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NON-DESTRUCTIVE 2-D BEAM PROFILE MONITOR USING GAS SHEET IN J-PARC LINAC

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Abstract

A beam profile monitor using interaction between the beam and the gas molecules distributed in sheet shape has been developed. Ions or luminescence generated by passing the beam through the gas sheet has the information of cross-section shape of the beam. The gas sheet beam monitor will become a useful tool to measure the profile of high power beams because it has no breakable element such as wires. Furthermore, 2-D beam profile can be obtained at a certain position of beam line. We applied the gas-sheet based beam profile monitor to J-PARC LINAC, where the negative hydrogen atoms are accelerated to the energy of 400 MeV. The vacuum system was carefully designed not to make an unacceptable pressure rise in nearby cavities when the gas was injected. The clear image of the beam profile was successfully obtained by detecting the ionized N_2 gas.

INTRODUCTION

Non-destructive beam profile monitors, which detect ions, electrons, or fluorescence generated by the interaction between the gas molecules and the projectile beam, are required for any accelerators [1-3]. In high-power beam accelerators, traditional methods for the beam profile measurements, such as scanning/multi-wires or phosphor screen, are not allowed due to the problems of cutting of the wires, large radioactivation of the screen, and so on.

The Japan proton accelerator research complex (J-PARC) aims to produce the proton beams with the power of 1 MW by the 3-GeV rapid cycling synchrotron (RCS), corresponding 133 kW negative hydrogen H^- beam power with the energy of 400 MeV in the injection LINAC. A non-destructive beam profile monitor, which uses the dense sheet-shaped gas, has been developed to measure the profile of the beam with such high power. The previous paper described the slit design based on the simulation and the measurement results of the generated dense and thin gas sheet [4]. As a verification experiment, cross-sectional shape of electron beam was clearly observed by detecting the ionized molecules in the gas sheet interacted with the electron beam. In response to the successful results in the laboratory, the beam profile monitor using the gas sheet was applied to the J-PARC LINAC. The system was carefully designed to avoid the unacceptable pressure increase in the beam line.

In this article, the design concept of the gas-sheet based beam profile monitor for the LINAC is firstly introduced. Secondly, the vacuum system design and the measurement results of the pressure distribution along the beam line are mentioned. Finally, the first observation of the cross-sectional profile of H^- beam with the energy of 400 MeV in the J-PARC LINAC was described.

GAS-SHEET BASED BEAM PROFILE MONITOR IN J-PARC LINAC

Basic Concept of Beam Profile Observation

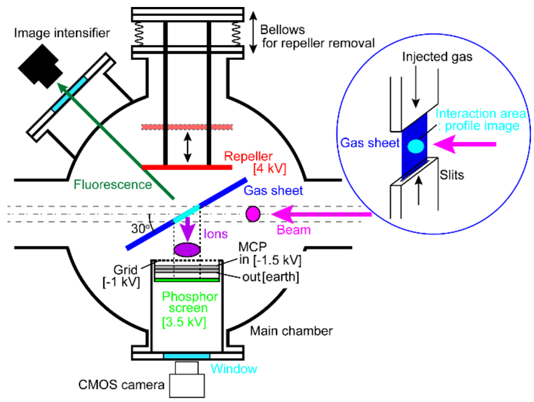

Figure 1: Conceptional diagram of a gas-sheet based beam profile monitor in J-PARC LINAC. N_2 was used for the injected gas.

Basic idea of the beam cross-sectional shape observation at the interaction point between the beam and gas sheet was described in the previous paper [4]. As shown in Fig. 1, the gas-sheet based beam profile monitor for the J-PARC LINAC follows the same concept. As described above, there are several candidates for the particles detected, that are ions, electrons, or photons. Because the orbit of electrons is easily distorted by the potentials generated by the beam itself, the observed beam profile would be distorted. Therefore, the system was designed to detect the ions or fluorescence. The sheet-shaped nitrogen gas was generated in the beam trajectory at an angle of 30° by passing through the slits with the 0.1 mm thickness. This angle is decided for the gas sheet not to directly collide with a repeller and micro channel plates (MCP). The slits are located both up and bottom sides to create more uniform thickness of the gas-sheet than that in the previous test case where the slit is set in the one side. The ions, which are generated with a cross-sectional shape of the beam at the intersection point between the beam and the gas sheet, are extracted by an electric field, which is created by applied voltage to the repeller and an inlet of the MCP. The ions release secondary electrons in MCP: 2 stages of type F1217-01 provided by Hamamatsu Photonics K.K., which are then multiplied with the amplification of more than 10^6 [5]. The channel diameter and pitch of the MCP is 12 μm and 15 μm, respectively. The electrons output from the MCP hit a phosphor screen, and the beam profile at the

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phosphor screen was monitored by a CMOS camera with a display resolution of 1980×1080. The space resolution is about 0.1 mm in the phosphor screen due to the extruding of output electrons from MCP. Typical applied voltage for each component is shown in Fig. 1.

As shown in Fig. 1, The system is also designed to detect the fluorescence when the repeller pulled out between the intersection point and an image intensifier used as a detector. For the true beam profile measurements, the fluorescence detection is more ideal than the ion detection because the fluorescence doesn't be deformed by the electrical potential generated by the beam itself. However, the reaction cross-section of the fluorescence is significantly lower than that of the ionization. Thus, this time, the ion detection was performed as the first trial of the beam profile observation.

Vacuum System Design and Performances

The gas injection line and vacuum system for the gas-sheet based beam profile monitor shown in Fig. 2 was designed to satisfy the following demands.

1. Pressure rise in the beam line due to the gas injection should be minimized.
2. Effect of the existing vacuum system has to be minimized when the monitor is maintained or unexpectedly large gas flow is injected.

Amount of gas used as the gas sheet is only a small part of the total injected gas. The redundant gas, which was cut by the slit, becomes not only the source of the large pressure rise in the beam line but also the background of the beam profile due to the ionized residual gas. To fulfil the first demand, such redundant gas was differentially pumped out by a turbo molecular pump (TMP) with a pumping speed of 400 l/s with a dry scroll pump as a foreline pump. For another consideration to satisfy the first demand, a cryopump was used as the main pump because it has the largest pumping speed among the commercially available pumps when the pumping apertures are the same. The cryopump with a pumping speed of 5000 l/s for N_2 was installed in the main chamber of the beam profile monitor. Furthermore, a TMP with a pumping speed of 400 l/s was additionally installed about 0.5 m upstream of the beam profile monitor to suppress the gas flow to the debuncher cavity and the annular-ring coupled structure cavity (ACS), which is located about 7 m and 22 m upstream, respectively. The admissible pressure rise in each cavity is 1×10^{-6} Pa and 1×10^{-7} Pa for the debuncher and the ACS, respectively. Figure 3 shows the estimated pressure rise from the base pressure along the beam line when enough high pressure of the gas sheet was generated. The pressure rise due to the gas injection was estimated to be only several 10^{-7} Pa and less than 10^{-10} Pa at the debuncher and ACS, respectively. Figure 4 shows the measured pressure distribution along the beam line when the amount of the injection gas was changed by operating the variable valve in the gas injection system. The measured pressure consists with the estimation.

To fulfil the second demand, the gate valves (GV) are installed in both sides of the main chamber and the Bayard-Alpert gauges (BAG), whose measurable lower limit is 5×10^{-8} Pa, are installed in both sides of the GV. By taking this configuration, the new apparatus can be maintained by only making the main chamber atmospheric pressure. The GV are automatically closed when the value of the nearby BAG exceeds a threshold value.

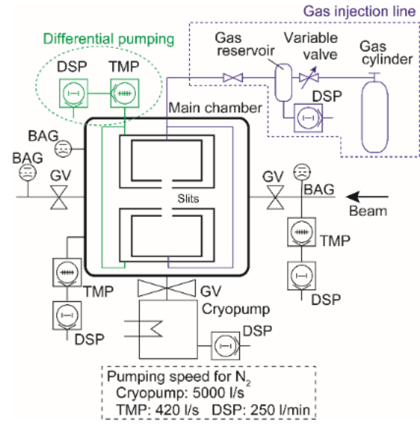

Figure 2: Diagram of the vacuum system for the beam profile monitor. Abbreviations represent TMP: turbo molecular pump, DSP: dry scroll pump, GV: gate valve, and BAG: Bayard-Alpert gauge.

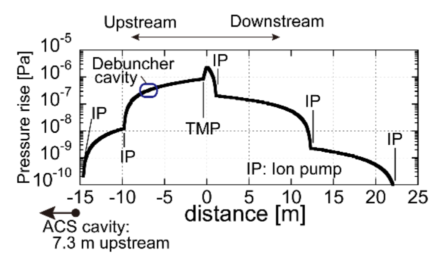

Figure 3: Estimated pressure rise along the beam line due to the gas sheet generation with the gas flow rate of 10^{-5} Pa m^3/s. The origin of the horizontal axis is the position of the main chamber of the beam profile monitor.

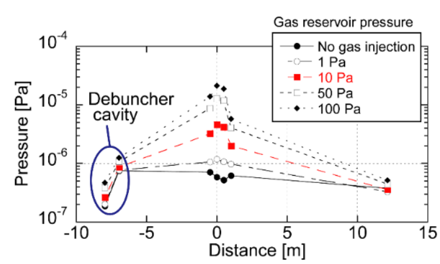

Figure 4: Measured pressure distribution along the beam line as a function of the gas reservoir pressure. The origin of the horizontal axis is the position of the main chamber. The gas reservoir pressure of 10 Pa shown in red squares corresponds to the condition in Fig. 3.

TRIAL BEAM PROFILE MEASUREMENT

The trial observation of the 400 MeV H^- beam by the gas-sheet based beam profile monitor was performed in the J-PARC LINAC. The peak beam current I_{beam} of 5-30 mA with 100 μs bunch length at the repetition rate of 2.5 Hz was used for the trial. Figure 5 summarize the typical

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procedure for the cross-sectional shape measurement by the new beam profile monitor. First, without gas injection, absence of the background by ionized residual gas, secondary particles, etc. was checked for each beam current. Next, the trace of the beam with the minimum peak current was observed by increasing the amount of injected gas, but without the differential pumping of the redundant gas by the slit. In this case, only the gas density in the entire main chamber increases without generating the sheet shaped gas. Then, the gas sheet was generated by differentially pumping the redundant gas, and the beam spot was observed. The induced gas was minimized to suppress the beam trace, which was now the background against the horizontal beam profile. When the beam current increases the injected gas was reduced to minimize such background.

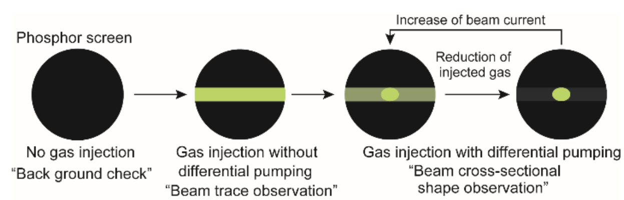

Figure 5: Typical procedure for the beam cross-sectional shape observation by the gas-sheet based beam profile monitor.

Figure 6 shows an observed "raw" beam profile at phosphor screen, which is a snapshot of the 60 fps movie taken by the CMOS camera. In this case, I_{beam} is 5 mA, the pressure in the gas reservoir at the gas injection line P_{in} is 10 Pa, and the pressure in the main chamber P_{main} is 5×10^{-6} Pa. The movie data was analysed by the MATLAB□ -based developed software. The flame synchronized with the 2.5 Hz beam was manually selected and averaged in the software. Figure 7 show the preliminary profiles of the averaged beam after gas-sheet angle correction. The beam size was roughly 4 mm in the horizontal full width at half maximum (FWHM) for the I_{beam} of 5 mA, while that measured by the scanning-wire monitor was 3.8 mm. With the correction of the gas-sheet thickness, both values would reasonably agree with each other.

Although, the first trial beam profile measurement was successfully performed, there are many tasks down the road. The main challenge is the measurement of the true beam profile. There are some conceivable sources to make the difference between the observed and true cross-sectional beam profile as follows.

1. Distribution of the gas density in the gas sheet including the sheet thickness,
2. non-linearity of the applied electrical field to extract ions,
3. and electrical field generated by the beam.

The first item is now being performed in the laboratory using the same slit. The effects of other items will be corrected by the help of calculation code, such as CTS software [6]. However, the ambiguity of the electrical field by the beam would remain because the true beam profile is not known. They become ignorable when the fluorescence is observed. Thus, the challenge for the fluorescence detection is started in parallel with the precision enhancement of the ion detection.

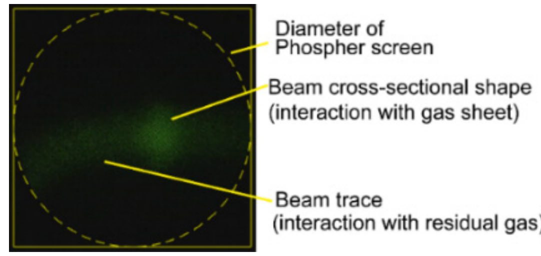

Figure 6: Observed beam profile at phosphor screen taken by CMOS camera. The condition is I_{beam}: 5 mA, P_{in}: 10 Pa, P_{main}: 5.3×10^{-6} Pa.

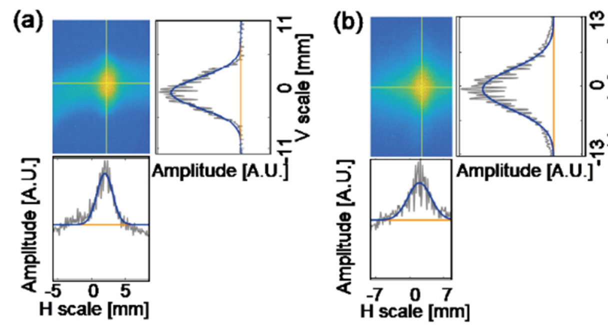

Figure 7: The averaged and angle corrected beam cross-sectional shape. (a) I_{beam}: 5 mA, P_{in}: 10 Pa, P_{main}: 5.3×10^{-6} Pa. (b) I_{beam}: 30 mA, P_{in}: 1 Pa, P_{main}: 7.2×10^{-7} Pa. Notice that the amount of the injected gas is very low for the high beam current.

CONCLUSION

The gas-sheet based beam profile monitor system was installed in the J-PARC LINAC. The vacuum system was designed to minimize the pressure increase in the beam line. The measured pressure distribution showed the large amount of gas injection didn't affect the pressure in the cavities. The trial observation of the cross-sectional shapes of the 400 MeV H^- high current beam were successfully performed. The challenges for the true beam profile observation are undergoing.

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