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PROGRESS ON GAS-SHEET BEAM PROFILE MONITOR

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Abstract

A non-invasive beam profile monitor using a gas sheet detecting produced photons was developed and tested at a 400 MeV beam line in J-PARC Linac, which accelerates 50 mA, 500 µs pulse length H^- beam. Around such energy, since the emission cross section takes a minimum and high intensity radiation noise is induced by the beam, a very low signal-to-noise ratio was anticipated. In this study, the primary noise source was investigated to reduce them. The most dominant one was the background light, such as induced by a B-A gauge filament, but it can be negligible with gating function of an image intensifier composing the photon detector system. A beam-induced radiation directly acting on the image intensifier follows. Even though these radiation noises existed, the high-intensity J-PARC Linac beam could be observed.

INTRODUCTION

A non-invasive beam profile monitor using an extra gas injection is developed and tested in many institutes [1–3]. The extra injected gas, particularly of sheet shape, enables a two-dimensional transverse beam profile measurement as well as efficient monitoring due to enhancement of local gas density. We developed and quantitatively demonstrated a photon-detection-type beam profile monitor using a sheet-shaped gas formed based on a rarefied-gas dynamics [4–6]. At first, we evaluated it with 3 MeV H^- high intensity beam at J-PARC RFQ test stand, which is composed of spares of the J-PARC Linac front-end components for commissioning the RFQ. The developed monitor gave a beam profile well consistent with the one measured with a wire-scanner monitor by applying a reconstruction analysis based on a measured response function of the monitor [6]. In addition, it was found that, for a beam below medium energy (MEBT), the monitor has a potential to reduce a beam emittance through a space-charge neutralization, which is caused by plasma produced in the beam-gas interaction process [7].

For the next step, we are attempting to detect a high-energy beam, which is 400 MeV at J-PARC Linac end. At this energy, the cross-section of the beam-gas interaction takes a minimum, and a radiation noise level is very high as compared with the 3 MeV case. These conditions lead a very low signal-to-noise ratio (S/N) and make the measurement difficult. In this paper, we report the recent effort on measurement of a high-energy beam.

EXPERIMENTALS

Gas-Sheet Beam Profile Monitor System

The gas sheet monitor shown in Fig. 1 comprises a sheet generator, which is a pair of two facing rectangle conduits,

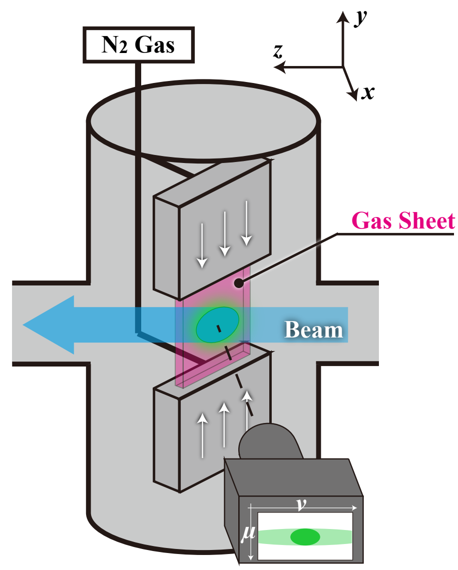

Figure 1: Schematic diagram of the gas-sheet beam profile monitor. The X and Y profile informations are reflected in μ, ν directions in the captured image.

some vacuum pumps, and a photon detector system. The details of the gas sheet generator and the vacuum system were reported in reference [8]. The maximum gas injection pressure at the generator inlet was 1 kPa to prevent a discharge of nearby cavities, where the gas pressure of the cavity increased from $2{\times}10^{-7}$ Pa (base pressure) to $4{\times}10^{-6}$ Pa. The photon detector system consists of a set of optical lenses, an image intensifier which can amplify photon intensity up to 10^4 times with a built-in multi-channel plate (MCP), and a CCD camera of 16-bit full HD, where a sensor pixel is 5.5 µm square each. The solid angle of photon detection is about 0.012 sr (0.1% of 4π). The image intensifier has a gating function more than 25 ns. The CCD camera can take an image at over 1 ms of shutter speed.

Beam Line

The developed monitor was installed in J-PARC Linac end section. There are three beam dumps near the monitor position: 0-deg. dump at 30 m away, 30-deg. dump at 47 m away, and 100-deg. dump at 150 m away. Radiation from these dumps is one of the noise source of the beam profile measurement, and should be evaluated. The beam parameter is 400 MeV, 50 mA peak current, and 50-500 µs beam pulse length, where the nominal one for user operation is 500 µs.

Measurement Method

To measure a high-energy-beam profile accurately, there are two issues reducing S/N: low photon emission cross

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section and high radiation noise. The cross section typically takes a minimum at the energy of around 1 GeV. Since reducing noise on an image is essential, we attempted to clarify the radiation source and reduce its effect. As shown in Fig. 2, possible primary noise sources on the image are (1) non-synchronized background fluorescence, such as B-A gauge light, (2) non-synchronized dark current in the image intensifier, (3) synchronized background fluorescence due to incident radiation/beam on a chamber wall, and (4) synchronized radiation noise acting directly on the photon detector system. These noise sources can be separated by use of the high-speed gating of the image intensifier or the CCD camera shutter speed.

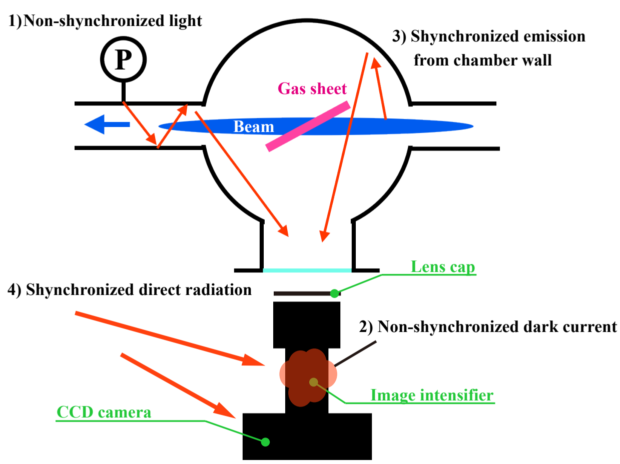

Figure 2: Possible primary noise sources.

400 MEV H⁻ BEAM OBSERVATION AT J-PARC LINAC

Non-Synchronized Noise

At first, the non-synchronized background fluorescence was evaluated by changing the shutter speed of the CCD camera. Figure 3 compares an image of 600 s shutter speed containing 1320 pulses at 2.2 Hz with a 1000-frame-averaged image of 1 ms shutter speed capturing single pulse of 100 µs. The image intensifier gating was not used. A beam-induced signal could be detected with the latter condition, while the S/N was very low for the former condition. Therefore, the non-synchronized noise, which is caused by B-A gauge light and dark current on the image intensifier, is clearly dominant to reduce the S/N. In addition, since the beam signal could be seen in the 1 ms one, the non-synchronized noise can be reduced enough by trimming the beam timing. A beam-timing gating with the image intensifier is indispensable to reduce the noise because the short exposure of the CCD camera leads to a low signal intensity, like 100 out of 16 bit, and a low dynamic range of measurement. In the following, the gating width of the image intensifier was set to the beam pulse length.

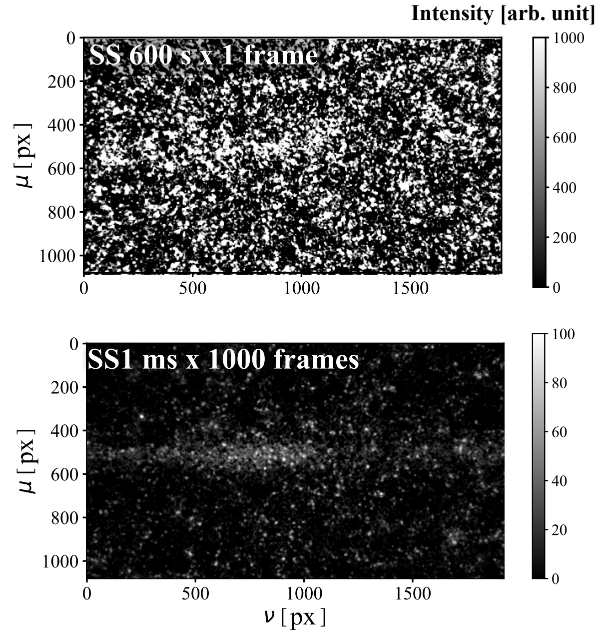

Figure 3: Comparison between the shutter speeds of the CCD camera; upper and lower panels show an image with 600 s of shutter and an image with 1 ms of shutter.

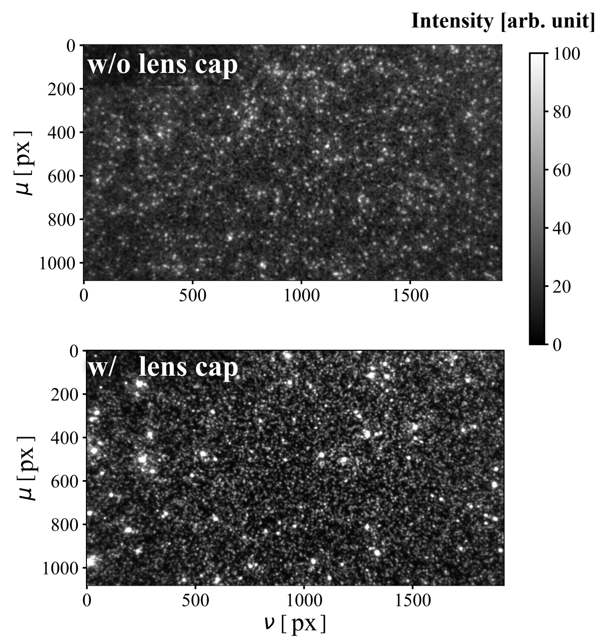

Figure 4: Evaluation of influence of the lens cap.

Synchronized Noise

The rest noise source is synchronized to the beam and can be separated into two kinds: a real fluorescence on the chamber wall and a direct radiation on the detector. To clarify the dominant one, we compared an image with and without a lens cap as Fig. 4. The beam pulse length was 50 µs. No gas was injected in this measurement. The lens cap has

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no influence on the captured image, and the dominant source is determined as the radiation directly acting on the image intensifier or the CCD camera. In addition, since the noise intensity depended on the intensifier gain, a direct radiation on the image intensifier is the dominant source of the noise. Thus, the image intensifier will be shielded or placed away from the beam line to increase S/N.

As described above, there are three beam dumps near the monitor, and we evaluated the influences of the radiations from these dumps. Figure 5 shows images for the beam destination of each dump. The image for 100-deg. dump is the same as the lower panel in Fig. 4 and showed in a different intensity range. The dump has a strong dependance on the noise intensity, and it indicates that the radiation from dump can be a dominant source.

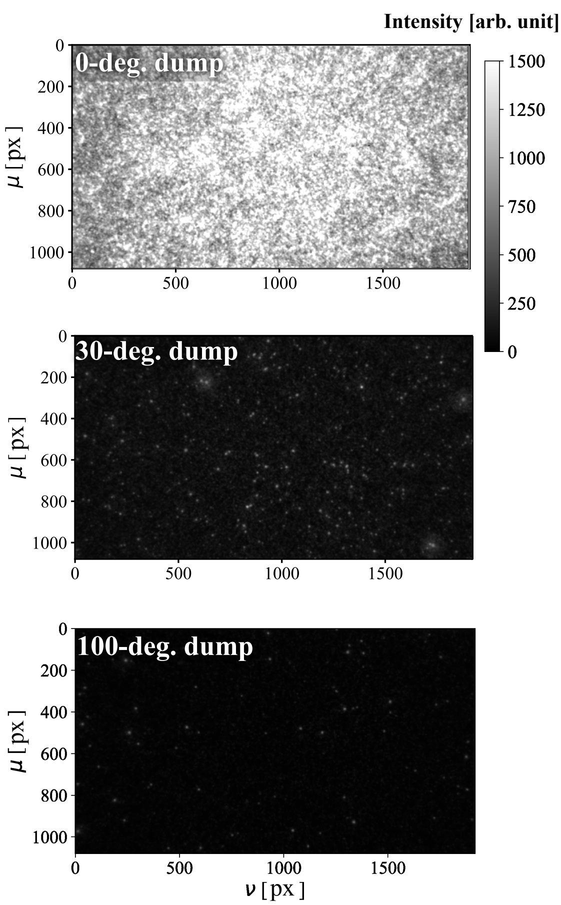

Figure 5: Evaluation of backscattering radiation from each dump.

1-MW-Equivalent Beam Measurement

To demonstrate a high-intensity beam profile measurement with the developed gas sheet monitor, 1-MW equivalent H^- beam, 50 mA peak current and 500 μs pulse length, was monitored as shown in Fig. 6. The repetition rate of the beam pulse was 0.7 Hz due to the dump capacity, whereas the nominal one is 25 Hz. The camera exposure time was 300 s, which contained 210 pulses. The signal intensity depends on the injected gas pressure, and it is found that the signal may reflect the beam profile. The quantitative profile requires to be reconstructed from the captured image based on a measured response function, whose method has been already established [6]. Considering user operation, the repetition rate increase over 35 times, and clearer profile can be obtained in the same measurement time duration.

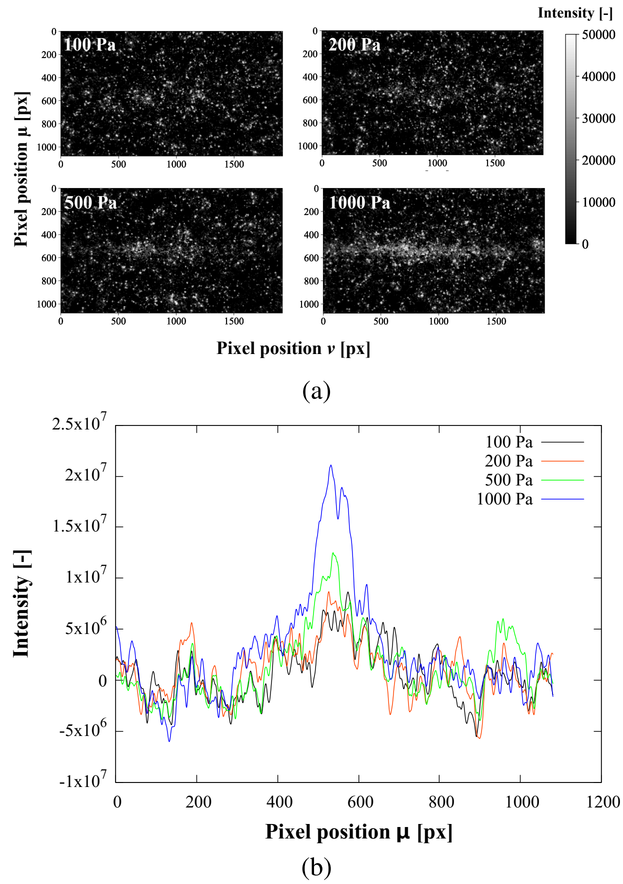

Figure 6: The 1-MW-equivalent beam profile measurement at four inlet pressure conditions: (a) captured images and (b) their 1-D intensity distribution.

CONCLUSION

A non-invasive beam profile monitor using a gas sheet was tested with the J-PARC Linac 400 MeV H^- beam. At this energy, low emission cross section and high intensity radiation noise were anticipated. The background light due to a B-A vacuum gauge was dominant, but it can be reduced to be negligible by using the MCP gating of the image intensifier. In this condition, the radiation directly acting on the image intensifier became dominant. Even though the radiation noise existed, the beam-induced signal could be detected at 1 MW equivalent condition. As the next step, we are preparing a flexible radiation shield tightly covering the image intensifier to reduce the direct radiation noise.

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