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Beam Commissioning at JSNS of J-PARC

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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, which are produced at a thick mercury target and a thin carbon graphite target by 3-GeV proton beams, respectively. The first beam was achieved at the target without significant beam loss. To obtain the beam profile at the mercury target, we applied an activation technique by using a thin aluminium foil. The calculation results given by the accelerator team showed good agree with the experimental data.

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] were installed in the Materials and Life Science Facility (MLF) shown in Fig. 1. The 3GeV proton beam is introduced to the mercury target for a neutron source and to a carbon graphite target for a muon source with thickness of 20-mm. 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. Before injection to the RCS, the proton beam is accelerated up to 181MeV by 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.

Recently it became evident that pitting damage is imposed on the target container of the mercury target[4]. Several facilities are studying the effect; Alternating Gradient Synchrotron (AGS) and Weapon Neutron Research facility (WNR) are pursuing off-beam experiments[5]. It was reported that the damage was proportional to the fourth power of the peak current density of the beam[5]. Therefore, beam profile monitoring plays an important role in comprehending the damage to the target.

In this paper, beam commissioning is described for the spallation neutron and muon source at the J-PARC, which began in May 2008. As the beam commissioning, turning of the beam orbit and the monitoring of the beam were performed.

2. Beam optics

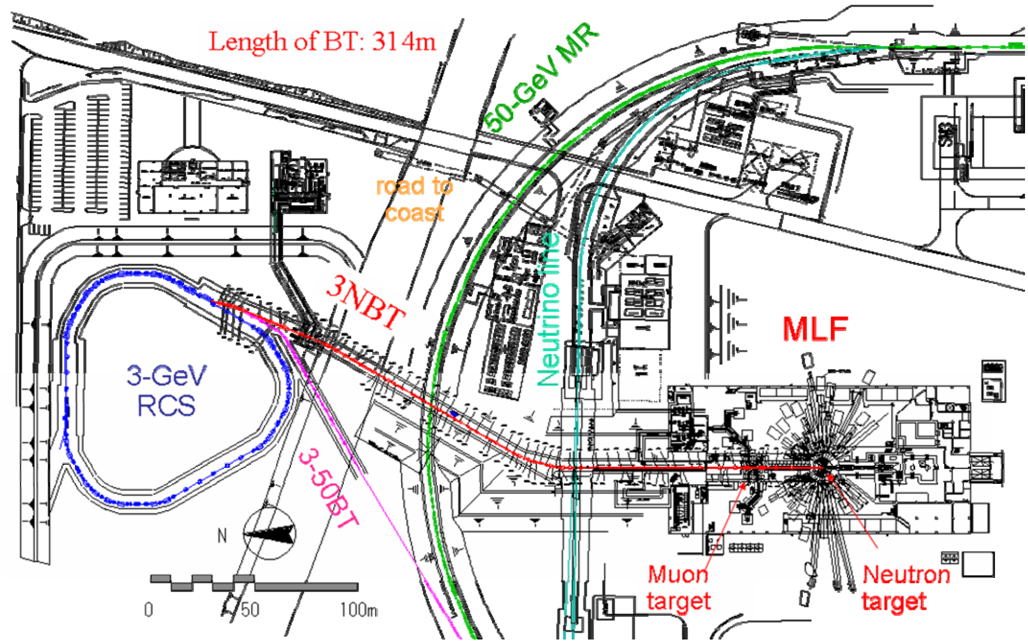

Fig. 1: Layout of JSNS and MUSE in J-PARC. The beam transport line (3NBT) introduces the beam to both facilities located in the MLF building.

As the details of the design of the beam optics are described in Refs. [6, 8], the concept is described briefly here. In order to allow hands-on maintenance, acceptable beam loss is limited to 1W/m except the area close to the targets. At the RCS, a beam collimator with an aperture of 324 π mm· mrad is installed for shaping the beam. During acceleration in the
RCS, the beam emittance shrinks to 54 and 81π mm· mrad by adiabatic dumping for 181 and 400 MeV injections, respectively. However, a small fraction of the beam may exist with an emittance up to 324 π mm· mrad due to blow-up by space charge. Therefore we decided to have an aperture larger than 324π mm· mrad along the entire beam line.

In Fig. 2, Dx and Dy represent the dispersion functions in the horizontal and vertical directions, respectively. In order to coordinate other accelerator facilities in J-PARC such as 50-GeV synchrotron and neutrino beam tunnel, the proton beam is bent to upper direction. In the design, an achromatic beam transport line was aimed at to suppress the expansion of the beam due to momentum spread for both horizontal and vertical directions.

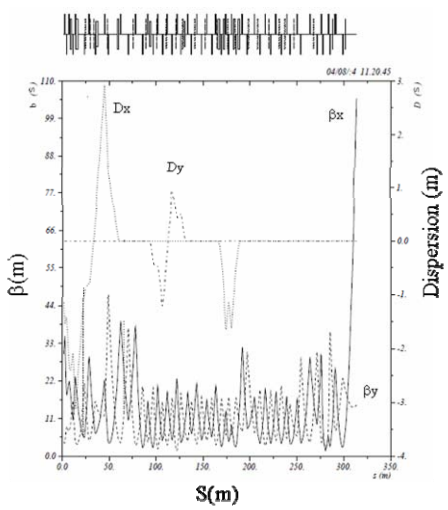

Fig. 2: Beam optics from the exit of RCS to the JSNS.

2.1 Alignment

In order to carry out the beam commissioning efficiently, exact alignment of the magnet is important. Using a laser tracker (Leica LTD-500), all magnets except around the muon target area were aligned precisely. Although uneven settlement remains in the tunnel, all components were aligned to the position as designed within accuracy of 0.1 mm.

3. Beam monitors for diagnostics

3.1 Beam current monitors

To measure the beam intensity, Current Transformers (CTs) are installed in the beam line. Inside the current transformers, a titanium duct is attached for connecting to other vacuum component. For the reduction of gas emission, the ducts were baked out. Normally, the vacuum components for the beam transport system are baked out at a temperature of 150°C. Because the insulator material of the current transformer cannot stand the treatment of 60°C, the combined assembly was baked out at a temperature less than 60°C. Data of the monitors are acquired by a network-based CAMAC controller (cc/NET TOYO) via the Experimental Physics and Industrial Control System (EPICS) standard.

3.2 Profile monitors

To measure the beam position and shape, Multi-Wire Profile Monitors (MWPMs) are installed in the beam line. Silicon carbide (SiC) wires are utilized as sensors due to their small interaction with the primary beam. Because the Rutherford scattering cross-section is proportional to the square of the atomic number of the wire material, a low atomic number material has been selected to minimize beam scattering. The wire frame can be moved out so that the beam can pass without interaction when no measurement is performed.

For the safety of the operation, it is very important to watch the beam profile on the target. In order to watch the profile continuously, a stationary type of beam profile monitor was located at the proton beam window, which is located 1.8 m upstream of the neutron target. From the view point of the easiness of the maintenance, the profile monitor is combined with the proton beam window. At the muon production target, a movable type of the profile monitor is located.

3.3 Beam positions monitors

In order to watch the center position of the beam without disturbance, Beam Position Monitors (BPMs) are installed. Beam position monitors consist of quadruple electrodes. The position of the beam is measured by the induction of wall currents in the electrode. The center position of the beam is derived from difference among the signals.

4. Beam commissioning

4.1 Result of beam commissioning to the MLF

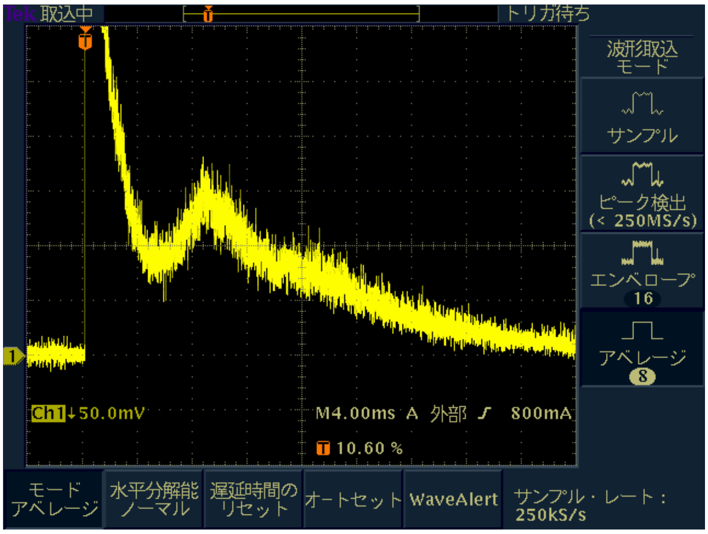

Fig. 3: Time-of-flight spectrum for the first neutron beam measured by the current mode time-of-flight (CTOF) technique[11]

Without significant beam loss, the first beam was able to be introduced to the MLF on 30 May 2008. The intensity of the first proton beam was approximately 4×10^{11} ppp and the transmission efficiency larger than 90 %. After fine tuning of the beam orbit and beam monitor system, the beam profile was measured by the MWPM located at the proton beam window. As for the first neutron beam measurement at JSNS, it was planned to carry out measurement employing the Current mode Time-Of-Flight (CTOF)[11] technique because of its reliability and convenience. In Fig 3, the neutron TOF spectrum is shown, which can be obtained only one shot. By the comparison with the calculation, it was found that the calculation showed good agreement with the experimental result.

Since the proton beam profile on the spallation neutron target is very important, we tried to obtain the beam profile on the target. In order to achieve good performance of the neutron source, there was not enough left around the target to place any devices for the beam profile measurement. To fit the requirement with the tiny space around the target, we adopted an activation technique, which required only small space for thin foil. Placing a sheet of aluminium foil (0.3 mm in thickness) on the target, the beam profile was obtained from the residual dose distribution on the foil. After irradiation, the foil was removed from the target and attached to the imaging plate (Fuji Film BAS-SR 2040) to read the dose distribution. Figure 4 shows the observed result. It was found that the beam shape had been Gaussian with FWHM of 42.5 and 18.8 mm in horizontal and vertical directions, respectively. These widths show quite good agreement with the data obtained by the β function of optics and the beam emittance obtained by the SIMPSONS[6] including the scattering on the proton beam window. The center position of the beam is continuously observed by BPM. It was found that the stability of beam position was good and the deviation of the center position was typically 0.6 mm at BPM position.

In Fig. 4, it was also found that beam was not skewed in real space. Figure 5 shows the comparison of the vertical profile results obtained by activation technique and MWPM, the latter of which gives the beam profile projected on the horizontal and vertical axis, placed at proton beam window. It was found that both results showed remarkably good agreement. Therefore it was concluded that the beam current density could be derived from the result of the MWPM.

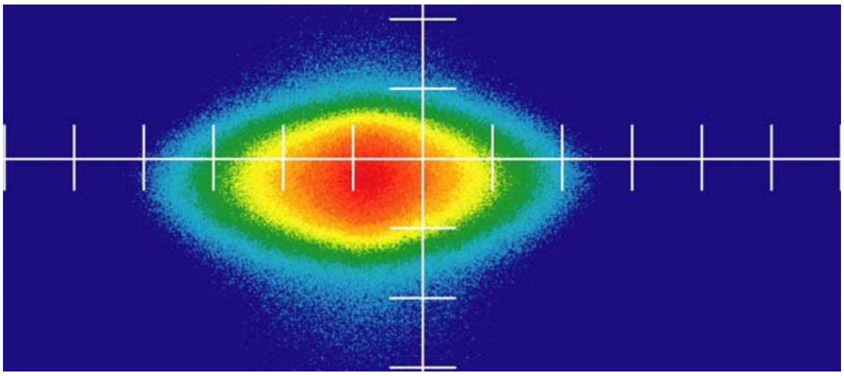

Fig. 4: Beam profile observed by the activation of the aluminium foil(0.3mm-t) located on the spallation neutron target (one division in figure is 10 mm)

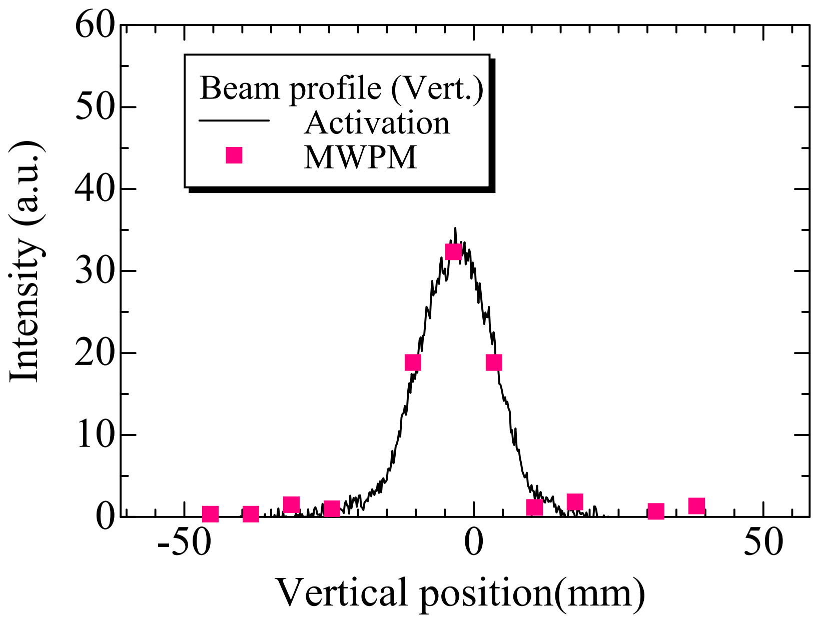

Fig. 5: Comparison of results of vertical beam profile obtained by activation technique and multi-wire-profile-monitor(MWPM).

4.2 Measurement of transverse emittance of the beam

In order to obtain beam characteristics, Q-scan was performed in the most downstream section of the beam transport line, where it was observed that the beam width depended on the field of a quadrupole magnet. As a preliminary result, it was obtained that the Root Mean Square (RMS) beam emittance was 1.6π·mm· mrad. Calculation by SIMPSONS showed that the emittance was 1.5 π mm· mrad in horizontal, which showed good agreement with the observed result.

4.3 Measurement of response of steering magnet

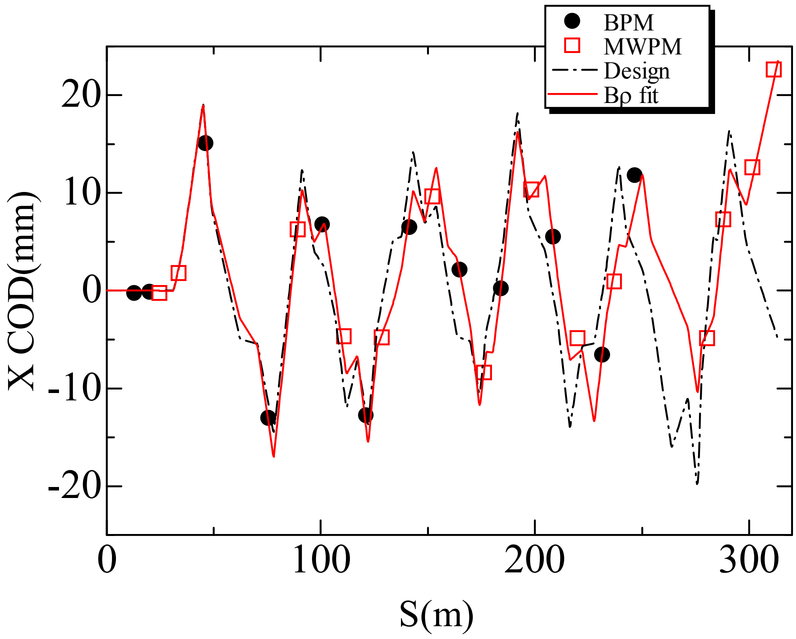

Fig. 6: Center orbit distribution by changing the kick angle of the horizontal steering magnet located most upstream. Circles and squares show the result obtained by BPM and MWPM, respectively. The dashed-and-dotted curve shows the result by design calculation. The solid curve is calculation result by adjusting Bρ of quadrupole magnets to be fitted to the experimental results.

Response of steering magnet on the beam position is important to correct beam orbit as intended. Figure 6 shows the result of the beam orbit distribution along the beam line by changing the kick angle of the most upstream horizontal steering magnet by 1 mrad. Although the original design showed good agreement in general, the considerable disagreement was found in the down stream section. So as to fit the orbit to the experimental result, it was calculated by changing quadrupole magnet field equally. Consequently, the calculation by decreasing Bρ by 2% reproduced the experiment in whole beam line very well. This fact indicated that the fields of the quadrupole magnets are 2% smaller than design value, although the magnetic field for each quadrupole magnets was measured. In the magnetic field measurement, a hall prove sensor was used. The response of the hall prove might cause 2% disagreement. In Fig. 7, the original design calculation is compared with the experimental result when the magnetic fields of all the quadrupole magnets were increased by 2%. It shows the remarkable good agreement between experiment and design calculation. It is demonstrated that the beam optics behaves as designed.

5. Trend of proton beam power

Trend of proton beam power is shown in Fig. 8. After early stage of beam commissioning, it was confirmed that the critical issue did not exist and we have been ramping up the beam power since then. In December 2008, a short duration of 100-kW operation was demonstrated and continuous 20-kw operation began. In November 2009, we started delivering beam of 120 kW with remarkably good availability as 90%. For short duration of 1 hour, we demonstrated 300-kW beam operation to the spllation neutron source. It was shown that the beam loss was very small and the beam status was very stable. Even after beam operation at 300 kW, the residual dose in the beam transport system was as small as background level.

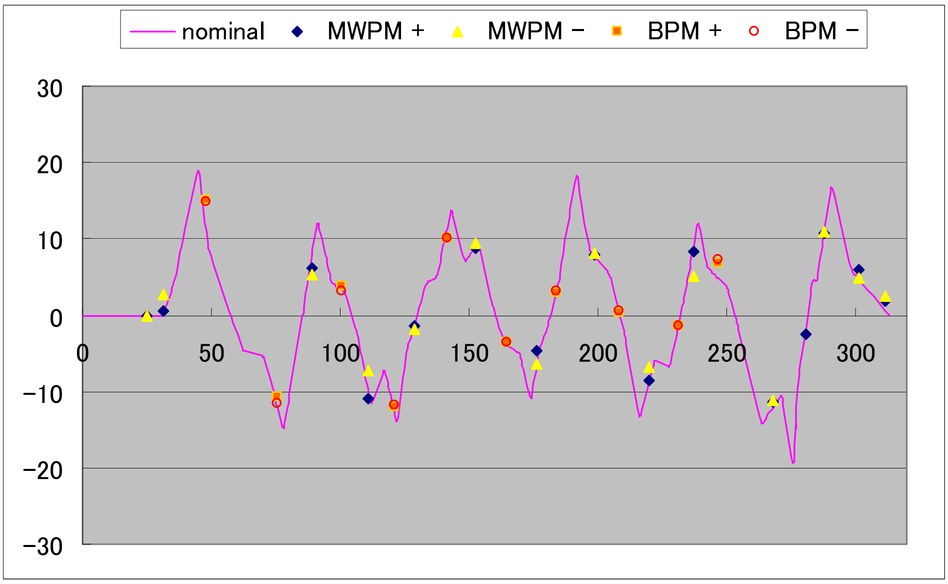

Fig. 7: Comparison of original calculation with experimental result, when the magnet fields of all the magnets were increased by 2%

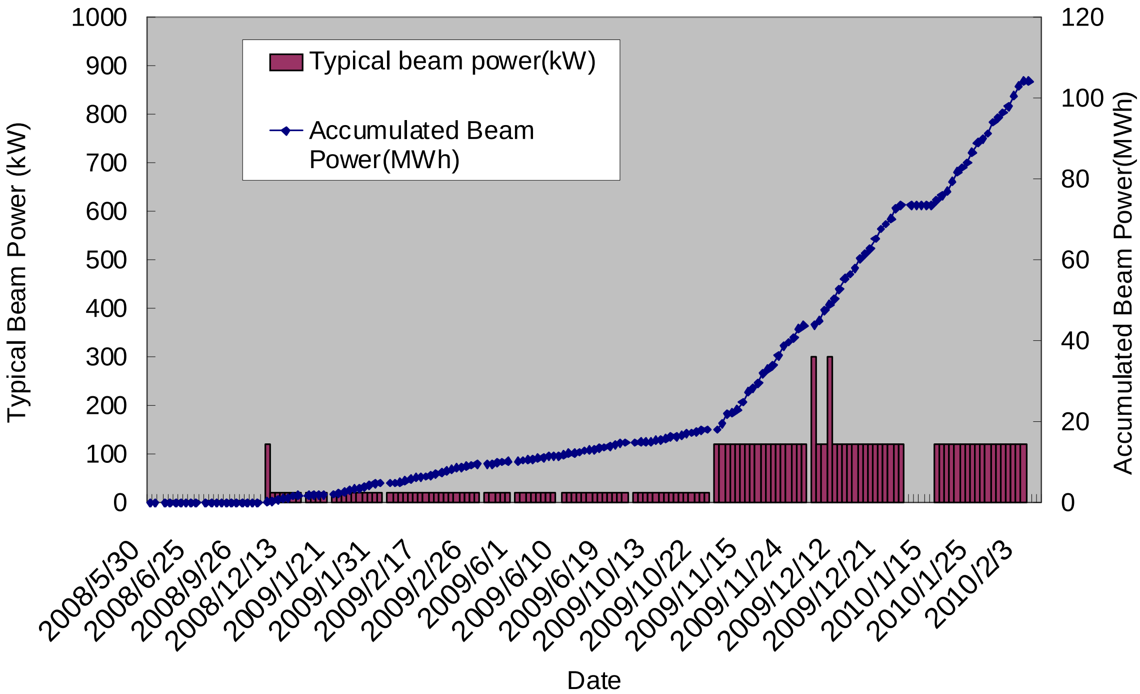

Fig. 8: Typical beam power to deliver to spallation neutron source (vertical bar, left axis), accumulated beam power (diamonds, right axis)

6. Summary

The beam commissioning to the spallation neutron target of J-PARC started in May 2008. The muon facility of MUSE began operation in September 2008. The first beam was transported to the target without significant beam loss. To obtain the beam profile at the target, an activation technique was applied by putting thin aluminium foil on the target. Since beam monitors worked very well located at the beam transport line even in the first beam, the beam tuning was able to be finished by very small number of shots. It was found that the beam shape had been Gaussian with FWHM of 42.5 and 18.8 mm in horizontal and vertical directions, respectively. These widths show quite good agreement with the data obtained by the β function of optics and the beam emittance obtained by the SIMPSONS[6] including the scattering on the proton beam window. We have demonstrated 300 kW beam operations. In summer of 2010, continuous operation to 200 kW will begin.

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