DEVELOPMENT OF A BEAM PROFILE MONITOR USING AN OXYGEN GAS SHEET

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

Abstract

A non-destructive beam profile monitor using an oxygen gas sheet is being developed for ion beams. To produce the gas sheet, a nozzle beam method is employed. Besides taking use of a large magnetic moment of an oxygen molecule, the sheet is shaped by a high gradient magnetic field. A profile of the 8 MeV proton beam from NIRS- Cyclotron is measured by using the sheet. This paper gives the design and the present status of the monitor.

1 INTRODUCTION

Non-destructive type beam profile monitors are classified typically into three groups: (1) ionization type with residual gases[1,2,3], (2) flying wire method[4] and (3) ion probe method[5,6]. Each monitor attains perfection and has its own excellent characteristic respectively. Although from the point of view of very fast detection such as single-several bunch observation, those monitors are not adequately fast. The reasons are the fact that the former ionization efficiency is insufficient and the others sweeping time of probe needs over 10 msec.

Then we try to develop a very fast monitor by using high-density gas sheet[7]. To generate an intense molecular beam is essential for the monitor. So the nozzle beam method is employed[8, 9]. By using this method, it is possible to obtain several thousand times as intense as conventional molecular source. Its flux intensity becomes about 10^{19} molecules/sr.sec[8]. In the case of continuous beam, the vacuum pump of such an intense molecular beam generator is very large-size and its pumping speed amount to several thousand l/sec. In our system as a pulsed beam employed, pump size is not become so large (1000 l/s for a section).

Besides as the sheet is laid inclined 45 degrees to the transverse beam, horizontal and vertical beam profiles would be measured simultaneously. The thickness of the gas sheet becomes thinner, the ionization point is determined more clearly. In such a point of view, a high gradient magnetic field is applied to an oxygen molecule (magnetic moment: 2.0 Bohr-Magneton, spin: 1) to be focused. The designed sheet size at the colliding point with ion beams is 1mm x 100 mm.

2 GAS SHEET GENERATOR

2.1 Over View

The sheet generator is composed of differential pumping system with five chambers (see Fig. 1).

The sheet beam generated by the nozzle and the skimmer in the gas jet chamber, runs to the detector chamber through the slit chamber and the magnet chamber. In the slit chamber, the diverged molecules are rejected and evacuated, and in the magnet chamber an oxygen sheet beam is deflected to increase the intensity at the median plane with the multi-pole magnet. In the monitor chamber the sheet beam collides with an ion beam to detect the beam profile, and in the detector chamber the profile and the intensity of the sheet beam itself are measured.

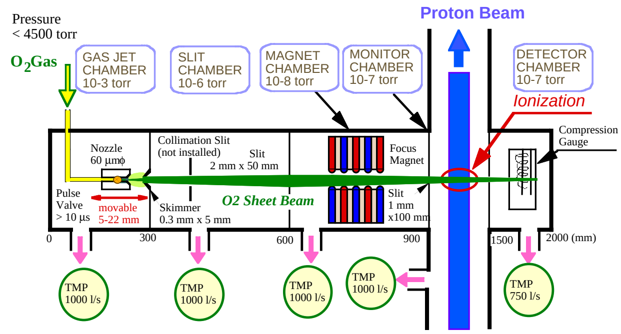

Figure 1: Schematic view of the neutral gas sheet generator.

2.2 Nozzle-Skimmer

As molecules are madedone adiabatic free expansion in the space between the nozzle and the skimmer, the molecules have supersonic velocities and cooled. They become a molecular beam passing through the collimation slit. The nozzle aperture is 60 µm and the rectangular skimmer aperture is 0.3 mm^V x 5 mm^H.

As the pressure in the nozzle should be high, in our system it is able to increase up to about 4500 Torr limited the pulse electro-magnetic valve (> 10 µs). The upstream gas flow of the nozzle is made feed back control within 1% by mass flow system (MKS 250E, 670A).

2.3 Focusing Magnet

The layout of the focusing magnet for an oxygen molecular beam is shown in fig. 2. Controlling the field strength the pole gap is variable in a range of 3 to 12 mm. It is compose with permanent magnets (NdBFe) and high permeability material (Permendur) for the poles. This type of magnet is usually used for the Multi-pole Wiggler in SOR rings[10].

In case of 5 mm pole gap, it generates a magnetic field of about 1 Tesla at the tip of the pole. Its mean gradient field in a vertical direction giving kick force to the beam is amount to about 4×10^4 gauss/cm. In such a focusing it is necessary to taking consideration of chromatic aberration and the deviation of the magnetic moment occurred by some kinds of the rotational level of an oxygen molecule[11, 12]. Reducing these effects the oxygen beam should be adequately cooled (about 10 K degree).

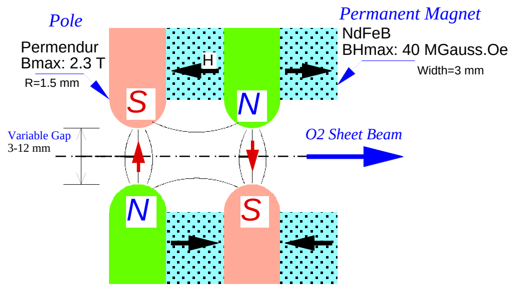

Fig. 2: Layout of one cell of the focusing magnet (total : 25 cell).

An oxygen beam trajectory in the magnetic field of 1 T was calculated assuming that the temperature of the oxygen gas is 10 k degree , the rotational quantum number(k) is 1 in such a low temperature, and the populations of magnetic sub-states(M) are even. The calculation shows that focal lengths of the J=2 state are 15 cm (-15 cm) and 30 cm (-30 cm) for M=2 (M=-2) and M=1(M=-1) respectively, and that of J=1 state is 30 cm (-30 cm) for M=1(M=-1). The focal lengths of M=0 states (J=2, J=1, J=0) are assumed infinite. Fig .3 shows the vertical intensity distribution of an oxygen beam calculated on the above-mentioned condition. The focusing magnet is already installed and the effect on the oxygen beam will be measured immediately.

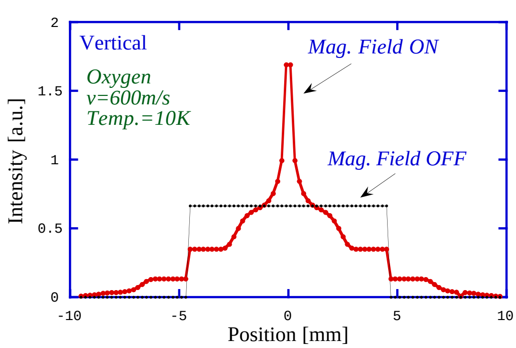

Fig. 3: Calculated Vertical intensity distribution of a molecular oxygen beam.

2.4 Gas Sheet Detectors

The intensity of the sheet beam is measured with the compression gauge method. The compression chamber has a small slit (1 x 14 x 0.5^t mm^3) and a B-A gauge is installed in it. Moving the gauge along the horizontal or vertical direction with linear mover the spatial intensity distribution of the sheet can be measured.

A new non-destructive type sheet profile measurement system using a high power laser beam (30 mJ, 30 ps) is under construction. The concept is that a high power laser spot of 40 μm makes ionization for whole oxygen molecules involved the spot region. Produced ions are collected and multiplied in a MCP and its charges are counted with photon counting detector. Also the position of the laser spot can be swept.

2.5 Present Status of the Gas Sheet

Sheet beam profiles measured without the focusing magnet are shown in fig. 4. In the horizontal direction the sheet has almost good uniformity (<3.7%), and in the vertical direction the thickness of the sheet is 2.2 mm of FWHM. It corresponds to 1.3 mm thickness at the beam colliding point. These values are reasonable to our design. In this situation the maximum density is about $8x10^8$ $molecules/cm^3$ and the optimum gas pressure is about 900 Torr in the nozzle. The density is considerable lower than the design value. It means apertures and distance of the nozzle and the skimmer has not been optimized.

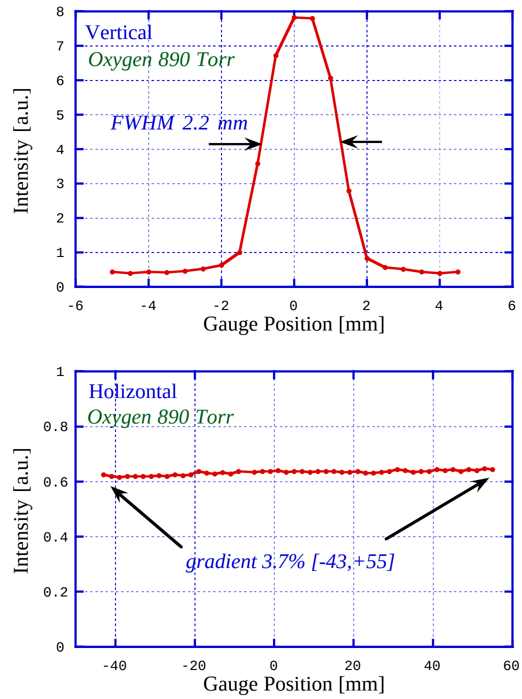

Fig. 4: Sheet beam profiles of vertical and horizontal direction respectively measured in the detector chamber.

3 BEAM PROFILE MEASUREMENT SYSTEM

3.1 Ion Collection Electrode

An ion beam profile is measured by detecting O_2 ions generated by the beam because an ion is less disturbed by undesirable electromagnetic field excited by the beam than an electron.

Using inclined sheet beam the structure of conventional multi parallel electrodes disturb the sheet. So we have made a half of sphere type concentric electrodes (see fig. 5). Because open windows are considerable narrow the radial electric field is expected to become less distortion. Using radial electric fields a picture is gained geometrically about 3.0 times at the front of the MCP.

3.2 Observation Optics

Ionized ions are forced to run to the MCP (Hamamatsu F2226) along the radial electric field induced by the concentric electrodes. Injected ions in the MCP make secondary electron emission. These electrons are multiplied in the MCP up to 10^7 maximum. Then multiplied electrons are hit the screen positioned downstream of the MCP. On the screen monochromatic light whose wavelength is 470 nm is emitted. The light decay time of the screen is about 100 ns at 1/10. A CCD camera attached an image intensifier (I.I. :max. gain $2x10^6$: Hamamatsu C4078) is used for observing the screen image. Also the I.I. can be gated of the range of from 5 ns to DC.

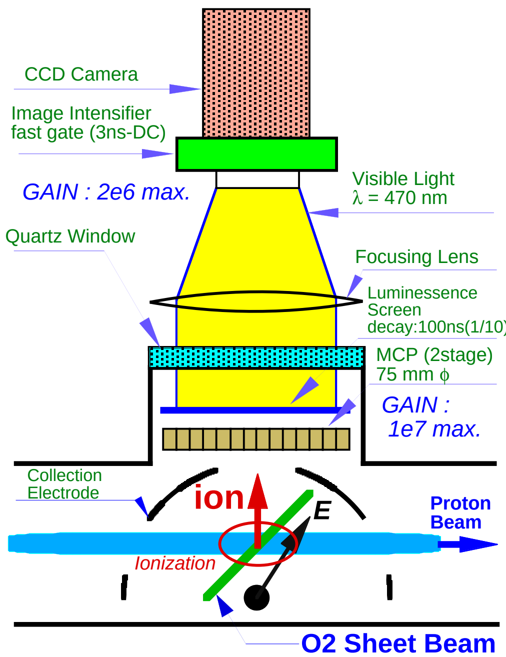

Fig. 5: Layout of the beam profile detector.

The total system gain of this optics is about 60. It means one electron generated in the MCP converts to 60 electrons in the I.I.. Typical parameters for this calculation are: MCP gain is 10^4, luminescence gain of the screen is 30, collection rate of the lenses is 0.002 and quantum efficiency of the I.I. is 0.1. As the detectable minimum numbers of electrons are 10 in the I.I., the calculated total system gain is sufficient.

4 BEAM TEST

A profile of 8 MeV proton beam whose mean current is 50 nA (see fig. 6) is measured. The proton beam passes from up to down in the picture. The figure shows that the proton beam ionizes residual gas along the path and the effect of O_2 sheet beam is not detected. This fact means that the density of the sheet beam is too low ($3x10^{-8}$ Torr) comparing to the pressure ($3x10^{-7}$ Torr) in the chamber.

On another measurement such a ionization beam profile by residual gases can be clearly observed with proton beam whose current is 1 nA. At this time the gains of the MCP and I.I. are about $5x10^4$ and $1x10^4$ respectively. The margins of these gains are both of about 10^2. As produced ion pairs are about $1.4x10^4$ pair/sec by calculation[13], it is estimated our system can observe at least 10^2 pair/sec.

Installation of our monitor into the NIRS-HIMAC synchrotron is planed. It is expected fast profile measurement in a revolution (calculated ion pair: $6.2x10^3$/rev.) becomes possible because our detectors has a sufficient sensitivity. The remaining theme is to obtain high-density sheet beam.

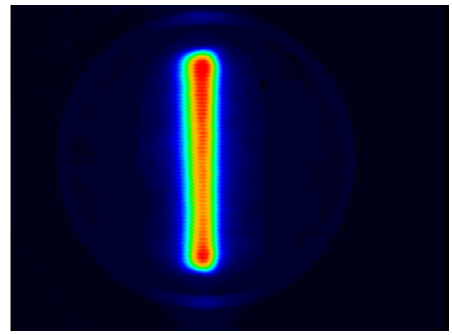

Fig. 6: Measured beam profile of a 8 MeV proton beam whose mean current is 10 nA.

5 FUTURE DEVELOPMENT

Next step is to study high intensity proton beam like the JHF 50 GeV synchrotron (10^{13}-10^{14} protons). In such a case it is difficult to collect ionized ions because of strong induced field around the proton beam. It is expected scintillation light emitted from excited gas sheet may be used. The study of light detection will be done.

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