ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAL018

A NON-DESTRUCTIVE 2D PROFILE MONITOR USING A GAS SHEET

N. Ogiwara†, J. Kamiya, Y. Hikichi, Y. Namekawa, M. Kinsho, Y. Hori, JAEA/KEK, Tokai, Japan
K. Hatanaka, T. Shima, K. Takahisa, M. Fukuda, RCNP, Osaka, Japan

Abstract

We are developing a non-destructive and fast-response beam profile monitor using a dense gas sheet target. To make a gas sheet, we apply the beaming effect in vacuum science and technology. The emitted molecules through a long rectangular channel are forced to concentrate on a plane. The gas sheet with a thickness of ~ 1 mm and the density of 2×10^{-4} Pa is easily generated by the combination of the deep slit and the supplementary slit. Here, the gas sheet is produced by the deep slit, and the shape of the sheet is improved by the supplementary slit. The usefulness of this monitor was shown by the following experiments: 1) For the electron beam of 30 keV with a diameter greater than 0.35 mm, the position and the two-dimensional profiles were well measured. 2) Then the profiles of the 10 and 400 MeV proton beam with a current of several microamperes were well measured, too. 3) Recently, the profiles of the 400 MeV H^- ion beams in J-PARC linac were measured.

INTRODUCTION

A non-destructive and fast-response beam diagnostics for extensive researches has been strongly required in the J-PARC. An idea to realize the beam detection is to introduce a gas-sheet target so as to yield luminescence lights or ions from the sheet target by the collision with the beam [1-4]. Because the intensity of the lights or ions is proportional to the product of the beam intensity and the target density, mapping of the light (or ion) intensity refers to 2D profile of the beam. It is essential for realizing this type of monitor to generate a thin gas sheet with a high and uniform density. The density higher than 10^7 molecules/mm^3 and the thickness of around 1 mm are required in the accelerators in the J-PARC [3].

Thus, we have developed a compact gas-sheet generator, which is composed of two kinds of slit. Gas molecules are forced to concentrate on a plane through a deep slit (long rectangular channel), and then the thickness of the sheet is controlled by the supplementary slit. This report will show the design of the gas-sheet generator and the performance examinations. Then, the usefulness of this type of monitor will be shown by some beam-experiments.

GAS SHEET GENERATOR

Simulations for the Basic Design

Details of the simulations for the design of the gas sheet generator were shown in previous reports [5,6]. Here, the outline is reviewed. The molecules are assumed to impinge over the incidence plane *A* and to outgo from the exit plane *B* through the long channel shown in Fig. 1. The letters *a*, *b*, and *L* represent the lengths of the long and short sides, and the depth of the slit, respectively. Origin of Cartesian coordinates (x, y, z) is placed on the center of the plane *B* and the azimuth λ is also defined as shown in Fig. 1.

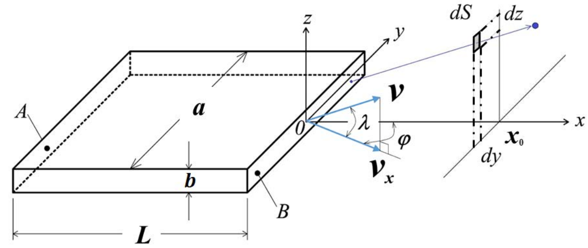

Figure 1: Calculation model.

The outgoing molecules from the exit gather on the *xy* plane, when the following two conditions are satisfied [6]: $L \gg b$ and $a \gg b$. The fraction Σ of outgoing molecules collimated within the azimuth $|\lambda|$ of less than 0.01 rad is shown in Fig. 2 as functions of L/b and a/b. For the slit with the parameter set of (L, a, b) = (100, 50, 0.1) (mm) the value of Σ is 0.275.

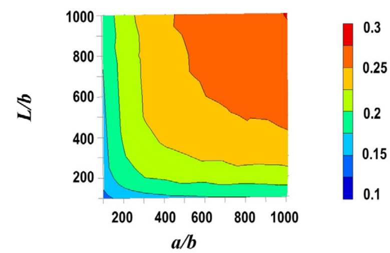

Figure 2: Fraction Σ as functions of L/b and a/b.

Experimental Investigation of Spatial Distribution of the Emitted Molecules

Intermolecular collisions are not handled in the above simulations. By increasing the pressure in the slit, the collision between the molecules becomes easily to happen and may lead to spread the thickness of the gas sheet. Thus, we have experimentally investigated the influence of the inlet pressure on the spatial distribution of the emitted molecules. The details of the experiments will be shown in near future [7]. Therefore, the outline is shown.

Ar gas molecules are fed to the incidence plane *A* and finally leave the exit plane *B*. After leaving the plane *B*, the Ar gas molecules impinging onto the virtual screen (which is placed on the plane $x = x_0$) are measured through a small hole on the plane by the flux monitor (see Fig. 1).

The ambient Ar pressure is very low, as the pumping speed of the chamber is very large (~ 7 m^3/s). Therefore,

†norio.ogiwara@j-parc.jp

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAL018

the Ar+ ion current by the flux monitor refers to the density of the gas sheet.

Typical results are shown in Fig. 3 for the slit with the parameter set (L, a, b) = (100, 50, 0.1) (mm). The screen is placed at x = 75.0 mm. Fig. 3a shows the z-value dependence of the spatial distribution, and Fig. 3b shows the y-value dependence, respectively. From the data shown in Fig. 3a), the thickness of the sheet is independent of the inlet pressure less than ~ 0.04 Pa. Above 0.04 Pa, the thickness increases with the pressure due to the intermolecular collision. The data in Fig. 3b) shows that the gas sheet density in the area within 20 mm from the center along the y axis is almost uniform. And this feature is independent of the inlet pressure, that is, independent of the intermolecular collision in the slit.

In addition, the density of the gas sheet was investigated as a function of the inlet pressure [8]. The density of 2×10^{-4} Pa was obtained with the inlet pressure of 100 Pa.

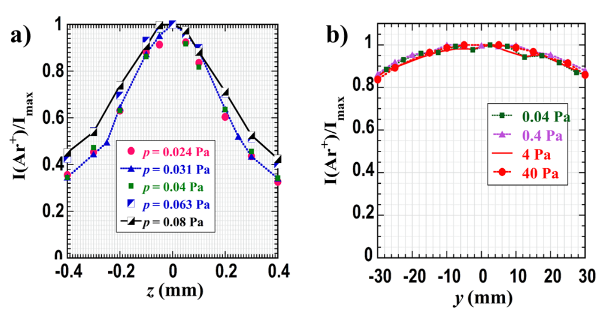

Figure 3: Spatial distributions of the emitted molecules; a) z-value dependence, and b) y-value dependence.

Generator for Demonstration Experiments

According to the above, a supplementary slit was added to the generator to keep the thickness of the gas sheet fixedly. Thus, the gas sheet generator for demonstration experiments was constructed [8]. Main parts of the generator are the deep slit for producing a gas sheet and the supplementary slit for controlling the shape of the sheet. The deep slit, which is formed between 2 SUS304 plates, has a length of 50 mm, a breadth of 0.1 mm, and a depth of 100 mm. On the other hand, the supplementary slit is placed on the cover of the differential pumping. The dimensions are as follows; a length of 60 mm, a breadth of 0.3 mm, and a depth of 10 mm.

Characteristics of this generator were experimentally studied [8]; The depth of the gas sheet is 1.5 ± 0.2 mm from the Ar^+ current profiles along the z axis. The depth is also found to be almost independent of the inlet gas pressure.

Generator for Linac in the J-PARC

To obtain the 2D profile using the gas sheet, it is desirable that the gas sheet has the uniform density over some area on the xy plane. However, the density decreases with the distance from the exit plane of the deep slit, as described in the previous report [8]. We are able to settle this difficulty by employing the set of 2 slits. For the slit with the parameter set (L, a, b) = (100, 50, 0.1) (mm), the same 2 slits are placed 75 mm apart from each other, and in twofold rotational symmetry. Furthermore, the exit planes are face-to-face and parallel. By doing so, there appears a uniform gas sheet in the center. The size is around 50 mm × 50 mm.

The gas sheet generator for the linac in the J-PARC was designed and constructed based on the above consideration. Schematic view is shown in Fig. 4. The generator consists of the same 2 units. The same 2 units are placed on a base plate, and in twofold rotational symmetry. One unit consists of three parts; the deep slit, the supplementary slit, and the equipment for differential exhaust. The deep slit has a length of 120 mm, a breadth of 0.1 mm, and a depth of 100 mm. The dimensions of the supplementary slit are as follows; a length of 160 mm, and a breadth of 0.3 mm. Furthermore, the supplementary slit units with the equipment for differential exhaust in order to make the unit compact. The distance between the faces of supplementary slits is set to be 100 mm.

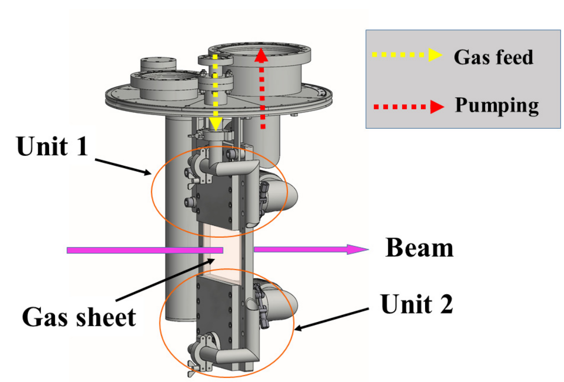

Figure 4: Gas-sheet generator for the monitor at the linac in the J-PARC.

The angular and density distributions were investigated by the test-particle Monte Carlo method. The fraction of outgoing molecules collimated within the azimuth $|\lambda|$ of less than 0.01 rad is estimated to be 0.285. Then, the uniform density is predicted over the area within ~40 mm of radius from the center

Now, the gas-sheet characteristics are experimentally investigated.

BEAM DETECTION EXPERIMENTS

Until now, we have succeeded to detect the following beams: a) electron beams of less than 30 keV, b) 10 and 400 MeV proton beams in RCNP, and c) 400 MeV H^- ion beams in J-PARC linac.

Detection System

The experimental layout for the beam detection with the gas sheet was already described [8]. The outline is described. The ions generated by the collision of the gas sheet to the accelerated beam enter the MCP. Then, the secondary electrons due to the ions are amplified through

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAL018

the MCP. The fluorescent screen illuminated by the MCP is observed by the CMOS camera through the quartz window. Thus the ions by the collision of the beam with the gas sheet are detected. The gas sheet is formed orthogonally to the plane formed by the electron/proton beam and the axis of the MCP. Moreover, the sheet and the electron/proton beam cross each other at around a 30° angle, not so as to avoid the collision with parts of the detector and the gas sheet.

Demonstration Experiments

The following experiments were carried out with the generator for demonstration experiment: electron beam detection, and proton bema detection.

Electron beam detection The electron beam has a diameter of greater than 0.35 mm and the current of greater than 1 μA. The bright spot, which is caused by ions that are generated by the collision of the electron beam with the gas-sheet generator for demonstration experiment, is clearly observed on the fluorescent screen illuminated by the MCP. The clear beam profiles can be obtained by analysing the light intensity, as shown in Fig. 5.

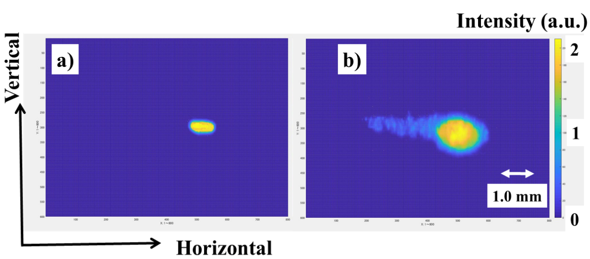

Figure 5: 2D profile images of the 30 keV electron beam; a) ~ 0.35 mm in a diameter, and b) ~ 1 mm.

Proton beam detection At the RCNP (Research Center for Nuclear Physics) Cyclotron Facility, Osaka University, we carried out the proton-beam detection experiments, using the 392 MeV beam (≤ 1 μA) and 10 MeV proton beam (≤ 4 μA).

With the 392 MeV beam, we had to use the graphite foils with a thickness of 25 μm in the beam line to maintain a good vacuum condition. Therefore, there is rather large background noise. However, beam positions previously observed by the fluorescent screen are found to reappear on the MCP, while the 392 MeV beam has the current of greater than 300 nA and the diameter of around 2 mm.

400 MeV H- Beam

Performance test of the gas-sheet generator It was tested at the RCNP to confirm the utility of the gas-sheet generator for the linac in the J-PARC. Here, the 10 MeV proton beam was used as the noise level was not so high. Although gamma rays are generated by the stopping of the beam at the graphite block, the clear beam profiles can be obtained with the gas-sheet generator.

Preliminary experiments in the J-PARC After the confirmation test at the RCNP, the beam monitor with the gas-sheet generator was installed at the linac in the J-PARC. The preliminary experiments to detect the H^- beam were carried out. The 400 MeV beams with the current of 10-50 mA were clearly observed. The details are revealed in another paper in this conference [9].

SUMMARY

We have been developing a new type of gas-sheet generator to realize the non-destructive profile monitor. Two types of generators have been constructed: 1) the generator for demonstration experiments to show the usefulness of this type of the monitor, and 2) the generator to investigate the characteristics of the 400 MeV H^- beam in linac of the J-PARC.

Both generators consist of the main three parts: the deep slit for producing a gas sheet, the supplementary slit for improving the shape of the sheet, and the equipment for differential exhaust. Especially the generator for the linac in the J-PARC was improved to obtain the uniform density over the area within ~40 mm of radius from the center.

The usefulness of the monitor with these gas-sheet targets was shown by the following experiments: 1) For the electron beam of 30 keV, the position and the two-dimensional profiles were well measured. 2) Then the profiles of the 10 and 400 MeV proton beam with a current of several microamperes were well measured, too. 3) Recently, the profiles of the 400 MeV H^- ion beams in J-PARC linac were measured.

REFERENCES

[1] B. Vosicki, K. Zankel, *IEEE Trans. Nucl. Sci.*, 22 (1975) 1475.

[2] R. Galiana, D. Manglunki, C. Manzeline, in *Proc. 1991 IEEE Particle Accelerator Conference*, San Francisco, 1991, pp. 1198-1200.

[3] Y. Hashimoto, T. Fujisawa, T. Morimoto, Y. Fujita, T. Honma, S. Muto, K. Noda, Y. Sato, S. Yamada, *Nucl. Instrum. Method A*, 527 (2004) 289.

[4] V. Tzoganis, H. D. Zhang, A. Jeff, C. P. Welsch, *Phys. Rev. ST Accel. Beams* 20 (2017) 062801.

[5] N. Ogiwara, and J. Kamiya, *J. Vac. Soc. Jpn.*, 55 (2012) 152-155.

[6] N. Ogiwara, *J. Vac. Soc. Jpn.*, 56 (2013) 146-150.

[7] N. Ogiwara *et al.*, submitted for publication.

[8] N. Ogiwara, Y. Hikichi, Y. Namekawa, J. Kamiya, M. Kinsho, K. Hatanaka, T. Shima, M. Fukuda, in *Proc. IPAC'16*, Busan, Korea, May 2016, pp. 2102-2104.

[9] J. Kamiya, Y. Hikichi, M. Kinsho, A. Miura, N. Ogiwara, presented at IPAC'18, Vancouver, Canada, Apr.-May 2018, paper WEPAL014, this conference.