers were tested in simulation based on the availability of the conical skimmers and manufacturing capability. It is found that the combination of a 400 µm first conical skimmer, 2 mm round pinhole second skimmer and 0.7 mm×9 mm third skimmer will satisfy the requirement. According to the simulation, a gas jet of Nitrogen and Neon can be expected as shown in Fig. 4, where the final gas jet sizes are 21 mm×1.8 mm and 21 mm×1.6 mm separately in case of stagnation pressure of 5 bar.

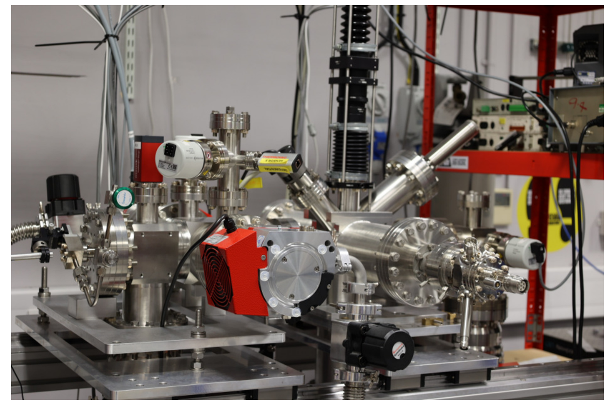

Figure 3: Image of the gas jet monitor in Cockcroft Institute.

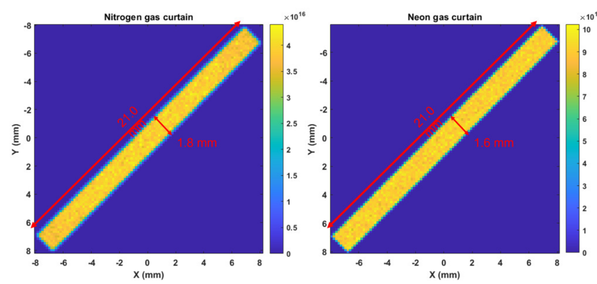

Figure 4: The images of gas jet density distribution from the simulation. Left: Nitrogen; Right: Neon.

To validate the simulation results, a movable gauge system [16, 17, 19] was used to measure the gas jet density and its distribution. The movable gauge system has a pinhole opening with a diameter of 1.0 mm. The measured density distribution will be a convolution of the real density distribution and the pinhole size. The comparison of such a convolution of the simulated gas jet density distribution from Fig. 4 and the measured data is shown in Fig. 5. Note that the working gas used here is nitrogen. The measured gas jet is shorter in length compared to the simulation case, which might be due to the slight misalignment between the nozzle-skimmer-assembly to the third skimmer. This can be revealed by the tails at both ends of the measurement where the top tail is sharp cut while the bottom one has a Gaussian distribution. The misalignment can be mitigated with a better assembling procedure. On other hand, the width for both of them is comparable with an size of 2.1(2) mm and 2.1(1) mm respectively, which indicate the simulated width of 1.8 mm is valid. In a summary, the jet size and density requirement can be met by using the new geometry for the nozzle-skimmers-assembly. The result pressure in each chamber with jet off and on is shown in Table 1.

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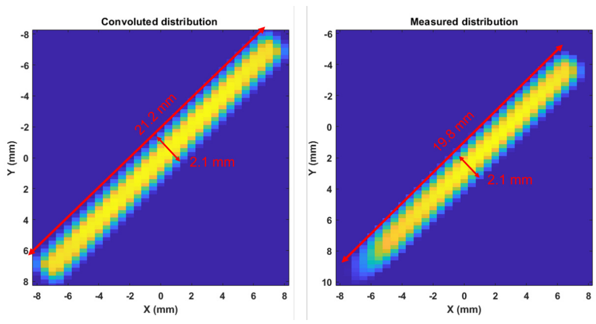

Figure 5: Comparison of gas jet density distribution for the new geometry. Left: simulation convoluted with pinhole; Right: measurement.

Table 1: Measured Pressure (mbar) in Each Vacuum Chamber, with Gas Jet off and Gas Jet on at a Stagnation Pressure of 5 Bar.

Jet	Nozzle	SkimmerI	SkimmerII	Interaction	Dump
On	5.4×10^{-3}	1.2×10^{-5}	1.1×10^{-6}	9.2×10^{-9}	1.3×10^{-7}
Off	5.0×10^{-9}	2.3×10^{-10}	2.8×10^{-9}	1.2×10^{-9}	2.0×10^{-9}

IMAGING A LABORATORY ELECTRON BEAM

A laboratory electron source (Kimball Physics Inc. EGG-3103) was used with 5 KeV in energy and 0.6 mA in current. An image of such electron beam by this monitor is shown in Fig. 6 by using the photon-counting method [15]. The integration time is 100 s and the gas used is Nitrogen. The broadening due to the gas jet thickness can be seen in the horizontal direction because the original electron beam is round. The reason for using a thicker jet is to increase the photon rate and thus decrease the total integration time to find the signal in the intended LHC experiment where the cross-section is still an unknown parameter and might be overestimated. According to Fig. 7, the X profile of the image, the photon rate from the current version is improved from 18 photon/s to 300 photon/s. Once the cross-section is confirmed through later LHC measurement[18], the thickness could be reduced to increase the resolution by decreasing the slit size of the third skimmer.

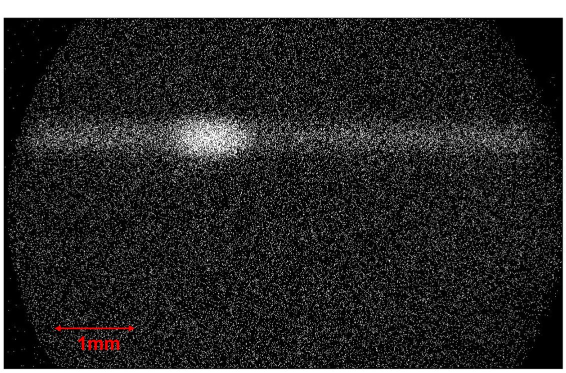

Figure 6: Image of an electron beam from the gas jet monitor.

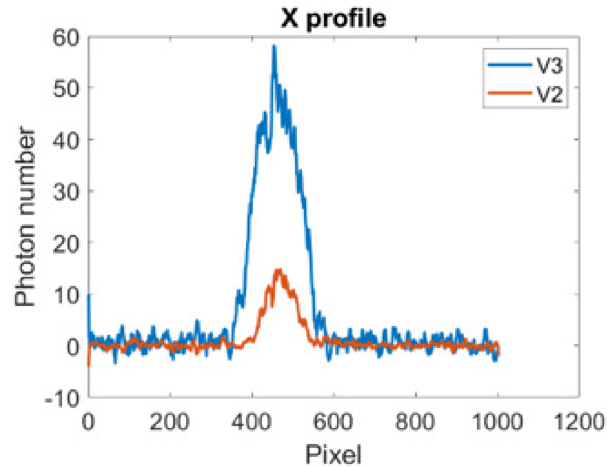

Figure 7: Comparison of the photon rate between old (V2) and new (V3) version of the nozzle-skimmer-assembly.

CONCLUSION

This contribution describes the commissioning of a new version of the gas jet beam profile monitor which is intended to be used in the EBTS and the LHC. A new geometry was established by the simulation to satisfy the distribution requirement for the LHC and the EBTS and then verified by gas density distribution measurement. The measurement with the laboratory electron beam showed an improved signal to noise ratio which is beneficial for the intended LHC beam measurement. Currently, the setup has been delivered to CERN and the initial testing there shows a very similar result. For the future, the measurement in the EBTS and the LHC is under preparation, and the details can be seen in [18].

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