BEAM PROFILE MEASUREMENT USING THE HIGHLY-ORIENTED PYROLYTIC GRAPHITE

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Abstract
The mitigation of heat loading is one of the important issues for beam instrumentation to measure the high-power proton beam. Recently, the highly-oriented pyrolytic graphite (HOPG) material was used for the target probe of the bunch-shape monitor at the front end in the Japan Proton Accelerator Research Complex (J-PARC). Since the thermal conductivity of the HOPG is high, it is suitable to measure both transverse and longitudinal beam profiles under the condition of high heat loading. As an application of the HOPG, for example, the thin HOPG may be used as a substitutive material of the target wire for the transverse profile monitor such as the wire scanner monitor. The possibility of the HOPG target for both transverse and longitudinal beam profile monitors is discussed from some results of the test experiment using the 3 MeV negative hydrogen ion beam at the test stand.

INTRODUCTION
In the Japan Proton Accelerator Research Complex (J-PARC) linac [1], a bunch-shape monitor (BSM) [2] with improved heat resistance has been installed to measure intense and low-energy negative hydrogen (H\textsuperscript{–}) ion beam at the front end [3–5]. The introduction of highly-oriented pyrolytic graphite (HOPG) [6, 7] into the target probe of the BSM enables stable longitudinal profile measurement around the central region of the intense beam. As for the transverse profile measurement, the carbon nanotube (CNT) wire is used for the target wire of the wire scanner monitor (WSM) to measure the transverse profile in the front end of the J-PARC linac because the CNT wire has good characteristics to mitigate the heat loading for the intense beam. The thin HOPG target would potentially become the alternative material of the target probe for transverse profile monitors such as the WSM. We demonstrated a test experiment to measure the transverse profile using the HOPG target. In addition, the transverse profile was measured using the beam-derived secondary electrons.

EXPERIMENTAL SETUP
A BSM with a HOPG target was installed on the test stand in the J-PARC linac building. Figure 1 shows the experimental setup of this study. The H\textsuperscript{–} ion beam is accelerated to 3 MeV with an ion source and a radio-frequency quadrupole (RFQ) linac [8, 9]. The maximum peak current, macro pulse length, and repetition rate were 53 mA, 50 µs, and 1 Hz, respectively. The slow current transformer (SCT) was installed between the RFQ and BSM to measure the output beam current from the RFQ. The peak current was tuned by changing the output of the ion source during the test.

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Figure 1: Experimental setup of the test stand [3].

Figure 2 shows the photographs of the CNT wire (left) and HOPG (right) target mounted on the target holder. One of the differences between the CNT wire and the HOPG target is the size: the diameter of the CNT wire was 0.1 mm and the size of the HOPG target was 0.2 mm (width) × 1.0 mm (thickness), respectively. The size of the target probe affects the spatial resolution of the transverse profile monitor. As for the CNT wire, the wire with a diameter of a few tens of µm could be used [10]. On the other hand, the size of the HOPG target depends on the way of manufacturing. The current thin HOPG is manufactured by diamond wire sawing [11]. Laser cutting is attractive but its cost is expensive and adjusting laser parameters will be difficult. Further investigation is necessary to manufacture the very thin HOPG target similar to the size of the CNT wire. If the thinner HOPG is obtained, the spatial resolution of the HOPG might be equivalent to one of the CNT. An attractive feature of the HOPG is the flexibility in applying voltage compared with the CNT.

TRANSVERSE PROFILE MEASUREMENT
The transverse profile was measured with the BSM module using the HOPG target. Figure 3 shows the schematic diagram of the signal acquisition for the measurement. The principle of the measurement was the same as the WSM. The electric signal induced by the interaction between the H\textsuperscript{–} ion beam and the HOPG target was amplified through a preamplifier and recorded using a digitizer. The target holder

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on which the HOPG target is mounted can be moved in a horizontal direction by the motor actuator. Therefore, when the signal intensity was obtained for each horizontal position on the target, the horizontal beam profile can be measured. Figure 4 shows the typical transverse profile measured with the HOPG target. The measured transverse profile was fitted with a Gaussian.

The correlation between the transverse profile and beam current was measured to study the characteristics of the HOPG. The area of the transverse profile is estimated to correlate with the beam current. The transverse profiles were measured while changing the beam current and the correlation between the transverse profile area and beam current was determined. Figure 5 shows the correlation between the horizontal profile area and beam current measured with the SCT. The dotted line shows the linear fitting. There is a proportional relationship between the transverse profile area and beam current. The value of the transverse profile area in the low current region decreased due to beam losses in the beam transport between the ion source and RFQ. It is because the beam tuning could not be enough optimized in the low current operation.

The transverse profile area implies the net charge due to the H<sup>-</sup> ion beam. The dominant signal source is the electron deposition on the target from the H<sup>-</sup> ion beam. However, a part of electrons might be emitted from the HOPG target, which results in the decrease of the transverse profile area. The bias voltage was applied to the HOPG target to avoid electron emission from the target. In this study, the bias voltage of +50 V and –50 V was applied to the HOPG target. Figure 5 shows the bias voltage did not affect the electron emission from the HOPG target. Perhaps, the loss of charge due to the electron emission might not be large enough to observe an effect.

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The transverse profile can also be measured by measuring the amount of beam-derived secondary electrons detected by the BSM while scanning the target position. The measurement of transverse profiles in the BSM by this secondary electron measurement method has been reported for a tungsten wire target [12], which is commonly used in the BSM. Figures 6 and 7 show the schematic diagram to measure transverse profiles using secondary electrons and measured transverse profiles using the induced current and secondary electrons, respectively. The transverse profile using the secondary electrons was consistent with one using the induced electron.
current. As a result, the transverse profile could be measured using the secondary electrons for the HOPG target.

**Figure 6:** Schematic diagram to measure the transverse profile using secondary electrons.

**Figure 7:** Measured transverse profiles using the induced current and secondary electrons.

**SUMMARY**

The HOPG is an attractive material as the target probe to measure the intense beam because it can effectively mitigate heat loading. The transverse profile is measured using the HOPG target as the alternative wire for the WSM. The estimated correlation between the transverse profile and the beam current shows good linearity. The bias voltage up to ±50 V applied to the HOPG target did not affect the transverse profile measurements. The measured transverse profile using secondary electrons was consistent with one using induced current for the HOPG. As for the maximum peak current in the measurement, while the transverse profile could be measured with a peak current of around 60 mA for both the CNT and HOPG, further study is necessary for the maximum acceptable peak current to the HOPG.

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**REFERENCES**


