DEVELOPMENT OF PROFILE MONITOR SYSTEM FOR HIGH INTENSE SPALLATION NEUTRON SOURCE

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Abstract

At the JSNS in J-PARC, a mercury target is employed as the neutron production target. It is well known that the damage on the mercury target is proportional to the 4th power of the peak current density of the primary proton beam on the target. For the high intense neutron source, the profile on the target is important to drive the neutron source with the continuously observation of the profile. We have developed to Multi Wire Profile Monitor System (MWPM). During beam operation, when the abnormally of the beam is found, the beam is cut out by the Machine Protection System (MPS). For the measurement of the two dimension observation on the target, we have developed the system based on the residual radiation measurement by using an imaging plate (IP). It is found that the beam width observed by the MWPM and the IP shows good agreement.

INTRODUCTION

In the Japan Proton Accelerator Research Complex (J-PARC) [1], an MW-class pulsed neutron source, the Japan Spallation Neutron Source (JSNS) [2], and the Muon Science facility (MUSE) [3] will be installed in the materials and life science facility (MLF) shown in Fig. 1. The 3-GeV proton beam is introduced to the mercury target for a neutron source and to a carbon graphite target of 20 mm thickness for a muon source. In order to utilize the proton beam efficiently for particle productions, both targets are aligned in a cascade scheme, where the graphite target is located 33 m upstream of the neutron target.

For both sources the 3-GeV proton beam is delivered from a rapid cycling synchrotron (RCS) to the targets by the 3NBT [4, 5, 6]. Before injection to the RCS, the proton beam is accelerated up to 181MeV by a LINAC. The beam is accumulated in short two bunches having width about 150 ns and accelerated up to 3 GeV in the RCS. After extraction, the 3-GeV proton beam is transferred to the muon production target and the spallation neutron source.

Recently it became evident that pitting damage appears in the target container of the mercury target [7]. Several facilities are studying the effect; Alternating Gradient Synchrotron (AGS) and Weapon Neutron Research facility (WNR) are pursuing off-beam experiments [8]. It has been reported that the damage is proportional to the 4th power of the peak current density of the beam [8]. Beam profile monitoring plays an important role in comprehending the damage to the target. Therefore it is very important to watch continuously the status of the beam at the target at the JSNS especially for the peak current density. We have developed a reliable beam profile monitor for the target by using Multi Wire Profile Monitor (MWPM). In order to watch the two dimensional profile on the target, we have also developed the profile monitor based on the imaging of radiation of the target vessel after beam irradiation.

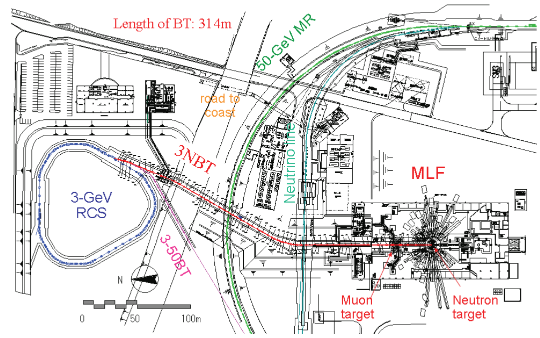

Figure 1: Layout of JSNS and MUSE at J-PARC. The beam transport line (3NBT) introduces the beam to both facilities located in the MLF building.

MULTI WIRE PROFILE MONITOR

Silicon Carbide (SiC) Wire

In order to obtain the characteristics of the proton beam, diagnostic system based on a Multi Wire Profile Monitor (MWPM) is developed. Principle of the MWPM is simple to observe the amount of the electron emission due to the interaction of the beam at the wire. As a material of sensitive wire, usually tungsten wire is selected due to large emission amount of the electron and having high temperature melting point. In the present system, silicon carbide (SiC)is chosen due to the high resistance of the radiation. Due to the interaction, the beam loss is caused, which is one of issues of the high intensity proton accelerator and the optimization of the beam loss is important. The angular differential cross section of Rutherford scattering is proportional to square of atomic number of wire material. Therefore wire material with low atomic number has advantage for beam loss. Here, we compare property between tungsten and SiC. Since the average atomic number of SiC is 10, the differential cross section of SiC becomes 1/55 times of the cross section of tungsten. In order to obtain the angular distribution after scattered by the wire is calculated with DECAY-TURTLE [9] modified at PSI [10]. It is recognized that SiC wire than tungsten gives less influence on the beam. In order to estimate of the lifetime

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of monitor wire, the displacement cross section of DPA is calculated with NMTC/JAM [11]. By the calculation, it is found that the DPA cross section of SiC and tungsten for 3-GeV proton is 278 and 7997 barn respectably, which shows that DPA of the tungsten is about 29 times larger than SiC. Furthermore, it is known that the SiC can stand up 100 DPA. Therefore we chose to use SiC as wire of as a standard model of the profile monitor.

MWPM

The view of MWPM is shown in Fig. 2. Along the beam transport line, 15 sets of movable MWPMs is placed to measure the beam profile. The MWPM frame has 31 wires of SiC with the spacing pitch of 6 mm for each horizontal and vertical directions. We employed the SiC wire having diameter of 0.1 mm, which has a tungsten core of 0.01 mm and is coated with 1μm of pyrolytic carbon. The wire frame made of aluminum oxide with purity more than 95 % is selected due to the high radiation resistance. In order to sustain with the fixed tension, wires are kept by the holder with spring, which gives the unique tension of 0.6 N to the wire. The frame of wires is placed in the vacuum chamber made of titanium, which is selected by the following reason, good vacuum characteristics and low activation. In order to avoid unnecessary irradiation of the wires, the frame can retract and moves like the pendulum motion. During the profile measurement, the beam loss due to the scattering at wires was observed by the beam loss monitor. For the practical aspect, beam loss cased at the MWPM can be utilized to confirm good performance of the beam loss monitors.

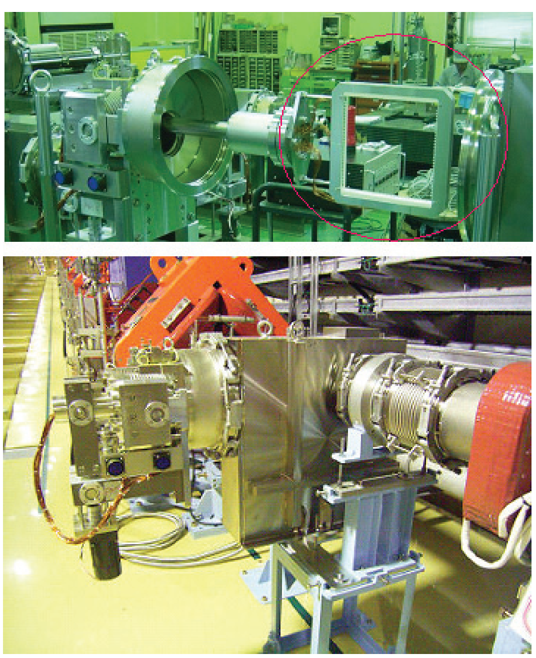

Figure 2: Movable MWPM placed at the beam transport line. (top: MWPM and frame inside the vacuum chamber. bottom: MWPM and chamber placed in the beam transport line.)

Profile Monitor at the Proton Beam Window (PBW)

It is important to watch continuously the characteristics of the proton beam introduced to the spallation target. Due to the high activations caused by the neutron produced at the target, remote handling technique is necessary to exchange the beam monitor for the target. In order to decrease the radiation produced at the spallation neutron target, shieldings above the monitor are required. To decrease the difficulties of the exchange work and decrease of the shielding, we combined the MWPM with a Proton Beam Window (PBW) for separation between the vacuum region of the accelerator and the helium region around the neutron target. The PBW is better to be placed closer to the target where distance between the target and the PBW is 1.8 m, which gives reliable profile at the target. In Fig. 3, the MWPM placed in the PBW is shown, which has the MWPMs in the center of the chamber. In order to avoid over heat load at target vicinities, beam halo monitors are placed as well. The chamber of the PBW has inflatable seal called pillow seal. Due to the pillow seal, we can exchange MWPM by the remote handling.

Wires at the MWPM on the PBW are continuously irradiated to the beam so that long life time is required. Since the monitor at the PBW is important, redundant system of the wire is utilized. In order to give the life time information about the wire for the future, both SiC and tungsten wires are placed.

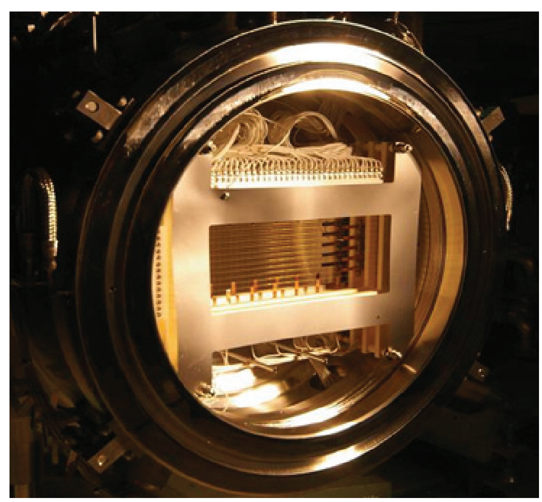

Figure 3: MWPM placed at the Proton Beam Window (PBW).

For the tuning of the accelerators, we have the beam dump located at the extraction section of the RCS made of iron, which has capability of the beam load of 8 kW. In order to watch the status of the beam toward the beam dump, another stationary MWPM is placed in front of the beam dump. During the beam tuning, the LINAC beam without circulation and acceleration at the RCS is directly introduced to the dump especially for tuning of the RCS

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injection. The time structure of the LINAC beam has a width of 0.5 ms in total with chop having the width of 600 ns. Although the time structure and the energy of the beam is completely different between LINAC and RCS, the MWPM gives reliable result of the beam profile, which helps tuning the accelerators very well.

Signal of the SiC Wire

Signal of the SiC wire after shaped amplifier is shown in Fig 4. All signals of MWPM is transfer to the local control room by twisted pare cables with high radiation Harding. As for the MWPM of the PBW, Mineral Insulator Cables (MICs) are applied because the cables receives quite high radiation does more than 1 MGy. The signal is fed to the inverter amp (Technoland N-GK 160 32ch Inverter AMP) and fed to the charge collective ADC (Technoland C-TS 301B) with the integration time range of 3 μs, which has integration charge range of -3000 pC in total and is driven by the CAMAC bus. The signals on the CAMAC bus are read out via crate controller of Toyo CC/NET. All signals is controlled by the EPICS [12] and is data base server.

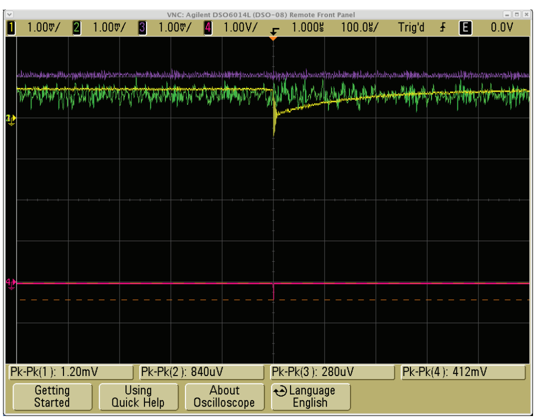

Figure 4: Signal of the MWPM after shaped by the inverter amplifier (yellow).

In Fig. 5, the beam profile at the PBW obtained by the present system is shown. Each result is fitted by the Gaussian and base distribution for every second. Result of the center position and the width is utilized to watch the status of beam injected to the target.

PROFILE MONITOR BY THE IMAGING PLATE

Imaging by Activation Aluminum Foil

In the beginning of the beam commissioning, we measured the profile by the activation technique using aluminum foil placed on the target vessel. In order to achieve good performance at the neutron source, enough space is not remaining around at the target to put any devices for the beam profile measurement. To fit the requirement with the tiny space around the target, we performed to activation technique which requires only thin foil space. Placing

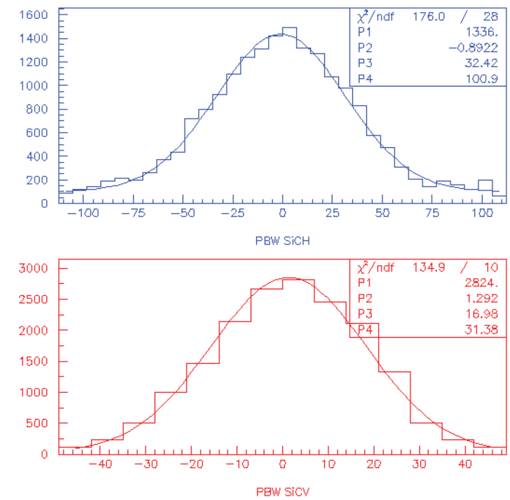

Figure 5: Beam profile obtained by the MWPM located at the proton beam window for 0.3 MW beam. Top and bottom graph shows the result for horizontal and vertical direction, respectively.

an aluminum foil (0.3mm in thickness) on the target, the beam profile was obtained from the residual dose distribution on the foil. After irradiation, the foil is removed from the target then foil is attached to the imaging plate (Fuji firm BAS-SR 2040) to read the dose distribution. Figure 6 shows the observed result.

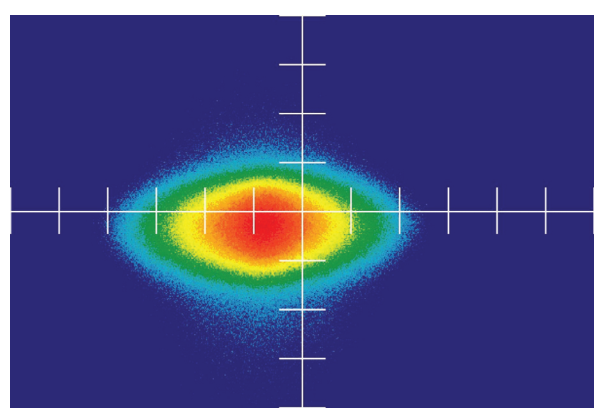

Figure 6: Beam profile observed by the activation of the aluminum foil(0.3mm-t) located on the spallation neutron target (one division in figure is 10mm).

Imaging Plate Attached to the Target After Beam Irradiation

In order to perform beam profile measurement by the activation, access to the target is necessary after beam irradiation. The radiation around the target is extremely high such as several tenth Sv/h therefore a remote handling technique is required. We have developed an activation technique by

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utilizing the IP. By remote handling technique, the IP is attached to the mercury target vessel shown in Fig. 7. The IP contained in holder was attached to the hook of in-cell crane by human hands. Around the entrance of hot cell, radiation was several tenth of μ Sv/h so that human can access. The IP approached to the target by the crane and contacted with the target by help of the master slave manipulator as shown in Fig. 7. Typical duration of exposure time was 5 min. After the exposure, the image of radiation was read out by the reader of the IP.

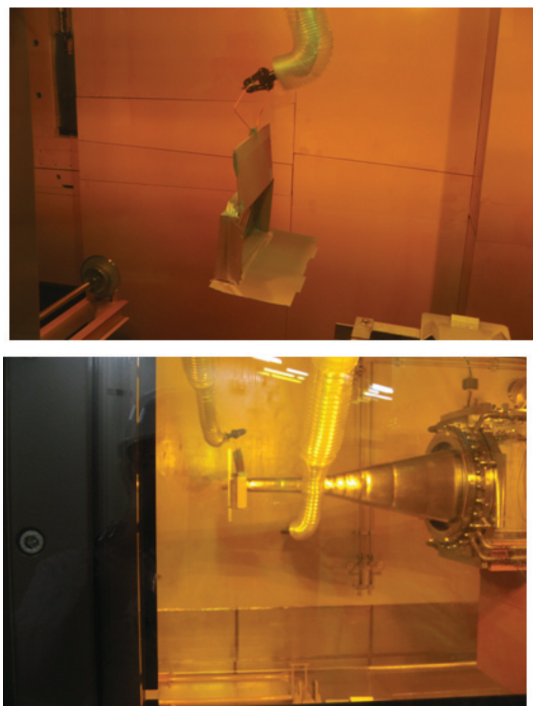

Figure 7: Activation technique using Imaging Plate (IP) located on the target vessel performed after irradiation at hot cell of the MLF. (top) IP holder placed crane (bottom) IP attached by the master slave manipulator.

Figure 8 shows the beam profile obtained by the activation technique with the IP after 120 kW beam operation. In the distribution, it is shown that a clear Gaussian peak exists without skew of the beam, which was also presented by foil activation technique.

The beam profile in horizontal distribution obtained by the IP is shown in Fig. 9. The distribution can be well described by the combinations of two Gaussian functions having small and large widths. The smaller one was thought to be the initial protons. The larger width was thought to be the secondary particles mainly neutrons. By using the shorter width, we obtained the primary beam width at the target.

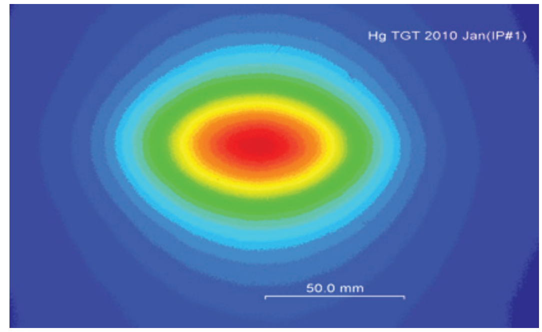

Figure 8: Two dimensional beam profile obtained by the IP attached to the target vessel.

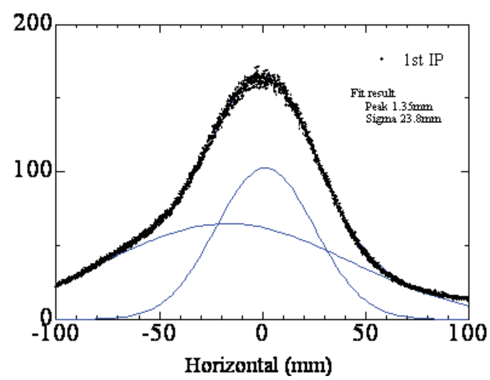

Figure 9: Beam profile in horizontal direction obtained by the IP with fitting of two Gaussian curves.

DISCUSSION

Comparison of Beam Widths Obtained by MWPM and IP

In Fig. 10, beam width for horizontal and vertical directions observed by the MWPM and the IP is compared as function of the beam run. The MWPM result is collected to become the width at the target by taking account of the beam gradient. As increase of the run number, the beam is gradually expanded due to decrees the damage of the target vessel. It is found that the beam width considerably agree with each other. Agreement of the width implies that reliable width can be obtained by the present profile monitor system. By using the MWPM, the present beam width can be obtained each beam pulse.

Machine Protection System

Data of the beam profile for every shots are watched by the control system driven by the EPICS and are stored in data base. If any anomaly of the beam was found, such as offset of the beam position, the beam should be immediately stopped for the safety reason. We have developed the machine protect system (MPS), which cut out the beam if the beam offset exceeded the threshold. Under the present protection system, high power beam operation of 1 MW can be performed with high confident.

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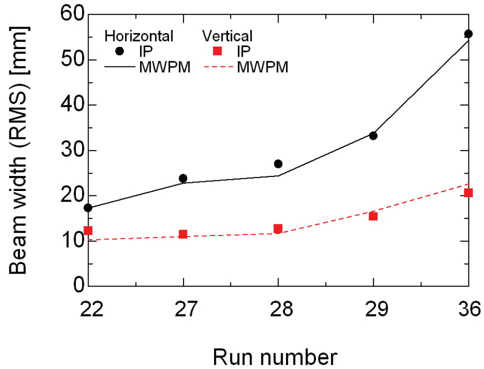

Figure 10: Comparison of the beam width, which is root mean square of the distribution, obtained by the IP and the MWPM as a function of beam run.

CONCLUSION

We have developed MWPM system by using SiC wires to built reliable and long life profile monitor system at the JSNS in J-PARC. In order to obtain two dimensional beam profile at the target of the spallation neutron source, it was developed that beam monitoring technique based on the activation technique by using the IP and remote handling devices. It is shown that the beam width obtain by the MWPM agrees with the result by the activation result by IP. Under the present profile monitor system, high power beam operation such as 1 MW can be performed with high confident.

Up to beginning of July 2012, the profile monitor wire has received the beam with the integration of about 1000 MWh. Even such high integration of the beam power, still both SiC and tungsten wires at the profile monitor of proton beam window are survived. In the next year, we have plan to exchange the proton beam window and the profile monitor.

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