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DEVELOPMENT OF A SUPERSONIC GAS-JET MONITOR TO MEASURE BEAM PROFILE NON-DESTRUCTIVELY

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Abstract

The measurement of the transverse beam profile is a great challenge for high intensity, high brightness and high power particle beams due to their destructive effects and thus non-destructive methods are desirable. Current non-destructive methods such as residual gas monitors and beam induced fluorescence monitors either requires a longer integration time or higher surrounding pressure to make a meaningful measurement. As a potentially improved technique, a supersonic gas-jet beam profile monitor has been developed by the QUASAR Group at the Cockcroft Institute, UK.

In this monitor, a 45 degree supersonic gas curtain is generated and interacts with beam when the beam crosses it. Ions generated by this process are then accelerated by an extraction electric field and finally collected by a Micro Channel Plate (MCP). Beam images are obtained via a phosphor screen and a CCD camera.

In this contribution, we briefly describe the working principles and present better beam profile measurement of a low energy electron beam using this monitor with newly installed pulsed valve.

INTRODUCTION

Beam profile monitoring is essential for any accelerator system in diagnosing the transverse property of particle beams. Many existing methods could be chosen based on the type, energy and lifetime of the specific particle beam as well as the system requirement such as vacuum condition and beam loss control. For an example, the beam diagnostic in the Ultra-low-energy Storage Ring (USR) [1] at GSI, in order to preserve a longer lifetime of the stored low energy antiproton beam, a vacuum condition of ~10^{-11} mbar is required. Meanwhile, considering the costly antiproton, a non-destructive method is preferred. These requirements basically limit the choice from the existing mature transverse diagnostics. Gas-based monitor, such as residual gas ionization monitor or fluorescent monitor, could be the potential candidate for USR project, because it reserves the vacuum condition quite well and disturbs the beam very little. However, a low ionization or fluorescent rate due to the low vacuum pressure requires a long integration time to obtain a meaningful profile and usually the measurement is in one dimension. In the USR case, the intrinsic integration time could be more than 100 ms which brings additional prerequisite for the primary beam stability. To reduce the integration time while keeping the non-destructive feature by using gas molecules, a novel 2-dimentional supersonic gas-jet ionization monitor is designed in Cockcroft Institute [2]. Previously, using the same principle, a magnetically focused oxygen molecular beam was implemented in HIMAC for fast heavy ion profile measurement [3] and a mechanically skimmed nitrogen beam in JPARC for the intense proton beam [4]. In this method, the localized gas intensity could increase by more than 5 orders of magnitude by the jet, which increases the ionization rate and thus shortens the integration time about the same order. Meanwhile, the vacuum is affected little due to the directionality of the supersonic gas-jet. In this paper, we will discuss the design and working condition of this monitor as well as recent results from an in-house low energy electron beam. Although the application is based on the USR due to its highly specialized requirement, this monitor could be generally used in any accelerators where the gas load is allowed.

WORKING PRINCIPLE AND TEST STAND

The schematic of the whole setup is shown in Fig. 1. The design is based on the Reaction Microscope [5]. To generate the supersonic gas flow, differential pumping technique is used in the nozzle chamber, the gas flow through a 30 um orifice from a high pressure area (few bar) to a low pressure area (about 10^{-1} to 10^{-2} mbar). With this large pressure difference, the gas will experience a free expansion process, and a supersonic flow will form inside a Mach disk. By placing the first conical skimmer (180 um in diameter) inside the Mach disk (less than 2 cm from the nozzle), we can guide a part of the supersonic flow into the following chambers to form a molecular flow and meanwhile avoid the effect from turbulence and other shock waves. An additional conical skimmer (400 um in diameter) is positioned 25 mm away from the first skimmer to further collimate the flow. In order to have a two dimensional measure of the primary beam profile, a third rectangular skimmer of 4*0.4 mm^2 is placed at 325 mm from the first skimmer before the interaction chamber under an angle of 45 degrees to create a screen-like jet. Detailed design and gas dynamics consideration including

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pump usage and alignment procedures can be referred to [6, 7].

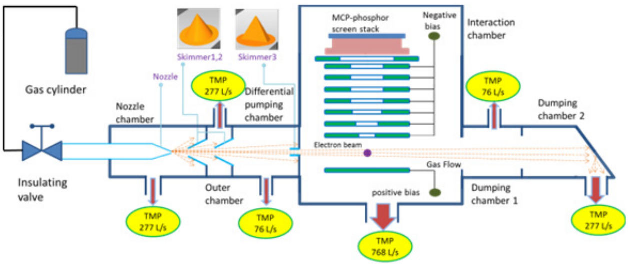


Figure 1: Schematic diagram of the supersonic gas jet setup.

In the interaction chamber, when the primary beam interacts with the supersonic flow, the gas molecules will be ionized. The ions generated in this ionization process are then accelerated by an extraction electric field. One circular solid metallic electrode is placed in the bottom of the reaction area and 8 parallel ring-shaped electrodes are above the reaction area. The bottom plate is positively biased while the top ones are biased with staged negative voltages to create a linear electric field of about 12 kV/m vertically. The top electrodes have central holes to let the ions pass through and the differences in the size of holes is to make the horizontal component of electric field small so as to minimize the distortion from the transverse distribution expansion of ions. The accelerated ions are collected by an MCP, and then the amplified signal reaches a phosphor screen. The finally image on the screen is recorded by a camera (Ueye 1024 x 768 8 bit CCD).

Figure 2 is a typical beam image from this monitor. Here, the initial pressure was 5 bar. The electron gun setting is 2.6 A filament current, 3.75 keV beam energy and 0.2 μA beam current. The camera setting is 70.0 ms shutter time, and 0 gain. In the current experiment environment, due to the out-gassing from the hot filament of the electron gun, the pressure inside the interaction chamber rises from $6.2*10^{-9}$ mbar to $1.2*10^{-8}$ mbar. Thus, a clear image of the primary beam from the residual gas can still be seen in the figure (the elongated line in x axis). In an actual application inside accelerator, such outgassing source can be eliminated and thus decrease the intensity of the residual gas image. The image from the supersonic gas-jet curtain is the top one with squeezed size which represents a more accurate measure of the primary beam in both directions. The shift from the residual gas image is due to the initial velocity of the ions from the gas jet.

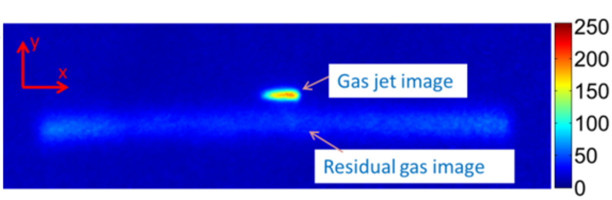
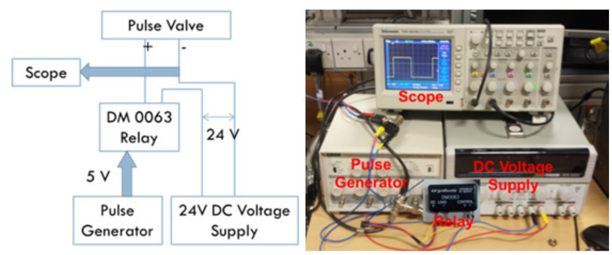


Figure 2: Beam profile from the supersonic gas-jet monitor.

NEWLY INSTALLED PULSE VALVE

Recently, we upgrade the insulating valve with a Festo solenoid pulsed valve. It features a maximum switching frequency of 280 Hz with 0.2 ms switching time, an operating pressure of 0-8 bar and a standard nominal flow rate of 200 l/min. We use a TGP110 pulse generator to trigger the pulsed valve externally. It has a frequency range from 0.1 Hz to 10 MHz and knobs for varying the period, pulse width and pulse delay individually. Its maximum output amplitude is 10 V which is less than the requirement of the pulsed valve operating voltage 24 V. Thus, a DC power supply (ISO-TECH IPS-3303) and a relay (Crydom DMO063) are used, together with the pulse generator to create a 24 V pulse. The electrical connection is shown in Fig. 3. The relay receives the 5 V trigger from the pulse generator and generates a 24 V signal from the power supply. A scope is used for monitoring the generated pulse.



(a) (b)

Figure 3: (a) Diagram of the pulse valve module; (b) picture of the pulse generation setup.

Figure 4 shows the pressure response in the differential chamber and dumping chamber of the pulse valve with 0.8 s period, 50% duty cycle. Here, helium gas was used with an initial pressure of 2 bar from the gas cylinder. Initial tests of the pulse valve include varying the period, duty cycle and the initial pressure of the gas loading. These tests show a characteristic time of about half a second for the vacuum condition to restore after each firing of the gas-jet. The maximum pressures inside both the differential and dump chambers are quite linear with the initial gas loading pressure. These tests suggest that by synchronizing the camera with the pulse valve and setting a proper shutter time, the signal ratio between the supersonic gas-jet and the residual gas can be doubled at least.

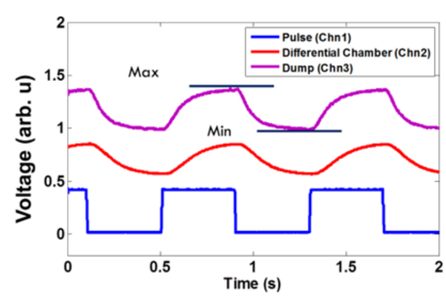


Figure 4: Time structure of the pulse valve and pressure response in the two chambers (as in voltage shown in scope).

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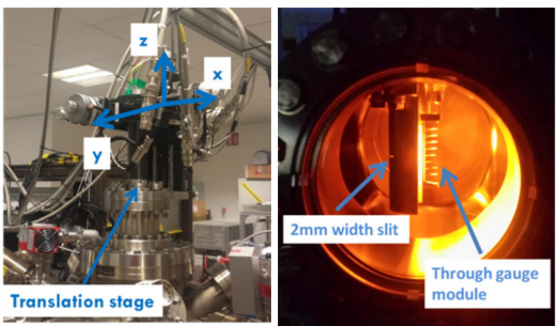
MOVEABLE ION GAUGE COMPONENT

The gas curtain distribution is essential in estimating the final resolution of this method, especially the axis which perpendicular to the gas-jet direction. To investigate this distribution, a moveable ion gauge assembly has recently been added into the setup between the interaction chamber and the first dumping chamber. The whole assembly includes a translation stage outside the vacuum chamber (see Fig. 5 (a)) and the attached ion gauge aiming at the gas jet curtain (see Fig. 5 (b)). To sample the gas-jet curtain, two kind of gauge assembly could be used including the through gauge module and the compression gauge module.

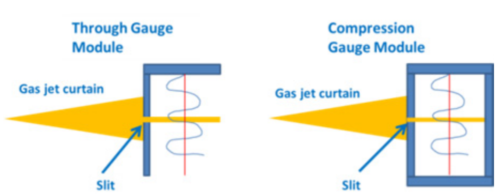


(a) (b)

Figure 5: Moveable ion gauge assembly: (a) 3D translation stage; (b) through gauge module inside.

The through gauge module, as seen in Fig. 6 (a), contains a slit in front of the Bayard-Alpert type ion gauge. In this configuration, only a small portion of the jet passes through the slit and its pressure is measured when the jet flow interacts with the gauge. The shortcoming is the competition of the signals from both the allowing portion of the gas jet and the surround pressure building up by the rest. Shorter pulses of the gas-jet could separate these two signals, but the real signal could be easily overlapped by noise.

For the compression gauge module, as seen in Fig.6 (b), the gauge is inside a small chamber with only a slit in the front to allow part of the jet to enter. The measured signal will be a time integration of the jet entering the slit. In this configuration, the pressure building up in the surrounding by the rest of the gas jet will have little influence on the measured signal. The only drawback is that we lose the time structure of the jet. These modules are currently installed into the whole setup.



(a) (b)

Figure 6: (a) Through gauge module; (b) Compression gauge module.

CONCLUSION

In this paper, we discussed the working principle, beam experiment and recent development of a novel supersonic gas-jet beam profile monitor. We report new components which have been implemented in the system and detail experiments will be carried out.

Future plans include jet distribution measurement. These results will help to understand and maximize the resolution of this monitor and benchmark gas dynamics simulations. The benefit of the latter one is to optimise the design of nozzles, skimmers, as well as the whole vacuum system to implement this monitor into various types of particle beam and working environments.

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