BEAM MONITOR LAYOUT FOR FUTURE ACS SECTION IN J-PARC LINAC

A. Miura[#], H. Oguri, J-PARC Center, JAEA, Tokai, Ibaraki, 319-1195, JAPAN
Masanori Ikegami, J-PARC Center, KEK, Oho, Tsukuba, 305-0801, JAPAN

Abstract

In J-PARC Linac, an energy and intensity upgrade project started since 2009 using Annular Coupled Structure (ACS) cavities. To meet with this upgrade, the design peak current will be increased from the present 30 mA to 50 mA, and the beam energy from 181 MeV to 400 MeV. Along with these significant upgrades of the beam parameters, beam monitors should be followed. Then, the beam monitors which will be used for the beam commissioning are newly designed and fabricated. These monitors will be delivered in the ACS beam line. Bunch shape monitor and scintillation beam loss monitoring system will be newly employed for the new beam line. In this paper, we introduce the beam monitors and their layout for the new beam line of energy upgraded Linac.

INTRODUCTION

J-PARC (Japan Proton Accelerator Research Complex) Linac aims to provide high intensity beams of peak current 50 mA, beam energy 181 MeV, pulse width 0.5 mA and repetition rate 25 Hz using an RFQ, three DTL cavities, fifteen SDTL cavities and two beam transports. There are two debuncher cavities in the beam transport including matching points to inject the adequate beam to

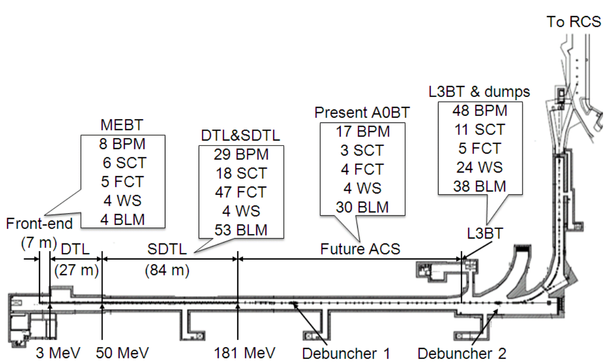

Figure 1: Delivery of beam monitors in the present J-PARC Linac. MEBT is a medium energy beam transport. DTL and SDTL are the drift tube linac and separated type DTL. A0BT and L3BT are the beam transport without cavities. BPM is a beam position monitor, SCT and FCT are the slow and fast current transformer as the peak beam current and phase monitor, WS is a wire scanner as the transverse profile monitor and BLM is a beam loss monitor.

the downstream rapid cycling synchrotron (RCS) [1]. Delivery of the beam monitors in the present beam line is shown in fig. 1.

In the energy upgrade project, present two debuncher cavities are replaced to SDTL section as the 16th acceleration cavity. Twenty one ACS (Annular-Coupled Structure Linac) cavities will be installed in the present A0BT subsection. To meet with this project, the beam monitors for the future ACS and L3BT subsection are newly designed and fabricated [2]. Beam monitors in MEBT, DTL, SDTL subsections and dump line will be taken over, but the most of all monitors in A0BT will be replaced with an installation of the ACS cavities. A part of L3BT will be modified to meet with the new design of debuncher systems.

[#]miura.akihiko@jaea.go.jp

BEAM COMMISSIONING TOOLS IN FUTURE ACS BEAM LINE

Requirement of Beam Monitors

Operational parameters of the energy upgraded linac are listed in Table 1. Bunch repetition frequency of ACS cavity will be three times higher than that of present cavity. The beam monitoring devices are still tuned at 324 MHz for the monitors in ACS subsection. But the beam position monitors and transverse profile monitors for the future beam line should be followed to the new beam parameters. In this section, beam monitors employed for the future beam line are introduced with the points of modification from present monitors [3].

Table 1: Operational Beam Parameters of Energy Upgraded Linac.

Particle	Negative hydrogen ion
Peak Beam Current	5 - 50 mA
Source Energy	180 - 400 MeV
Typical Bunch Length	1 - 2 deg. (rms)
Typical Transverse Side	1 - 2 mm (rms)
Pulse Width	0.5 msec
Bunch Repetition Frequency	324 MHz, 972 MHz for New ACS cavities
Operational Repetition Rate	1 - 25 Hz
Chopper beam-on ratio	56 %
Beam power	36 kW (133 kW after upgrade)

Beam Position Monitor (BPM)

J-PARC Linac employs the strip-line type beam position monitor (BPM). Basic design is taken over from the present BPMs and to take impedance matching between the electrodes and cables, we made the prototype model for the bench test to be compared with the electro-static simulation. A variety of the width of electrode is

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tried to match the corresponding impedance. Because the length of the strip-line electrode depends on the accelerated energy, we also modified the length of electrodes. Seventeen BPMs are presently working at the A0BT, but all BPMs will be replaced due to energy upgrade and additional ones will be installed.

Accuracy of the position is stably maintained at 0.1 mm, because the beam commissioning requires above accuracy to keep beam trajectory within plus-minus 1.0 mm. Forty-eight new design BPMs are newly produced.

Beam Current and Phase Monitor (SCT: Slow/Fast Current Transformer)

Two types of current transformers have been used to measure the peak beam current and phase. Slow current transformer (SCT) for the peak beam current measurement has a dynamic range of 0.1 - 80 mA and time response under 50 ns. The SCT has been chosen with 50 turns and additional winding to provide a calibration input capability. The fast current transformer (FCT) for the phase measurement has a good response of relative bunch phase under 1 %. The FCT has been chosen with only one winding. These two current transformers (SCT and FCT) are set into one vacuum chamber with one ceramic break. A package of current transformers is fixed on the end and entrance plates of cavities.

In the beam commissioning, beam transmission through cavities and transport is evaluated using several SCTs and beam energy is calculated using a pair of phase data taken from a pair of FCTs by time-of-flight method. Also, the RF set-point of cavity has been tuned with a phase-scan method, where the output beams energy from the DTL tank is monitored using two downstream FCTs.

Beam Profile Monitor (WSM: Wire Scanner Monitor)

In order to take the transverse matching, four wire scanner monitors (WSMs) are allocated in each matching section. Totally 36 WSMs are presently working in the linac and the beam transport line which connects with the downstream RCS. Four WSMs are presently working at the A0BT and all four will be replaced due to the locational problem.

Tungsten wire with 100 μm diameter is connected on the alminum frame for over 50MeV beam. Because the higher peak beam current will be supplied to the downstream of ACS subsection with the intensity upgrade, tungsten wire should be exchanged to the wire with thinner diameter due to thermal problem.

Dynamic range of the WSMs reaches over 10^4 order magnitudes [4] and it is enough high to measure the transverse beam halo of present beam operation. When the peak beam current is lamped up to the 50 mA, space charge effect would be more serious and emittance might be grown. The wire scanner monitors will play a very important role in the tuning of transvers matching.

Bunch Shape Monitor (BSM)

Three Bunch Shape Monitors (BSMs) have been newly developed and fabricated for J-PARC Linac at the Institute for Nuclear Research of the Russian Academy of Sciences. Three BSMs will be installed in the beginning of ACS section (in Fig. 2) in order to tune the longitudinal matching, because the acceleration frequency of 324 MHz until the end of SDTL is jumped to 972 MHz of ACS cavities.

The development of BSMs was started since 2009 and the completion of three BSMs was in 2012. Due to the earthquake, schedule of the BSM development was slightly changed but all three BSMs were successfully installed [5].

The BSMs had been commissioned with the beam and their operability has been demonstrated. In the beam commissioning, BSMs were checked with the consistency and started to use the beam dynamics study [6].

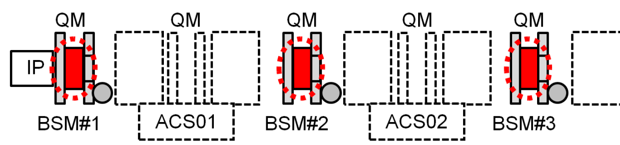

Figure 2: Bunch shape monitors (BSM) layout in the beginning of ACS section. Dotted circles are BSMs, QMs are quadrupole magnets (dotted QMs will be installed) and IP is an ion pump.

Beam Loss Monitor (BLM)

To prevent from the activation and heat load by intense beam loss, fast response of loss signals is required for the beam loss detection. We employed the gas proportional counter for the beam loss detection, because it is necessary to measure wide dynamic range of loss intensity for various beam energies. Because it has an advantage by composing with only a passive components, it is a practically key issue for the detector under the radiation surrounding. The beam loss monitor (BLM) system is composed of $Ar+CO_2$ gas filled proportional counter, which detect γ-ray, neutron and charged particles induced by lost particle.

The gas proportional BLMs are sensitive to the background noise of X-ray emitted from the RF cavities, plastic scintillation BLM with less X-ray sensitivity are tested for the beam loss measurement at the present DTL cavity. We successfully measured clear beam loss signals with low noise and confirmed the high time resolution. Although the DTL section is low energy part of the linac, fine structure of the beam loss was observed by the scintillation BLM. We also measured the beam loss occurred at the DTL varying the beam orbit [7-8]. The combination of a gas proportional counter and scintillation monitors would bring more accurate beam loss measurements with suppression of X-ray noise [9]. Beam loss detection system with the plastic scintillation BLM is presently developing, but it is hopeful to use the future beam loss detection system.

BEAM MONITOR LAYOUT FOR ENERGY UPGRADED LINAC

Periodical Layout for All ACS Cavities

A typical layout of the beam monitors is indicated in fig. 3. This layout is periodically defined from the beginning to the end of ACS subsection. An ACS cavity has two symmetrical modules and also has a drift space between the modules. BPMs will be installed between each quadrupole doublets. An SCT for the transmission measurement will be on the exit of cavity. Two FCTs are located between the exit of the cavity and the entrance of the next cavity to measure the beam energy at the drift space without any acceleration devices. The position of the BLM is temporary defined. This will be optimized by the vilification tests. Wire scanner monitors as the beam profile monitors are allocated only in beginning of ACS subsection to have a transvers matching between present SDTL and new ACS cavities.

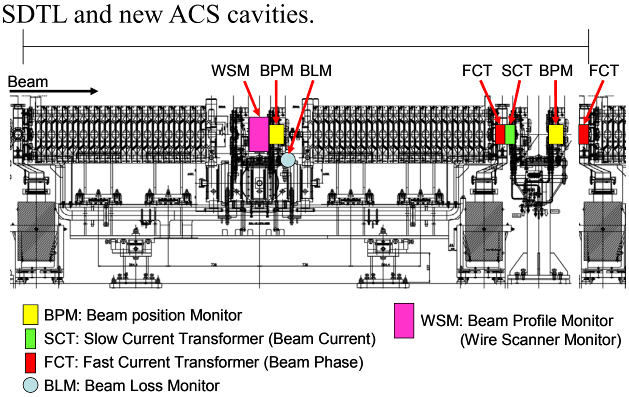

Figure 3: Periodical beam monitor layout of all ACS cavities.

Beam Monitors after ACS Subsection

Debuncher system for upgrade linac has been studied [10]. Suitable positions for 2 debunchers and RF amplitude of the first one are selected to meet the requirement of energy jitter for energy offset in longitudinal injection painting. Meanwhile with elastic setting of the second debuncher, momentum spread can be selected for attaining less beam loss in the downstream synchrotron after upgrade [11]. Pairs of FCTs are considered to measure the beam energy after ACS subsection. The distance of the nearest pair regularly corresponds to 2.5 $\beta\gamma$ and the far combination is defined to 21 $\beta\gamma$. This beam transport contains an irregular arrangement of the pair of FCTs because of the geometrical restriction, then the longest pair of FCTs in DB2 reaches 46.1m, shorter pair (8.7 m) will be usually used.

The adequate set-point of the debuncher 1 and 2 will be sought by the phase scan using these pairs of FCTs.

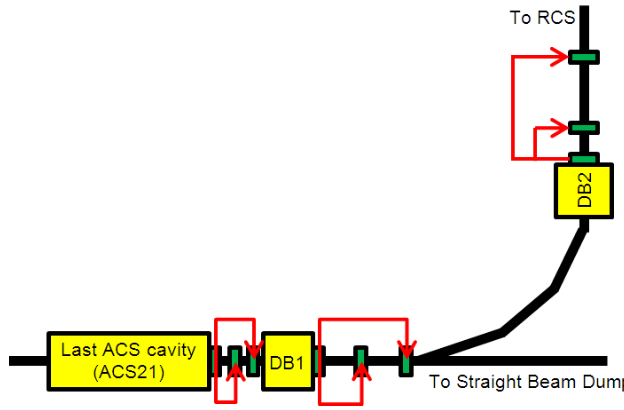

Figure 4: FCT Layout after ACS subsection. DB1 and DB2 are the first and second debuncher which will be newly installed. Every cavity has two pairs of FCTs such as the shorter and longer ones.

SUMMARY

In J-PARC Linac, an energy and intensity upgrade project started using Annular Coupled Structure (ACS) cavities. To meet with significant upgrades of the beam parameters, beam monitors used for the beam commissioning are modified. Also, the bunch shape monitors and scintillation beam loss monitoring system will additionally be employed. The delivery of the beam monitors in the future beam line is discussed with the beam commissioning. Finally, two debunchers are employed to take a jitter and momentum adjustment, and we design and new monitor system for the downstream of debunchers.

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