DEVELOPMENT OF A GAS-SHEET BEAM PROFILE MONITOR

Y. Hashimoto, Y. Fujita, T. Morimoto, S. Muto, KEK, Tsukuba, Japan
T. Fujisawa, T. Honma, K. Noda, Y. Sato, S. Yamada, NIRS, Chiba, Japan
H. Kawauchi, A. Morinaga, Science University of Tokyo, Chiba, Japan
K. Takano, J. Takano, Takano Giken CO, Ltd., Kanagawa, Japan

Abstract

For fast and non-destructive beam profile detection in ion synchrotrons, a monitor using gas-sheet target is developed. The pressure of the target is 2.5 x 10^{-7} Torr, the thickness 1.3 mm, and the width 100 mm. On a performance test using an extracted 8 MeV proton beam from NIRS-Cyclotron, a beam profile was successfully measured.

1 INTRODUCTION

Nowadays, fast beam diagnostic tools are needed for accurate beam operation of ion synchrotrons and beam physics. So we try to develop a non-destructive beam profile monitor using dense oxygen molecular gas-sheet target. Because, about measurement time and beam charge, usual residual gas profile monitor has limitations [1].

Now, a detection method is studied by using ions produced with collision of ion beam on a gas-sheet. The produced charges of ions are multiplied in double MCPs and make profile image on the screen positioned in the rear of the MCPs. So visible observation is possible with CCD camera attached Image Intensifier (I.I.). Such MCPs and I.I. also make the measurement sensitivity higher. For future intense proton beams in JKJ 50 GeV synchrotron, the other method with luminescence light from target is started to study [2].

For the fast detection, a dense gas-sheet target is essentially required. So as to obtain such a dense gas-sheet Nozzle-Beam method which is popular technic in molecular experiment [3] is employed. In this method the shapes and arrangement of the nozzle and the slit called skimmer, of course vacuum pumping abilities, are most important to obtain a dense beam. In this paper the situations of these developments are reported mainly.

As another feature for getting denser gas-sheet, in-situ multi-pole magnet producing inhomogeneous field is installed for focusing an oxygen molecular beam. The method is based on the fact that an oxygen molecule has a magnetic moment of 2 Bohr magnetons and a spin of 1. With this equipment the target density increased up to about two times in a preliminary test [2].

2 OUTLINE

As shown in Figure.1, the beam profile monitor consists of five sections which are evacuated with respective turbo-molecular pumps (1000 l/s and 750 l/s). Slits are mounted on the walls between successive chambers to reject the diverged gas and keep the detector chamber in good vacuum.

The nozzle and the skimmer are installed in the jet chamber for producing molecular beams. The sheet beam runs to the detector chamber through the slit chamber and the magnet chamber. In the slit chamber, the diverged molecules are rejected and in the magnet chamber an O_2 sheet beam is focused at the median plane with the in-situ multi-pole magnet.

In the monitor chamber the sheet beam collides with an ion beam. As the gas sheet is set inclining 45 degree to synchrotron beams, whole cross-sectional beam profile is able to detect. The dimensions of the gas sheet are 1.3 mm (T) x 100 mm (W). The ions produced by the collision are accelerated by the electrodes in a vertical direction and enter the detection unit. The molecules which are not ionized are evacuated in the next chamber.

When the gas is flowed by a pulsed operation, the pressure in the jet chamber, slit chamber, magnet chamber and monitor chamber are roughly 5×10^{-3}Torr, 3×10^{-5}Torr, 5×10^{-7}Torr and 6×10^{-8}Torr, respectively.

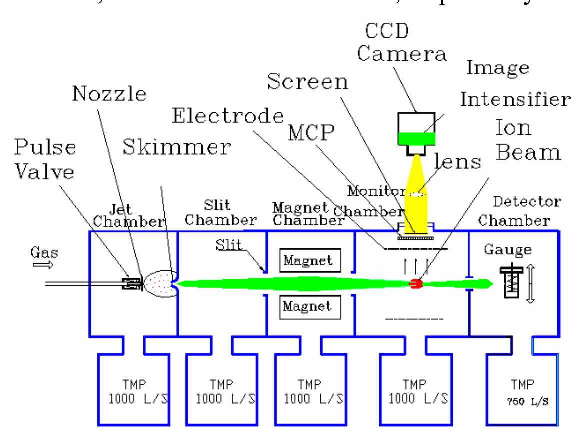

Figure 1: Schematic view of the sheet beam profile monitor

3 NOZZLE BEAM METHOD

Fig. 2 shows a schematic view of the gas jet from a sonic nozzle [3]. High pressure gas is released thorough an minute orifice into vacuum and then an adiabatic free-expansion is occurred. In the region near the orifice within 2 or 3 mm, molecules included in the expanded gas collide each other much frequently and are cooled. After the region such a collision is rarely occurred. Then the molecules have almost uniform velocity and run in radial direction. At the surroundings of the flow, some shock layers are formed. When molecules come to such shocks, they are caused to scatter due to the nonisentropic effect and the viscosity.

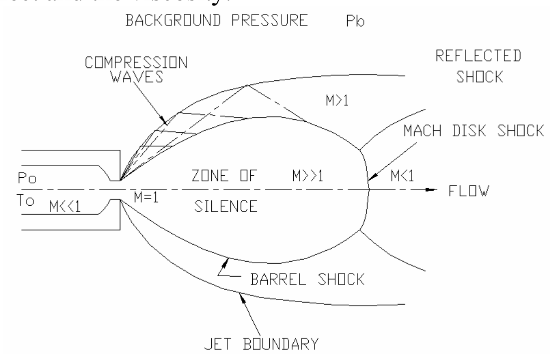

Fig.2 : Nozzle beam and its surroundings [3].

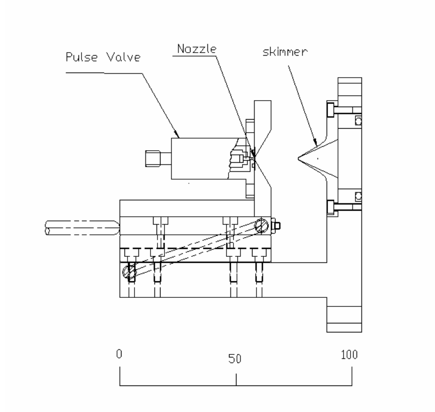

Fig.3 : Nozzle and Skimmer

The skimmer is set into the region of zone of silence to extract only center-line flow. Produced molecular beam called jet has characteristics mentioned below in general. (1) The velocity is almost uniformed termination velocity. In case of oxygen molecules termination velocity is 735 m/s. Its velocity spread is within several percent. (2) The molecules are cooled down to several Kelvin in the lowest case. (3) Typical flux intensity is 1 x 10^{19} molecules/sr.sec.

3.1 Nozzle

The nozzle is made of stainless steel of 0.2mm in thickness and has a small orifice. The nozzle diameter of 40, 60, 100, 150, and 200 µm are studied to obtain the highest beam intensity.

3.2 Skimmer

The skimmer is employed for rejecting a disused beam and extracting a required beam. Then the blade angle, the height of the pyramid, and slit sizes are especially important for obtaining the high intensity beams. The outer blades of the skimmer have a function of repulsing disused beam toward to the source side. To avoid interrupting the main gas flow in the zone of silence by rejected beam, the outer blades are required to be acute angles. On the other hand the internal blades are needed to be obtuse angles in consideration of no disturbing extracted beam and taking large vacuum conductance.

Concerning the slit placed on the top of the skimmer pyramid, the horizontal aperture was fixed for 3 mm on account of keeping 100 mm sheet width at the target. Some kinds of vertical apertures were prepared for examination, of 0.6, 0.9, 1.5, and 2.0 mm. Besides the skimmers having different blade angles and altered the size of the pyramid were made. In case of 0.9 mm vertical aperture, three kinds of blade angle sets were made, of 60/50 as the standard, 50/40, and 40/30 (outer/inner) in degree. About the skimmer pyramid size, comparing standard pyramid height of 13 mm, skimmers having 49 mm pyramid height were made in vertical apertures of 0.9 and 1.5 mm cases.

The materials for our skimmer are SUS303 or aluminum of A5052 for good manufacturing. The inside of the skimmer is cut by discharge machining and the outside is shaped by wire cutting.

The pulse valve and nozzle are mounted on a linear guide to adjust the distance between the nozzle and the skimmer as shown in Fig. 3. In this system molecular beams were pulsed with an electro-magnetic valve (Parker Instrm.; rise time >100 µsec) for reducing pump loads. The supplying gas flow is regulated within 1 % by mass flow system (MKS 250E, 670A).

4 CHARACTERIZATION OF A SHEET BEAM

4.1 Compression Gauge

The nozzle beam is measured with a compression gauge. The gauge comprises of B-A gauge and gauge chamber surrounding it. The gauge chamber has a slit with a width of 14.5mm and a height of 0.5mm for the beam entrance. The gauge is mounted on a linear guide allowing the gauge position to be changed, to measure not only the intensities of the beams but also the density distribution of them.

4.2 Density Distribution of the Sheet Beam

Using the compression gauge, the density distributions of the sheet beam were measured [1]. The sheet thickness was 1.3 mm by FWHM at the center of the target. The sheet thickness can be reduced by changing the width of the slit placed in front of the monitor chamber. The sheet width was 100mm, whereas uniformity of the intensity was 100±2 %. These values fully satisfy our demand.

4.3 Sheet Beam Intensity

The sheet beam intensity was measured by setting the compression gauge in the magnet chamber, which was positioned 60cm downstream from the nozzle. The beam intensities were measured for different distances between the nozzle and the skimmer at given source pressures.

The best results are shown in Figure 4. In the figure the beam intensity is expressed in Torr for a meaning of vacuum pressure ΔP in the compression gauge. In this case the nozzle diameter was 0.2 mm, the skimmer aperture sizes 2.0 (V) x 3.0 (H) mm^2, and the skimmer blades angles 60/50 (outer/inner) in degree. It is shown in the figure that the maximum beam intensity ΔP 8.5 x 10^{-6} Torr was obtained under a condition the source pressure (P_0) was 1800 hPa and the distance between the nozzle and the skimmer (*NS*) was around 24.5 mm.

It is also found that as P_0 is increasing, it means the extracted gas has to be increased proportional to P_0, *NS* becomes longer, and in too high P_0 region the intensity is going down. The first phenomenon is seemed that in short *NS* region molecules scattered by surroundings disturb main beam, so *NS* should be taken suitable distance. The second is seemed the pump ability is over. Regarding pump ability limitations, the pressure dependence of the beam intensity was measured. The beam intensity decreases when the vacuum pressures of the Jet chamber is 5 x 10^{-3} Torr or that of the Slit chamber is 1 x 10^{-5} Torr.

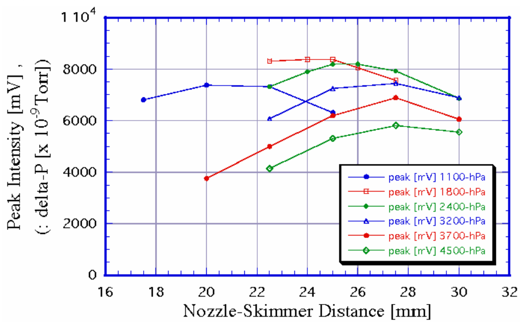

Figure 4: Beam intensity versus nozzle-skimmer distance for different source pressure.

Obtained quantity of ΔP 8.5 x 10^{-6} Torr is able to change into simple quantities as below. The beam flux (Q) equals to ΔP multiplied by the conductance (C) of the compression gauge slit of 0.7 L/s, as $Q=C\Delta P$. Also using a constant (α) of standard gases of 3.54 x 10^{19} molecules/Torr.L, Q is changed into the dimension of molecules/s, as $Q'=\alpha Q$. The density (ρ) of the sheet is gotten by dividing Q' by the passing volume through the area (s) of the compression gauge slit per second assuming that the beam velocity (v) is reached the termination velocity of 735 m/s, as $\rho=Q'/sv$. In case of expressing the sheet density (ρ') in Torr, ρ should be divided by α, as $\rho'=\rho/\alpha$. For changing Q' into the quantity per steradian, the solid angle (Ω)of the compression gauge slit of 2.1 x 10^{-5} sr is used, as $Q''=Q'/\Omega$. As these values are in inverse proportion to the square of the distance (L), as $1/L^2$, the values corresponds to the center of the target are obtained with the distance from the nozzle of 125 cm. These summary is shown in Table 1. The flux value is reached to the standard value of the typical molecular beam equipment of 1 x 10^{19} molecules/sr.s.

Another experiments described in the section 3.2 were also done. In case of the test using different skimmer blades angles, maximum intensity was obtained with the skimmer having blades angles of 50/40 (outer/inner) in degree. But about the others, the beam intensities were only 10% lower than that. On the occasion of the test with large height skimmers, almost no effects were shown.

Table 1: Beam Intensities

Position	Mag. Chamber	Target Center
Dist. from nozzle	600	1250
ΔP [Torr]	8.5 x 10^{-6}	1.95 x 10^{-6}
Q' [molecules/s]	2.1 x 10^{14}	4.84 x 10^{13}
Q'' [molecules/sr.s]	1.0 x 10^{19}	1.0 x 10^{19}
ρ [molecules/cc]	3.81 x 10^{10}	8.78 x 10^{9}
ρ' [Torr]	1.08 x 10^{-6}	2.49 x 10^{-7}

5 BEAM TEST

A profile of an 8 MeV proton beam extracted from NIRS Cyclotron has been measured to study performance of the whole system of the monitor [2]. Figure 5 shows the typical result when the beam current was 5 μA, the gate time 5 msec, and the sheet beam intensity 3.5 x 10^{-7} Torr.

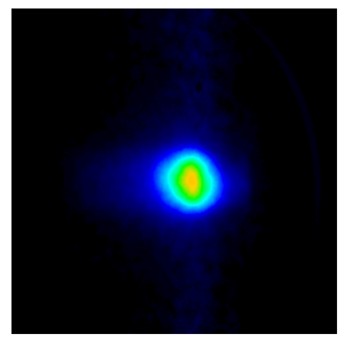

Figure 5: A measured beam profile.

6 CONCLUSION

The sheet beam intensity was reached to 1 x 10^{19} molecules/sr.s as expected. A profile of an extracted proton beam from NIRS-Cyclotron was successfully measured.

7 REFERENCES

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