Beam Commissioning at J-PARC/JSNS and MUSE

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Abstract. In J-PARC, Materials and Life Science Experimental Facility (MLF) is aimed at promoting experiments using the world highest intensity pulsed neutron and muon beams. Since November 2010, the beam operation in power of 0.2 MW started with remarkably good availability about 90 %. In order to confirm stable operation of the facility, especially for the structural integrity of the target, beam profile control at the target is very important. We developed the technique by using imaging plate which is attached on the target vessel by remote handling technique. Peak reduction by the expansion of beam at the target is an effective and practical way to mitigate the damage. A new technique was developed to measure heat load at the vicinities by measuring the temperature rise speed. During 5 min beam irradiation, the heat deposition at the vicinities was obtained by the differential of the temperature, which was 0.3 W/cc for 0.2 MW beam. Understanding the beam profile and the heat deposition at the vicinities, we carries out profile optimize the beam size. We succeeded restoring beam operation within short period and begun the beam operation for users.

1. 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. A 3GeV 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 33m upstream of the neutron target. For both sources the 3-GeV proton beam is delivered from a rapid cycling synchrotron (RCS) to the targets. Before injection to the RCS, the proton beam is accelerated up to 181MeV by a LINAC. The beam is accumulated in short bunches of less than 100 ns duration 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.

As increasing in the beam power, the damage of the target becomes serious. Especially for a high power short pulse spallation neutron source, the damage due to the proton beam on the target vessel for liquid metal target such as mercury is reported to be proportional of 4th power of the peak intensity of the proton beam [4, 5]. Reduction of the peak intensity is quite important for the beam injection system of the spallation neutron source using the mercury as the target material. The control of the beam profile becomes important. In order to confirm stable operation of the facility, especially for the structural integrity of the target, it is important to obtain the beam profile at the target. A multi wire beam profile monitor (MWPM) is installed at the proton beam window at 1.8 m upstream from the neutron target[6]. It is important to know the beam profile at the target. We developed the technique by using imaging plate which is attached on the target vessel by remote handling technique via master slave manipulators.

Peak density reduction of the proton beam due to the expansion of beam at the target is an effective and practical way to mitigate the damage. However, by the expanding of the beam, the heat load increases at the target vicinities, which is tolerable less than 1 W/cc. For the high beam power operation, it is important to recognize the heat load at the vicinities. We developed a new technique to measure heat load at the vicinities by measuring the temperature.

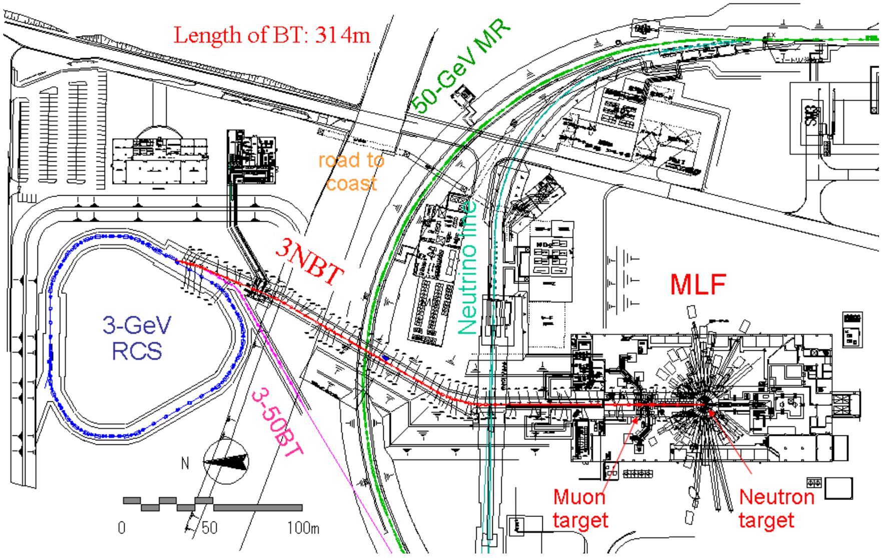

Figure 1 Layout of JSNS and MUSE at J-PARC. The beam transport line (3NBT) introduces the beam to both facilities located in the MLF building.

2. Measurement of the beam properties

2.1. Imaging Plate

With the increase of the beam power, the beam profile becomes more important. We continued the development of the proton beam profile on the target by the activation technique using an imaging plate (IP). After irradiation imaging plate is attached to the target vessel via remote handling technique, which is shown in figure 2. In the entrance of hot cell, the radiation level is at a level of several tenth of mSv/h so that human can access the entrance. The IP of Fuji firm BAS-SR 2040 was attached to the in-cell crane. The crane is approached to the target and hold by the master slave manipulator. From top of the crane position, typical approaching time to the target is less than 1 min. The typical duration of the exposure time was 5 min. After the exposure, the image is read out by the reader of the IP.

In Fig. 3, we show the beam profile result obtained by the IP after 0.2 MW beam irradiation in December 2010. It can be found that only simple distribution without the tilting, which is the same as the first experiment by foil activation technique. Also the horizontal distribution obtained by the present technique is shown. The distribution is well described by the integration of two Gaussian of having smaller and larger widths. The smaller width is contribution of the protons. With the increase of the beam power, the beam profile becomes more important. During the distribution, it was observed that a clear Gaussian peak exists without tilting. It should note that the result was obtained after 6 days of cooling time for residual radiations. It was demonstrated that the present technique can give reliable profile without saturation of the measurement for 1 MW operation with certain cooling period.

Simultaneously, a thermo luminescence dosimeter (TLD) was placed on the IP holder. Unfortunately, the dose observed by the TLD was saturated, which implied that the radiation was higher than 16 Sv/h at the target center.

During beam operation, the beam profile was continuously measured by the multi wire profile monitor (MWPM) located on the proton beam window. To obtain a long life time of the target, we expanded gradually the beam size through an increase of the beam power. The measurement of the beam width obtained by the IP and the MWPM showed good agreement, which implies that a reliable beam profile can be obtained on time by the MWPM. In actual beam operation, peak density of the proton beam is continuously observed by the MWPM. We will include system the beam stop system when the peak density exceeds allowable value to the safety of the target vessel.

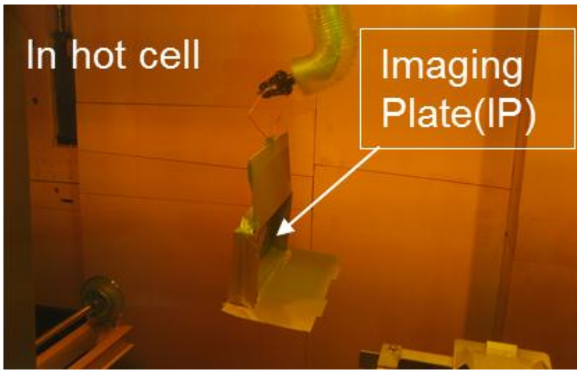

Figure 2 Photo of imaging plate hold by the master-slave manipulator to be attached with the front of the target

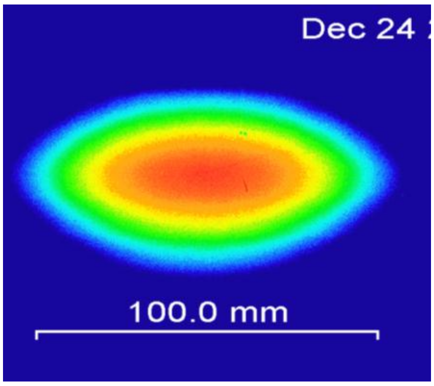

Figure 3 Beam profile result measured by the imaging plate at the target after 0.2 MW beam operation

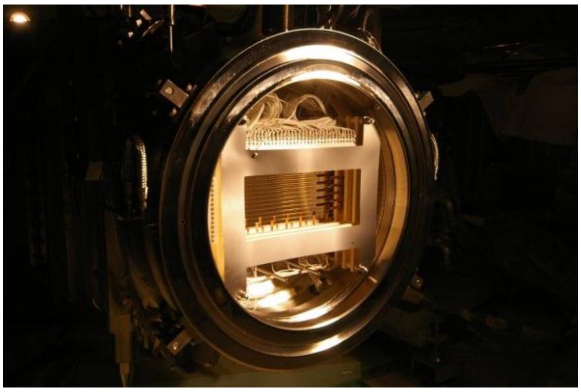

Figure 4 Multi Wire Profile Monitor (MWPM) at the proton beam windows located 1.8 m upstream of the neutron target

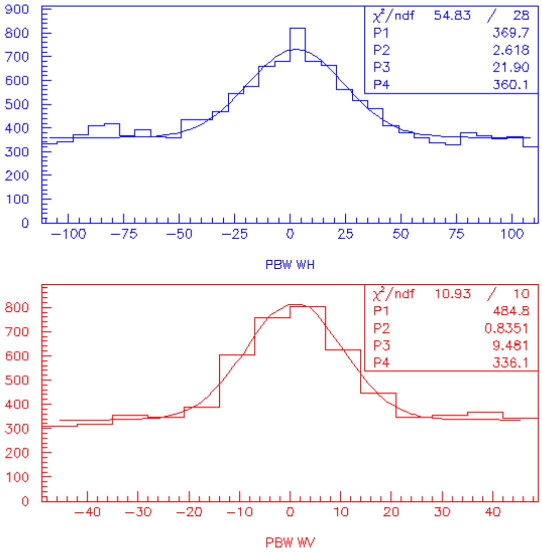

Figure 5 Result of the beam profile measured by MWPM (above: result for horizontal, below result of vertical axis)

2.2. Beam Halo monitor

To obtain the intensity of the beam halo at the target vicinities, we developed a technique based on the measurement of the temperature. Figure 6 shows the beam halo monitor placed in front of the proton beam window. Also the heat deposition at the entrance shielding of the target is measured by using of the thermocouple.

In the design of the neutron target station, the heat load at the target vicinities is limited to be smaller than 1 W/cc. In order to confirm the status, the heat deposition measured by the rising speed of the temperature. Using adiabatic approximation, the heat density is given by the time differential temperature. In the practical beam operation, a short term of the beam duration of 5 minutes gave the heat density at the vicinities. Figure 7 shows the temperature trend after the beam irradiation. From this result, it is recognized that the density is smaller than 0.3 W/cc. We also placed the beam halo monitor to observe the secondary electron emission, which gives us the relative intensity of the beam halo even in one shot of the beam. After the understanding the relationship between the two types of the beam halo monitor, we can obtain the halo intensity only by one shot of the beam, which makes the beam tuning efficiently. By the watching both intensities of the peak and the halo, we can carry out the tuning of the beam profile optimization.

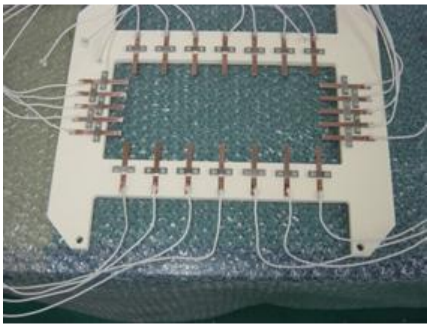

Figure 6 Beam halo monitors using thermocouples placed at the proton beam windows, which is shown in figure 4.

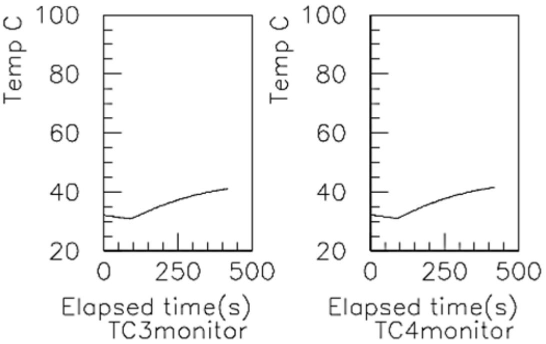

Figure 7 Trend of beam temperature due to the proton beam at the beam halo monitor of the proton beam window. Irradiation begins about 10 s in the horizontal axis.

3. Beam operation status

As the beam power increases, precision beam tuning is required in order to avoid the high residual radiation caused by beam loss around the beam duct and the magnets. On the other hand, it is better to minimize the duration for beam tuning in order to increase the beam time required by the users. In order to perform the beam tuning efficiently, we developed an expert beam operation system, which simulated the beam status from the result of the beam position obtained by the beam monitors. Through the result of the MAD code, the correction angle for the beam can be obtained at the steering magnets. This expert system helps significantly the operator to perform the beam tuning, which reduce the tuning time considerably.

In November 2009, we started to deliver 0.1 MW proton beam to the target with the remarkably high availability of about 90%. In a short test about 1 hour, we demonstrated the capability of 0.3 MW beam operation to the spallation neutron source. We confirmed that the beam loss was very small and the operational beam status was very stable. Even after a beam operation at 0.3 MW, the residual dose in the beam transport system was as small as the background level. Until the summer of 2010, we did not have any spare mercury target vessels. Without a spare target, if the vessel was broken, the beam had to stop operating for a long period of time to fabricate a new vessel. We maintained the beam power at 0.1 MW before the preparation of the spare target. Since November 2010, we had carried out the beam operation with the power of 0.2 MW to March 11th.

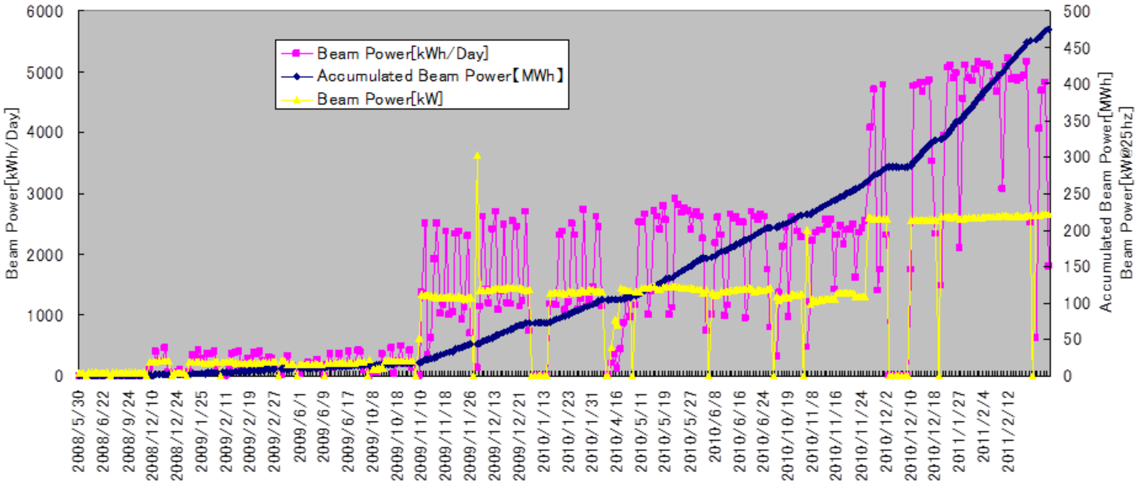

Figure 8 Trend of beam power in average (purple line in left axis) and peak(yellow in right axis), and accumulated beam power(blue at right axis) before the earth quake on Mar 11th 2011.

4. Restoring from the damage of earthquake

The earthquake, which is happened on March 11th 2011, caused profound damage to the beam transport system. For example, the beam tunnel wall significantly collapsed and the magnets were displaced. After repairing the wall, the alignment of the magnets was performed. By the earthquake, floor was depressed about 12 mm at the M1 tunnel located in the MLF building, which may cause significant beam loss at M2. We decided to perform realignment. However, the alignment must be finished within short duration of 3 months to match the recovering schedule. Therefore we bent down the transport line to minimize the adjustment and follow the tilting of the MLF building floor. Figure 9 shows the trend of floor level after the earthquake. In figure, the 2 mm of sink is shown at the LM1-11, which is located in the MLF building. Even now, the floor level is not stabilized so that we performed periodical survey of the floor level.

The proton beam was delivered to the mercury target since December 2011. Since January 2012, we had begun beam operation again for users at a power level of about 0.1 MW. After confirmations of status of the accelerator and the settlement of the beam transport line, the power will be gradually increased. As a trial case, we delivered the beam with power of 0.4 MW in March 2012. During the trial, no significant beam loss is observed. After installation of the helium bubbler supplying system at the mercury target, probably summer in 2012, we will begin the beam operation having the power larger than 0.3 MW as user beam operation. During the 0.3 MW, we will achieve the most high intensity pulse source having some reputation. As for muon, we already achieved the most high intensity pulse muon source.

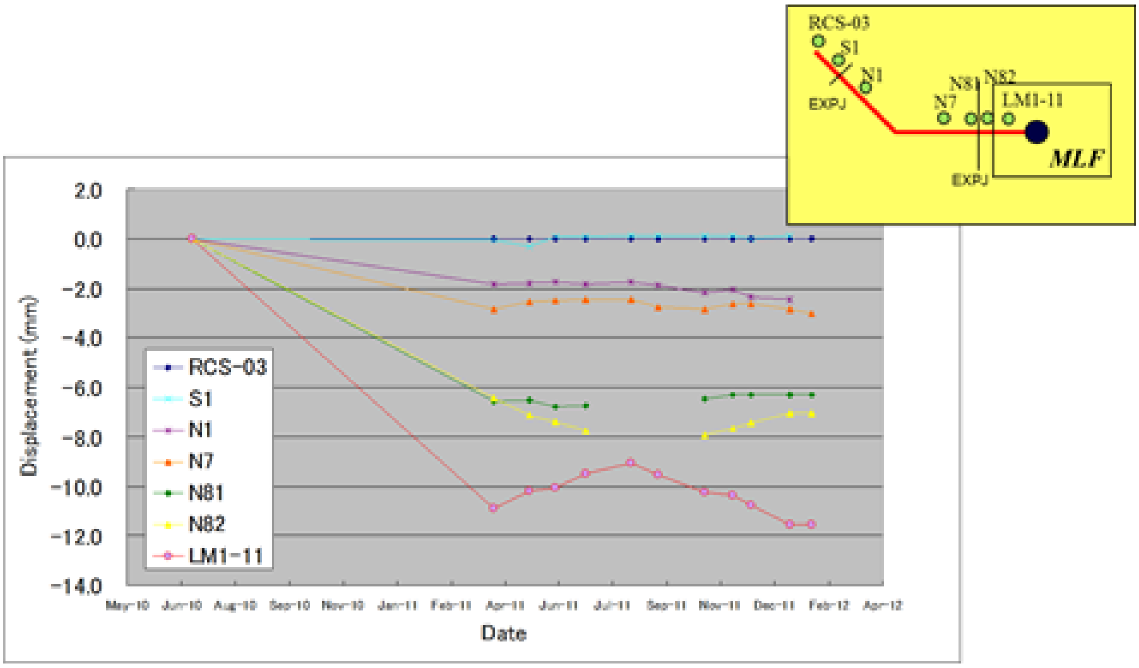

Figure 9 Trend of floor level after the earthquake on Mar 11th 2011 based on the result measured in Jun 2010. The observed position is shown in right upper side.

5. Conclusion

We developed the technique by using imaging plate which is attached on the target vessel by remote handling technique. Peak reduction by the expansion of beam at the target is an effective and practical way to mitigate the damage. In order to observe the heat densities at the vicinities of the target given by the proton beam, we developed the technique based on the measurement of temperature rising. During 5 min beam irradiation, the heat deposition at the vicinities was obtained by the differential of the temperature, which was 0.3 W/cc for 0.2 MW beam. Understanding the beam profile and the heat deposition at the vicinities, we carries out profile optimize the beam size. We succeeded restoring beam operation within short period and begun the beam operation for users.

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