INSTALLATION AND PERFORMANCE CHECK OF BEAM MONITORS FOR ENERGY UPGRADED J-PARC LINAC

A. Miura#, N. Ouchi, H. Oguri, K. Hasegawa
J-PARC Center, Japan Atomic Energy Agency, Tokai, Ibaraki, 319-1195, JAPAN
T. Maruta, Y. Liu, T. Miyao,
J-PARC Center, High Energy Accelerator Research Organization, Oho, Tsukuba, 305-0801, JAPAN
M. Ikegami
FRIB, Michigan State University, East Lansing, MI 48824-1321, USA

Abstract

An energy upgrade project has started in the J-PARC Linac since 2009. In the upgraded project, beam energy in the Linac has increased from original 181 MeV to 400 MeV using the additional 21 Annular-ring Coupled Structure Linac (ACS) cavities. The new beam monitors as the beam current monitors, the phase monitors, the beam position monitors and the transverse profile monitors (wire scanner monitors) were designed and fabricated. Till the end of November, 2013, all beam monitors were completely installed. From the middle of December, we started the beam commissioning to achieve the beam energy as 400 MeV, as well as to confirm the beam monitor functioning. We achieved the 400 MeV beam acceleration at the middle of January, 2014 using newly installed beam monitors. This paper describes the beam monitor installation and the beam commissioning results of beam monitor functioning.

INTRODUCTION

The Japan Atomic Energy Agency (JAEA) and the High Energy Accelerator Research Organization (KEK) have been organizing the Japan Proton Accelerator Research Complex (J-PARC) project at the JAEA Tokai site since 2001 [1]. The beam commissioning of the Linac started in 2006 and a 181-MeV beam was injected into the downstream 3-GeV rapid-cycling synchrotron (RCS). Since the beginning of J-PARC, user operation has successfully continued with the exception of a 10-month interval due to the Tohoku earthquake occurred at 2011. In parallel with the 181-MeV beam operation, a 400-MeV energy-upgrade project began in 2009. New Annular-ring Coupled Structure Linac (ACS) cavities had been developed [2] and the beam monitors had been designed and fabricated for the energy-upgrade project. During the summer shutdown, we installed the newly fabricated ACS cavities and related devices. Continuously we started the beam commissioning in December 2013.

NEW BEAM MONITOR LAYOUT OF 400 MeV LINAC BEAM LINE

The J-PARC Linac originally consists of a 50-keV negative hydrogen ion source, 3-MeV RFQ (Radio Frequency Quadrupole Linac), 50-MeV DTL (Drift Tube Linac), and 181-MeV SDTL (Separated-type DTL) [1]. We had two SDTL-type debunchers allocated at an ACS section and L3BT (Linac to 3-GeV RCS Beam Transport) in the original beam line. In the energy-upgrade project, we replaced the two original debuncher cavities to the end of the SDTL section as the 16th acceleration module of SDTL cavities. We installed new ACS-type bunchers for the longitudinal matching between the SDTL and the ACS cavities, because the operating frequency is 972 MHz of the ACS with three-fold frequency jump from that of the SDTL.

A number of beam monitors have been used in the original beam line, such as: the beam position monitor (BPM), beam current monitor (slow current transformer, SCT), beam phase monitor (fast current transformer, FCT), transverse profile monitor (wire scanner monitor, WSM) and beam loss monitor (BLM) [3].

Periodical layout of beam monitors in each ACS module is shown in Fig. 1. One module consists of two

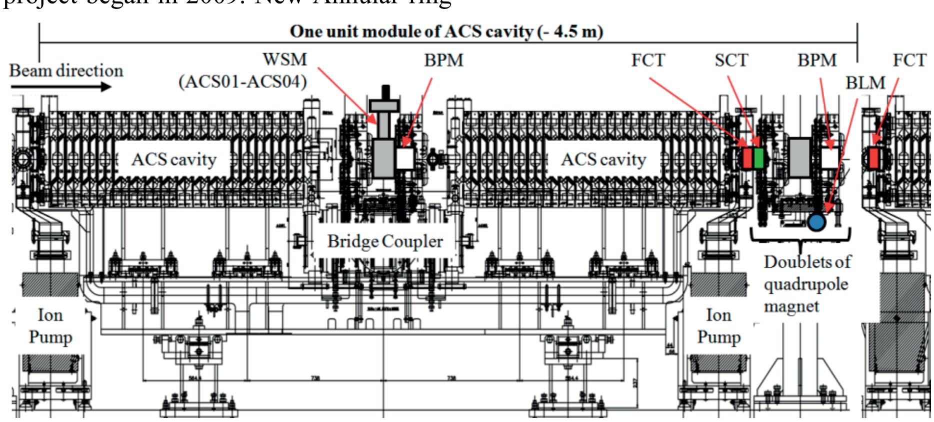

Figure. 1: Periodical beam monitor layout of all ACS cavities. MEBT2 is the second Medium Energy Beam Transport between SDTL and ACS section.

#akihiko.miura@j-parc.jp

ISBN 978-3-95450-142-7

accelerating cavities and a bridge coupler. There is a drift space for placing the quadrupole doublets at the bridge coupler and another drift space between the modules, where most of the beam monitors are installed. A pair of FCTs is located at the exit of the second cavity and at the entrance of the next cavity to measure the beam energy at the drift space without any acceleration devices by TOF (Time Of Flight) method. The distance of the pair regularly corresponds to 2.5 βλ (β: relative velocity, λ: wave length of the Acceleration RF); however we referred to the farther combination of FCTs which corresponded to 21 βλ [4]. An SCT and an FCT are in the one vacuum chamber package, where, the SCT is located behind the FCT. The BPM is mounted directly on the yoke of quadrupole magnet to get higher position accuracy with respect to the position of quadrupole magnet. This layout is adopted for all ACS modules with the addition of a WSM for some of upstream modules.

COMMISSIONING PLANS AFTER UPGRADE

The commissioning which was started from the mid December of 2013 had two important missions; 1) establish the 400-MeV operation and 2) make the suitable parameters for the high power beam operation with an output power of 1 MW. Before the establishment of 400-MeV operation, we had another two missions of the commissioning to reproduce the 181-MeV operation again in the new beam line and to confirm the functioning of beam monitors to be used for the tuning of cavities [5].

For the first step of the beam commissioning, we completed the reproduction of 181-MeV operation and confirmed the functioning of the beam monitors using 181-MeV beam. We check a signal response from the SCTs and FCTs while delivering the 181-MeV beam to the straight beam dump. Because the bunch structure of the beam can be reasonably sustained for the new ACS section, we can measure the beam energy with various FCT pairs using the TOF method. The beam energy measured with the FCT pairs should agree with each other within the expected accuracy for the TOF method with deceleration by exciting idle cavities. We confirmed the alignment offset of BPMs by the conventional beam based calibration (BBC) which is the examination by the responses to a change of strength of the quadrupole or the steering magnets [6].

COMMISSIONING FOR CONFIRMATION OF BEAM MONITOR FUNCTIONING

After the beam orbit correction and the transverse matching in the SDTL and ACS section to minimize the tuning error for the beam transmission, we checked the signal response of SCTs and FCTs using 181-MeV beam. We can see the signal of SCTs plotted along the beam line in Fig. 2. After SDTL section, the calibration errors and noisy channels are still remained, but some of SCTs can be reliable to measure the beam current.

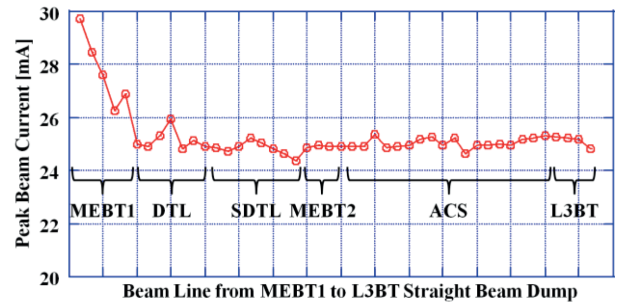

Figure 2: Beam Transmission along the Beam Line using 181 MeV. Horizontal axis means the beam line and vertical one does the peak beam current.

In the beam phase measurement, we should take account to the calibration with phase offsets from the FCT itself and the signal transmission line. After tuning of SDTL cavities, we used 181-MeV beam to compare the various FCT pairs for the energy measurement. If the calibration of the offset value and adjusted the reference 342 MHz correctly, output energy should be 181 MeV with the sustaining errors with 1.0%. As shown in Fig. 3, all data with only one exception are successfully obtained within 0.6% (corresponding beam energy as 1.0 MeV). Most of all FCT pairs can be used for the phase scan due to good performances of the energy measurement.

The proper amplitude and phase of each accelerating cavity of ACS were set by a phase scan method [7, 8, 9]. In the phase scan, the beam energy was measured by the TOF method with a pair of FCTs. An example of the phase scan result taken at ACS20 is shown in fig. 4. The agreements between the measured energy and the simulation were very well in fig. 4 which indicates the tuning error is within 1.0 % in amplitude and 1 degree in phase. The beam energy at the ACS section after the phase scan has a good agreement between the measured and the design energies with the difference of 0.6 % in the whole ACS section. The measured output energy at the last ACS cavity was 400.4 MeV, which is 0.10 % higher than the design value. After we injected the 400-MeV beam to RCS, the corresponding beam energy was measured by the closed orbit distortion method (COD). By this measurement, the energy shift is only 0.21 %. This result is slightly different from the energy

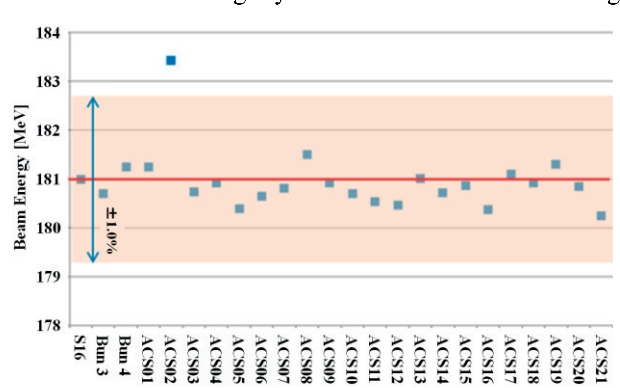

Figure. 3: Beam energy measurement obtained at 181-MeV by various FCT pairs. S16 is the 16th SDTL cavity, B3 and B4 are the 1st and 2nd Buncher cavity in MEBT2.

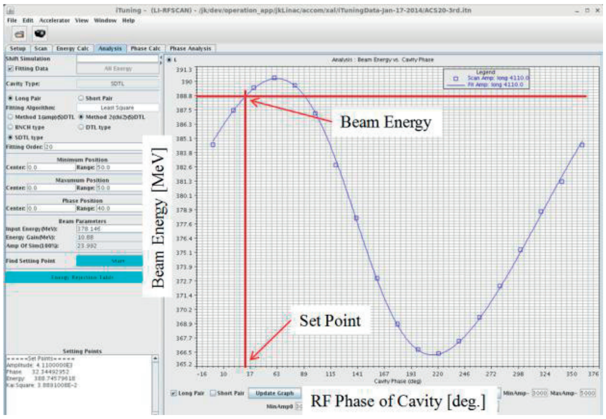

Figure 4: An example of phase scan result taken at ACS20. Dots are the measurement points taken with 20 degree intervals and curve is the simulation result.

measurement by TOF in Linac, but it is acceptable for the injection of RCS.

A BBC method is conducted to find the relative alignment offset of a BPM. This method requires a singlet quadrupole magnet and one of its upstream steering magnets as the tuning knobs. The offset of magnetic center is extracted by analyzing the deviation of beam orbit generated by the variation of QM and steering magnet. The beam orbit is measured using a BPM nearby a QM and a downstream BPM. Because all quadrupole magnets were replaced from MEBT2 to the end of ACS section and all magnets were aligned by the laser measurement system, we checked the alignment offset of BPMs in MEBT2. By performing this method, the offset was measured as 18.8-μm within an accuracy of a few 10-μm.

As for the BLMs, we have accumulated experience with respect to the relationship between the BLM signal level and the resulting residual radiation dose. However, this relation should not be valid after the energy upgrade because the surrounding geometry around the BLMs was completely different before the ACS cavities installation. We checked the waveform of BLM signal to compare the signal level between the X-ray from RF cavities and the real beam loss. We take an example of beam loss waveform in ACS18, because the typical waveform can be observed clearly in this part. The signal response from BLM in ACS18 can be seen with RF-on but without beam in the left of fig. 5. When the beam is on, the signal waveform is changed to right one. Actual beam loss can

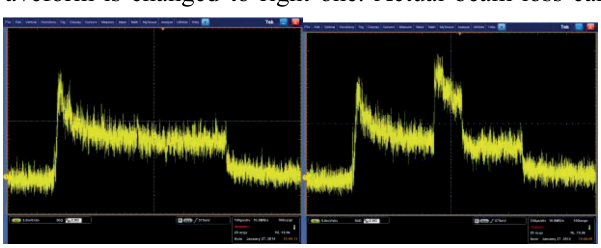

Figure 5: Beam loss signal taken at ACS18. In the figures, 100 μs/div is for a horizontal axis and 5.0 mV is for a vertical axis. An RF width is about 650 μs and a beam pulse width is 100 μs without chopping.

be clearly recognized with the difference between the beam-on and the beam-off. This situation can be acceptable for the Linac tuning.

SUMMARY

A 400-MeV energy-upgrade project in J-PARC Linac began in 2009. In parallel of new cavity development for the energy-upgrade project, beam monitors for the beam commissioning had been designed and fabricated. During the summer shutdown of 2013, we installed the beam monitors in the new beam line with ACS cavities. Continuously, we started the beam commissioning. Based on our experiences, we established the 181-MeV operation. Before the establishment of 400-MeV operation, we have confirmed the functioning of the beam current monitors the beam phase monitors, the beam position monitors and beam loss monitors while delivering the 181-MeV beam to the straight beam dump. First, we checked the signal response from SCTs and FCTs. Beam energy was measured using new pairs of FCTs in new ACS beam line. Because the accuracy of the measurement is kept under 0.6%, we can use the phase scan of proper setting of ACS cavities to establish 400-MeV. As the BBC measurement of BPM in MEBT2, the positions of BPMs and corresponding QMs are acceptable with the small mechanical offsets. After the establishment of 400-MeV operation, we confirm the beam energy in two methods using TOF method by the new pair of FCTs and COD method in RCS to be compared. Although the X-ray background signal is not perfectly suppressed, the clear beam loss signal is observed and we can continuously use these BLMs for the Linac tuning.

REFERENCES

[1] Y. Yamazaki ed., "Technical Design Report of J-PARC", KEK Report 2002-12 (2003).
[2] H. Oguri, Proceedings of IPAC2013, Shanghai, China, WEYB101, 2013.
[3] A. Miura, et. al., Proceedings of IBIC2012, Tsukuba, Japan, MOIA02, 2012.
[4] G. Shen, et al., Proc. of PAC07, TUPAN062, Albuquerque, New Mexico, USA, 2007.
[5] M. Ikegami, et. al., Proceedings of IPAC13, Shanghai, China, THPWO028, 2013.
[6] G. Shen, et al., Proc. of the 4th Annual Meeting of Particle Accelerator Society of Japan, and the 32nd Linear Accelerator Meeting in Japan, TP60, Wako Japan, 2007 (in English)
[7] M. Ikegami, et al., Proc. of PAC07, p. 1481, Albuquerque, New Mexico, USA, 2007.
[8] G. Shen, et al., Proc. of PAC07, p. 1529, Albuquerque, New Mexico, USA, 2007.
[9] H. Sako, Proc. of PAC07, p. 257, Albuquerque, New Mexico, USA, 2007.

ISBN 978-3-95450-142-7