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PROFILE MONITOR ON TARGET FOR SPALLATION NEUTRON SOURCE

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Abstract

Materials and Life Science Experimental Facility (MLF) in J-PARC is aimed at promoting experiments using the world highest intensity pulsed neutron and muon beams which are produced at a thick mercury target and a thin carbon graphite target by 3-GeV proton beams, respectively. Since damage due to the short pulsed proton beam at the mercury target vessel is proportional to the 4th power of the peak current density of the beam, decrease of the peak density is crucial for the beam injection system. To decrease peak density, a beam transport based on the nonlinear optics was developed. For reliable beam operation with the high-intensity beam, a reliable online 2D profile monitor with a long lifetime is indispensable to observe the beam introduced to the target. Furthermore, in J-PARC future facilities, high current density on the target will be required so that research and development have started to accept high density.

INTRODUCTION

In the Japan Proton Accelerator Research Complex (J-PARC) [1], a 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 Experimental Facility (MLF) shown in Fig. 1. Since 2008, this source has produced a high-power proton beam of 300 kW. In 2015, we successfully ramped up beam power to 500 kW and delivered the 1-MW beam to the targets. To produce a neutron source, a 3 GeV proton beam collides with a mercury target, and to produce a muon source, the 3 GeV proton beam collides with a 2-cm-thick carbon graphite target. To efficiently use the proton beam for particle production, both targets are aligned in a cascade scheme, with the graphite target placed 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 (3 GeV RCS to Neutron facility Beam Transport) [4–6]. Before injection into the RCS, the proton beam is accelerated up to 0.4 GeV by a LINAC. The beam is accumulated in two short bunches and accelerated up to 3 GeV in the RCS. The extracted 3 GeV proton beam, with a 150 ns bunch width and a spacing of 600 ns, is transferred to the muon production target and the spallation neutron source.

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. For observation beam introduced to the target, MWPM was placed at the proton beam window. In J-PARC center, facilities for research and development for Accelerator Driven System (ADS) is planned. Furthermore, to satisfy the demand of neutron and muon beam, second target facility is also expected. In those facilities, the beam will be more collimated than the JSNS so that a profile monitor will be required, which will stand higher current density than the JSNS.

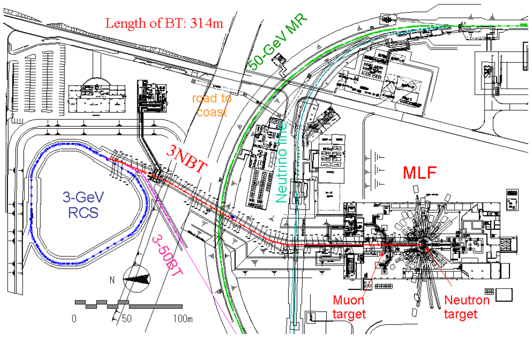

Figure 1: Plan of rapid cycling synchrotron (RCS) at the Materials and Life Science Experimental Facility (MLF) at J-PARC.

BEAM MONITOR SYSTEM AT THE BEAM TRANSPORT TO THE TARGET AT JSNS

Monitors Placed at Proton Beam Window

Continuously observing the characteristics of the proton beam introduced to the spallation target is very important. 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, shielding above the monitor was required. To reduce the difficulties of the exchange work and decrease of the shielding, we combined the beam monitors 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 the distance between the target and the PBW is 1.8 m, which gives reliable profile at the target. In Fig. 2, the MWPM placed at the center of a vacuum chamber of the PBW is

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shown. To avoid exceed heat at target vicinities, beam halo monitors are placed as well. The chamber of the PBW has inflatable vacuum seal called pillow seal. Due to the pillow seal, the monitors can be changed by the remote handling. To calibrate the sensitivity of each wire, the signal was observed by the scanning the position with narrow width beam. It was found that the difference of individual sensitivity was 6 % at most.

In an actual beam operation, the heat at the target vicinities such as shielding, which mainly does not have water cooling channel, is necessary for reducing the peak density. Beam halo monitors attached at the PBW to observe the heat deposition at the target vicinities such as reflector and shielding, which is not allowed to exceed 1 W/cm^3. A view of the beam halo monitor is shown in Fig. 3. We placed two types of beam halo monitors to obtain the thermal information by thermocouples and the emission of an electron by the electrode. Since the emission of electron indicates relative intensity of the beam halo, the beam halo relative strength, which can be normalized by the following thermal observation, can be obtained by several shots of the beam. To observe the absolute intensity of the halo, the thermocouple type was implemented, which consists of copper strips coupled with the thermocouple. With 5 minutes of 25 Hz beam operation, the absolute intensity of the beam halo can be determined by the differential of temperature by time. These procedures were normally performed in actual beam operation.

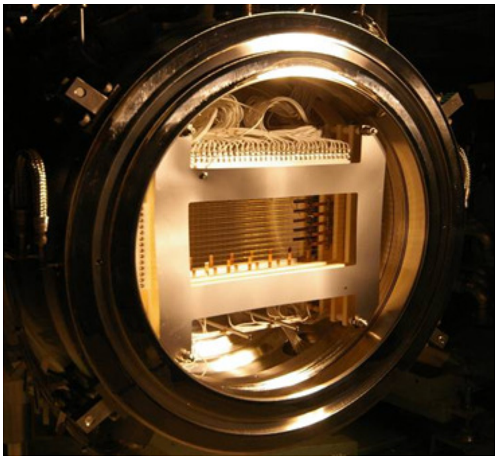


Figure 2: MWPM and beam halo monitors placed at the Proton Beam Window (PBW).

Since wires at the MWPM placed at the PBW are fixed type and continuously irradiated with the beam, long lifetime wire is required. The profile monitor at the PBW is important so that a redundant system using SiC and tungsten wires was applied. In summer of 2013, some spots were observed at the surface of helium side of the PBW, which were thought to be produced by the erosion of nitric acid produced by the radiolysis around the target. We decided to change the 1st PBW already received the integration beam power of 2000 MWh to the new one. After exchange 1st PBW, because of stability of signal, only SiC wires were employed, which were deployed 2nd PBW. After 4 years operation, the 2nd PBW was changed in summer of 2017.

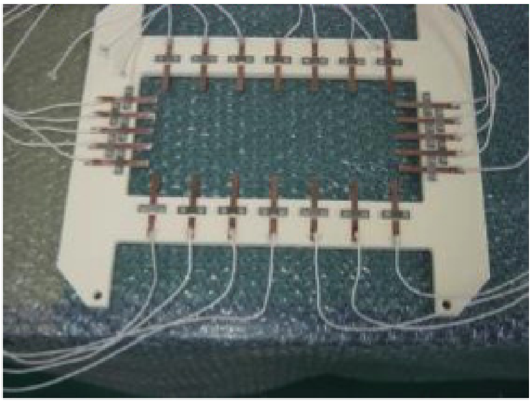


Figure 3: Thermocouple type of beam halo monitors placed at the Proton Beam Window (PBW).

Lifetime of SiC Wires

As a material of sensitive wire, usually tungsten wire is selected due to the large emission amount of the electron and having a high-temperature melting point. In the present system, silicon carbide (SiC) was chosen due to the high resistance of the radiation [7], which is thought to survive up to 80 DPA. To obtain accurate displacement on the wire, we have a plan to measure the DPA cross section.

Due to the interaction, the beam loss is caused, which is one of the 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 a square of an atomic number of the wire material. Therefore wire material with the low atomic number has an 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.

Until 2000 MWh, the wires still gave normal signals and, it was not found severe damage by inspection after irradiation. However, slight elongation of the SiC wires was observed as shown in Fig. 4 after changing spent the PBW. In future, by changing fixing part of the wire, such elongation can be thought to be mitigated.

subsectionBeam Profile with Nonlinear Optics

To obtain the beam profile at the neutron source, SAD code is utilized, which provide beam information by fitting the result given by the MWPM placed at upstream of the octupole magnet. Also revised DECAY-TURTLE [8] by Paul Scherrer Institute (PSI) [9] is utilized to simulate multiple scattering at the muon target. Figure 5 shows results of beam profile for 800 kW beam with and without excitation of the octupole magnets. The beam profile is shown in Fig. 5, which was observed by the MWPM placed at the PBW. It can be found that considerable flat distribution can be obtained by the nonlinear optics. The calculation results

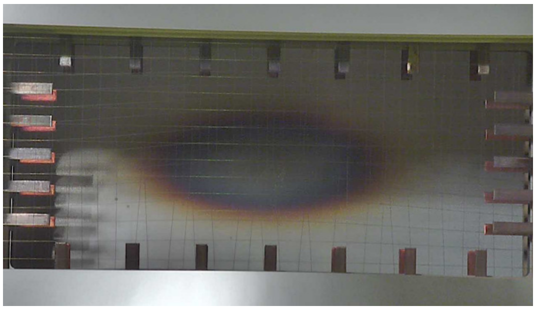
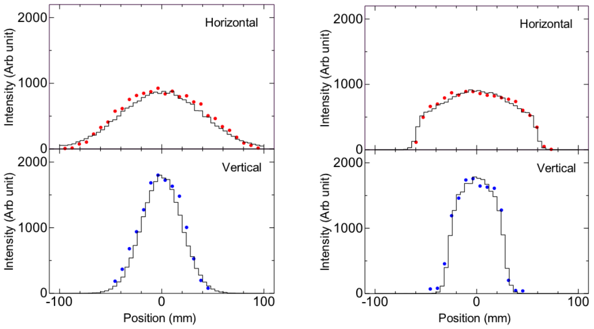


Figure 4: Inspection of SiC wire for MWPM placed at the PBW #1.

with and without excitation are also shown in Fig 5. The calculation results show good agreement with the experimental ones with and without octupole magnetic field. It is also confirmed that the calculated beam profile by using the muon target showed good agreement with the experiment for both cases with and without octupole magnetic field. By the calculation result, the peak density can be thought to be reduced by 30% compared with the linear optics.



(a) OCT 0A (b) OCT 698A

Figure 5: Beam profile obtained with calculations (line) compared with result by the MWPM (dots) supplying current of (a) 0 A and (b) 698 A to octupole magnet . Upper and bottom figure represents for horizontal and vertical directions, respectively.

DEVELOPMENT OF NEW PROFILE MONITOR

Until now the monitor wire survived up to 2000 MWh, which was at attached the first and the second PBW, however, it is not clear that the MWPM will survive for the long duration of 1 MW beam. The lifetime of the PBW is expected as 2 years for 1 MW beam [10], which has proton fluence 2 × 10^{21} /cm^{-2} and the integral beam power of 10000 MWh. To observe 2D profile, an online type profile monitor is desired because the present 2D beam profile by IP can be obtained after the irradiation. Therefore a new beam profile monitor based on luminescence due to the beam was started to develop.

Beam Imaging Test Using Ar Beam

In order to obtain a 2D profile on the target, luminescence monitor is planned which is painted on the vessel of the mercury target. It was reported that degradation of luminescence was observed at the SNS in ORNL so that the intensity of light was observed by using $^{40}Ar^{+15}$ beam having the energy of 150 MeV with flat-shaped distribution by using nonlinear optics [11] at Takasaki Advanced Radiation Research Institute (TIARA) of Quantum Beam Science Research Directorate (QST). In the experiment, Desmarquest AF995R (Al_2O_3 99.5% and CrO_3 0.5%) with a thickness of 5 mm and DRZ-High (Gd_2O_2S:Tb) with a thickness of 5mm were irradiated with Ar beam. The luminescence of AF995R was observed with the spectrometer (Flame-NIR: Ocean Photonics).

For the development of profile monitor system, the image of the luminescence from the AF995R and DRZ-High (Gd_2O_2S:Tb) was observed with the ordinary CCD camera through imaging fiber (Fujikura FISR-20) having 20000 pixels and length of 5 m having high radiation hardening.

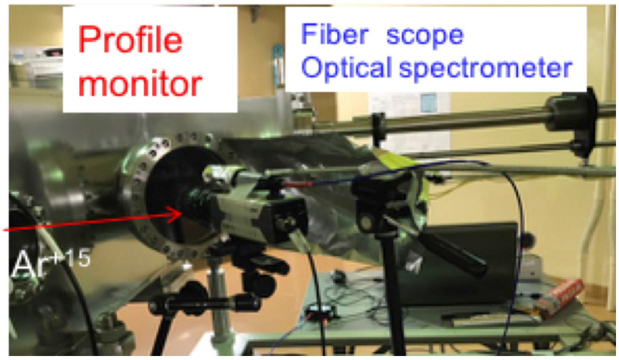


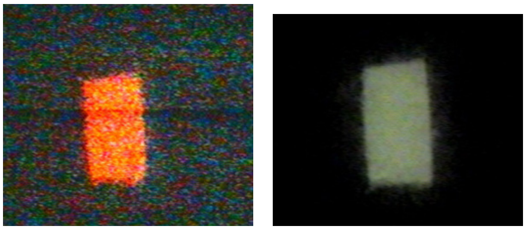
Figure 6: Experimental setup for imaging system.

Result of Beam Imaging

The 2D image of the beam obtained by the AF995R and DRZ-High is shown in Fig. 7, which is utilized square flat beam by nonlinear optics. Since the ordinary CCD camera is insensitive to the light with longwave length, the intensity of the red light emitted from the AF995R was very low intensity. In future, using 3 CCD camera, which has less dependence on wavelength, the image will be obtained. Since the DRZ-High emits short wavelength, the image has high intensity. It is confirmed that the image of the profile of the beam can be obtained with the present system.

Result of Luminescence Spectrum and Intensity

The spectrum is shown in solid line in Fig. 6 for the first shot of beam. The spectrum has a prominent peak at 694 nm with several unresolved shoulder peaks produced by the excitation state of Cr^{3+}. After the irradiation of Ar beam with 75 nA for 2.4 h to AF995R, it was found that the peak intensity decreased by 35% as shown in Fig. 8. In the first 0.2 h from the beginning, the intensity decreased rapidly. After the 0.2-h irradiation, the intensity decreased slowly and



(a) AF995R (b) DRZ-High

Figure 7: Beam profile obtained with fiber imaging system for (a) AF995R and (b) DRZ-High.

steadily, which can be fit well by one-dimensional function as shown in solid line in Fig. 9. The spectrum after the 2.4-h irradiation is also shown in dot line in Fig. 8. The intensity of the unresolved peak with wavelength region shorter than 694 nm had less decreased than the intensity at the peak of 694 nm. By observing the light in shorter wavelength with optical filter cutting long wavelength, the influence of degradation may mitigate.

Spectrum for UV Light

In future, many materials will be tested by irradiation of Ar beam. To identify the luminescence of sample, it is better without Ar beam before irradiation. Therefore, we tried to determine the luminescence by using ultraviolet (UV) light so-called black light. In Fig. 10, the spectrum of luminescence was compared with Ar and UV. It is confirmed that the luminescence shows good agreement for both cases.

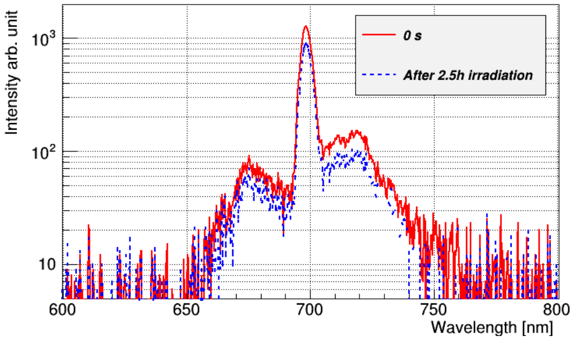


Figure 8: Spectrum of luminescence before and after irradiation Ar beam for 2.4 h.

CONCLUSION

For reliable beam operation at the JSNS in J-PARC, beam monitor system with the MWPM and the halo monitor was developed. By using the MWPM, beam parameter such as the emittance and Twiss parameter can be obtained by several shots of the beam. To mitigate pitting erosion at the mercury target, a beam transport system with nonlinear optics has been developed. By introducing nonlinear optics, peak current density can be reduced by 30%, which decreases the damage of pitting erosion about 80%.

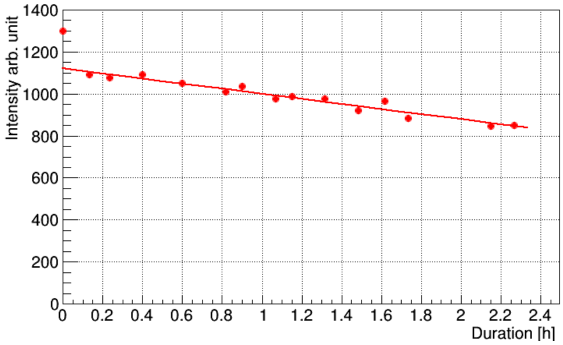


Figure 9: Trend of peak intensity for long duration irradiation of Ar beam with 75 nA. Line shows fitting result.

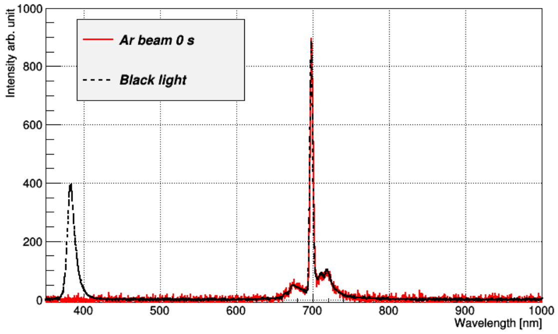


Figure 10: Comparison of spectrum of luminescence induced by black light (blue dot line) and Ar beam (red solid line).

Elongation of wires for profile monitors due to radiation damage was found after replacing the monitor. Some modifications will be applied to next profile monitors to observe correct beam profile. Just started development of luminescence profile monitor by using low energy Ar beam and degradation of luminescence was observed. In future, new material will be developed by the Ar beam experiment.

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