A GAS SHEET BEAM PROFILE MONITOR FOR THE HIMAC SYNCHROTRON

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Abstract

We have developed a beam profile monitor with an oxygen gas sheet beam and installed in the HIMAC[1]. A beam profile of single bunch was successfully measured for 6 MeV/u Ar beam with intensity of 6 x 10^7 ppb.

1 INTRODUCTION

Fast beam diagnostic tools are desired for accurate beam operation of ion synchrotrons and beam physics. We developed a fast non-destructive beam profile monitor [2, 3, 4] using a dense oxygen molecular gas-sheet target and tested it in the HIMAC (heavy ion synchrotrons of NIRS).

A principle of the monitor was already presented [2, 3, 4] and the measurements using proton beams of the NIRS-Cyclotron were also reported [2, 3, 4].

In this paper, performance of the monitor and the first observation of a beam profile of the HIMAC are presented.

2 OUTLINE AND PERFORMANCE

2.1 Outline

Figure 1 shows a schematic view of the beam profile monitor that is composed of five chambers with differential pumping system. The distance between the nozzle and the centre of the target is 1230mm.

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 beam molecules are collimated with a slit. In the magnet chamber, an oxygen sheet beam is focused to increase the intensity at the median plane with a multi-pole magnet [3]. In the monitor chamber, the sheet beam interacts with ion synchrotron beams. The ions produced by the collision are accelerated by the electrodes in a vertical direction and enter the detection unit. In the detector chamber, the profile and the intensity of the sheet beam itself are measured by a thru-ionization gauge [4].

The HIMAC must keep ultra high vacuum because of relatively low energy heavy ion synchrotron whose injection energy is 6 MeV/u and the maximum extraction energy is about 800 MeV/u. The vacuum pressure of the monitor chamber without gas flow is 2 x 10^{-10} Torr. When the gas is injected, the vacuum becomes worse down to 1 x 10^{-8} Torr, in the case that the gas flow is a pulse operation for 120 µsec and the gas source pressure is 5000 Torr.

Nevertheless, the vacuum of the synchrotron ring is hardly become worse, factor three at most, at the point 3 m apart from the target. It seems that the two ion pumps mounted to the monitor chamber fulfil their function. As the time constant of the vacuum pumping system of the chamber is almost 100 msec, disused gas is pumped away within the time.

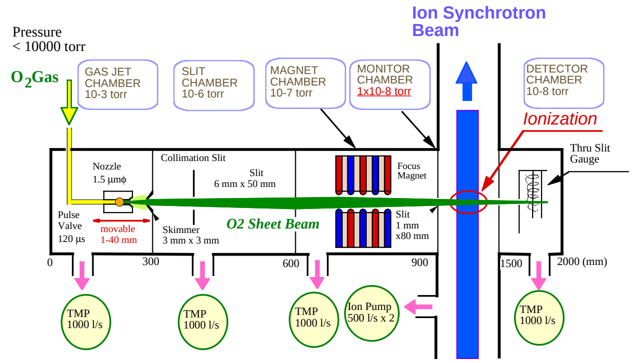

Figure 1: Schematic view of the gas sheet beam profile monitor.

2.2 Detector

Layout of the beam profile detector is shown in Fig. 2. Ions generated by the beam at the gas-sheet target inclined at 45 degree are accelerated to the MCP with a parallel electric field. The diameter of the electrodes is 230 mm and the gap distance is 70 mm. Both electrodes have a 100 mm hole at the central part for the ionized particles passing through. At the holes, fine wires whose thickness is 200 µm are mounted every 5 mm.

The electric field calculated by MAFIA shows that the ratio of the horizontal to the vertical electric fields are within 1 % in the range of 60 mm of the gap. It means that horizontal distortion of the collected ions are at most 200 µm. Besides, compensation electrodes which are not shown in the figure are installed both sides of detector electrodes in the beam line to avoid any effects on the synchrotron beam orbit.

The collected ions are multiplied by a two stage MCP (Hamamatsu F2226: max. gain 1 x 10^7, diameter 100 mmϕ). The luminescence light from a phosphor screen (decay time of the light: 100 nsec at 1/10, wavelength: 470 nm) positioned downstream of the MCP is detected by a CCD camera attached on an image intensifier (I.I. hereafter: Hamamatsu C4078, max. gain: 1 x 10^4). Analogue video signals from the camera are converted to digital signals and sent to a PC. The stability of data acquisition is tested using a stabilized light without luminescence light of the screen. The deviation of each data was less than 1 %.

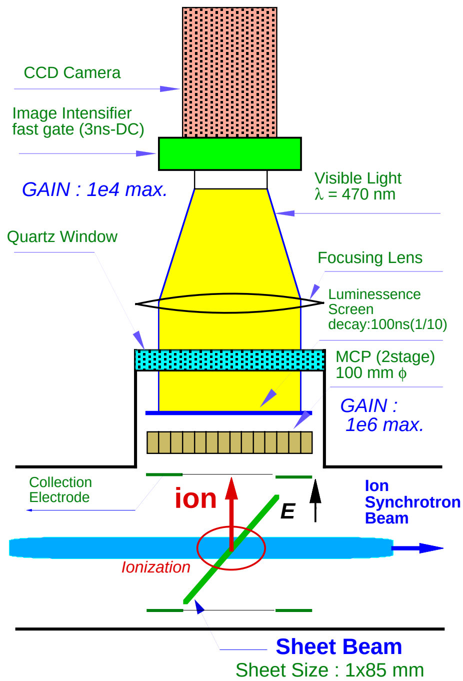

Figure 2: Layout of the beam profile detector.

2.3 Gas-Sheet Target

The oxygen gas-sheet target has a size of 85 mm width and 1.3 mm thickness. The spatial uniformity of the target density is 100±2 % [4].

The gas sheet density of 7.5 x 10^{-7} Torr was measured with thru-ionization gauge [4]. It is about three times larger than the typical molecular beam density of 1 x 10^{19} molecules/sr.sec [4, 5]. The reason is that a nozzle beam is hardly affected by the scattered molecules, so the intensity of the rising part of the pulsed molecular beam is two or three times higher than the hind part.

The time dependence of the density distribution of the pulsed oxygen sheet beam was measured with a proton beam extracted from the NIRS Cyclotron. The pulse width was 120 µsec, and the gate time of the I.I. was fixed at 20 µsec. The result is shown in Fig. 3.

The pulse shape at the target was calculated assuming that a rectangular 120 µsec pulsed oxygen beam was emitted from the nozzle. The calculated distribution of Mach 8 and Mach10 jets [4, 5] are plotted in the figure. The measured distribution is well described by a curve of Mach 10, especially near the peak. The molecules temperature in the parallel direction is about 14 Kelvin in calculation [4, 5] and velocities of the oxygen molecules are expected to be almost terminate velocity of 740 m/sec.

The region of 100 µsec of the pulse peak, that corresponds to the length of 74 mm, is used as a target. From the data, it has almost 10 % density deviation. When a detection of a beam size is 20 mm (σ), such a deviation only affects an error of about 2.5 %.

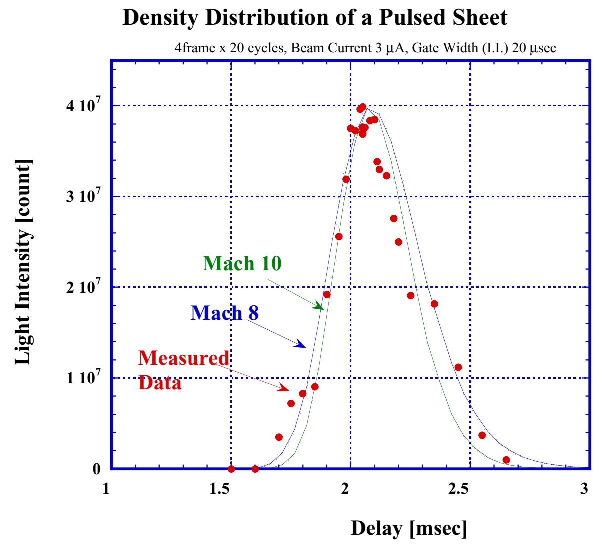

Figure 3: Time dependence of the density distribution of a 120 µsec pulsed oxygen sheet beam.

3 MEASUREMENT OF BEAM PROFILE

3.1 ExtractionBeam from the NIRS Cyclotron

Although a primary purpose of the monitor is to measure a profile of a circulating beam in a synchrotron, first we install the monitor in an extraction beam line from the NIRS cyclotron to study the performance.

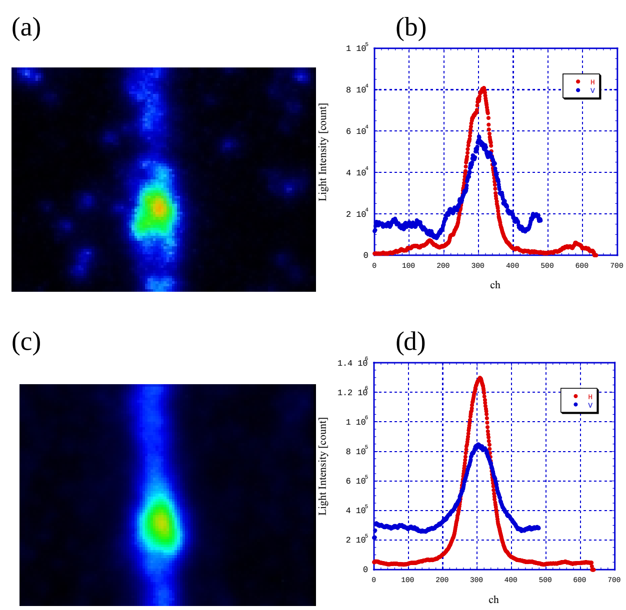

Figure 4: (a)(b) One shot beam profile of 5 µA proton beam with camera gate of 20 µsec, (c)(d) 20 cycles accumulated one with the same conditions.

A profile image of the proton beam whose energy is 8 MeV and the mean current is 5 µA is shown in Fig. 4 (a). The gate time of the I.I was 20 µsec. The projection data of horizontal and vertical directions are shown in Fig. 4 (b). Beam sizes are 4 mm^H and 5 mm^V, respectively (FWHM). The gate time of 20 µsec was considerably short and statistics was not enough. Under the same beam conditions, better S/N was obtained when the gate was opend 20 times more(Fig. 4(c) and (d)). The monitor also shows a good linearity as shown in Fig. 5.

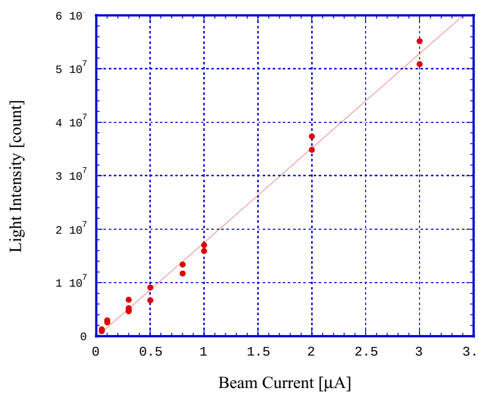

Figure 5: Linearity measured with the same beam conditions (10 cycles accumulated).

3.2 HIMAC Synchrotron Beam

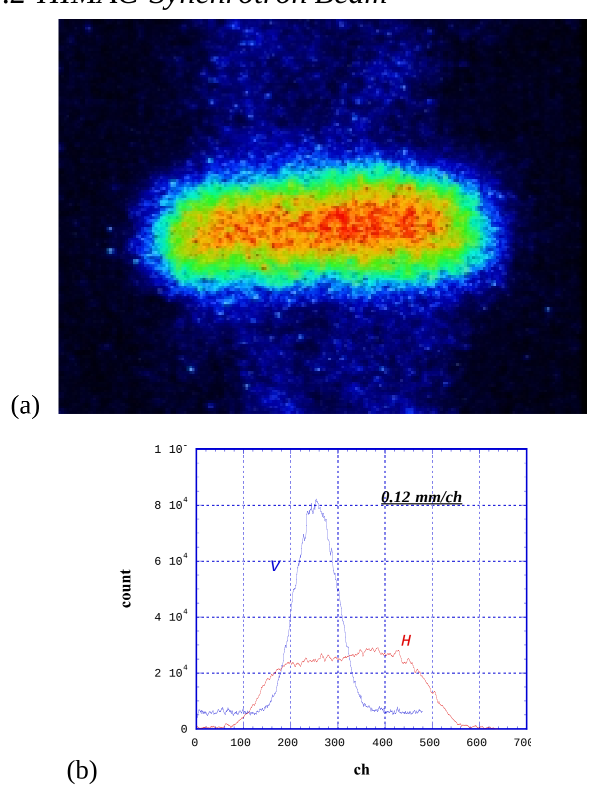

Figure 6: (a) A profile image of 6 MeV/u Ar beam at immediately after injection. (b) Projected beam profiles in the vertical and the horizontal direction.

Finally the monitor was installed in the HIMAC synchrotron, the beam profile of 6 MeV/u Ar beam at immediately after injection was successfully measured (Fig. 6). The beam intensity was 6 x 10^7 ppb (particles per bunch) and the I.I. gate time was 1 µsec which corresponds to the bunch separation of synchrotron beams. The magnification is 0.12 mm/ch. The data shows that vertical and horizontal beam sizes are 13 mm and 44 mm, respectively. Obviously, the cross-section of the beam is wide in horizontal because of the multi-turn injection.

We also measured a beam profile that was cooled with an electron cooling [6]. The energy was 6 MeV/u, the beam intensity was 5 x 10^6 ppb and the I.I. gate time was 8 µsec. Figure 7 shows beam profiles both before and after cooling. They show the vertical and the horizontal beam sizes are reduced down to 10 mm and 8 mm, respectively.

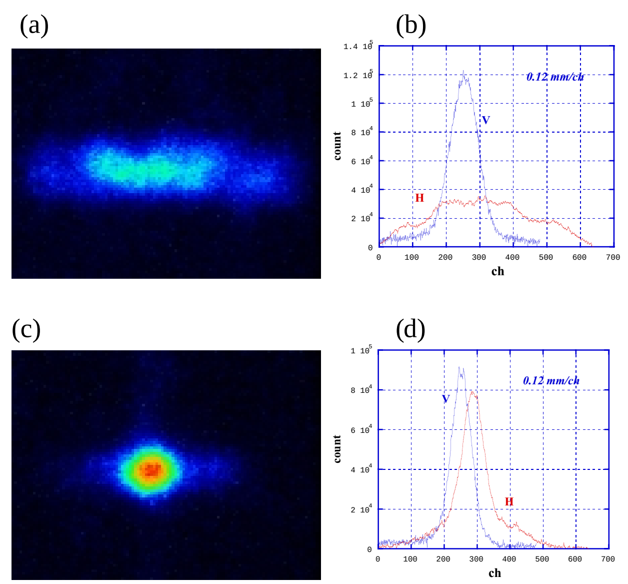

Figure 7: Electron cooling experiment in fixed energy of 6 MeV/u. Beam profiles of : (a)(b) before cooling, (c)(d) after 2.1 sec cooling.

4 SUMMARY

We have developed a beam profile monitor with a gas sheet beam and installed in the HIMAC. A beam profile of single bunch was successfully measured for 6 MeV/u Ar beam with intensity of 6 x 10^7 ppb. More beam studies to improve the monitor is planned in near future.

5 REFERENCES

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