BUNCH LENGTH MEASUREMENT OF 181 MEV BEAM IN J-PARC LINAC

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Abstract

In J-PARC Linac, an energy and intensity upgrade project has started since 2009 using Annular Coupled Structure (ACS) cavities. Because the longitudinal matching before ACS cavities is additionally required, we decided to employ the bunch shape monitors (BSMs) to measure the longitudinal beam profile. After three years from the start of BSM project, three BSMs were fabricated and installed. We tried to measure the longitudinal beam profile exited from SDTL cavities. In this paper, we introduce the outline of BSM, the first beam commissioning and related small problems.

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 ms and repetition rate 25 Hz using an RFQ, three DTL cavities and 15 SDTL cavities and two beam transports which have two debuncher cavities [1].

In the energy upgrade project, present two debuncher cavities are replaced by SDTL section as the 16th acceleration cavity. Twenty one ACS (Annular-Coupled Structure Linac) cavities are newly installed in the present beam transport after SDTL section [2]. To meet with this project, the beam instruments for the future ACS and downstream beam transport section for the beam commissioning are newly designed and fabricated [3]. Three BSMs were installed in the beginning of ACS section 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.

BUNCH SHAPE MONITOR FOR J-PARC LINAC

Bunch shape monitors (BSM) had been developed in collaboration with INR (Institute for Nuclear Research: Russia) for the measurement of the longitudinal beam width.

Configurations of Monitor

The general configuration of the J-PARC BSM is described in fig. 1 and fig. 2. The series of bunches of the beam under study crosses the wire target with 0.1 mm diameter and knocks out low energy secondary electrons. The electrons are accelerated by electrostatic field (-10 kV) and move almost radially away from the target. A fraction of the electrons passes through input collimator and enters RF deflector operating at a frequency equal to the Linac accelerating field frequency (324 MHz). Deflection of the electrons at the exit of the RF deflector depends on their phase with respect to deflecting field. Downstream of the drift distance the electrons are spatially separated and their coordinates are dependent on phase of the deflecting field. Adjusting the deflecting field phase with respect to accelerator RF reference, one can obtain a longitudinal distribution of charge in the bunches of the analyzed beam [3].

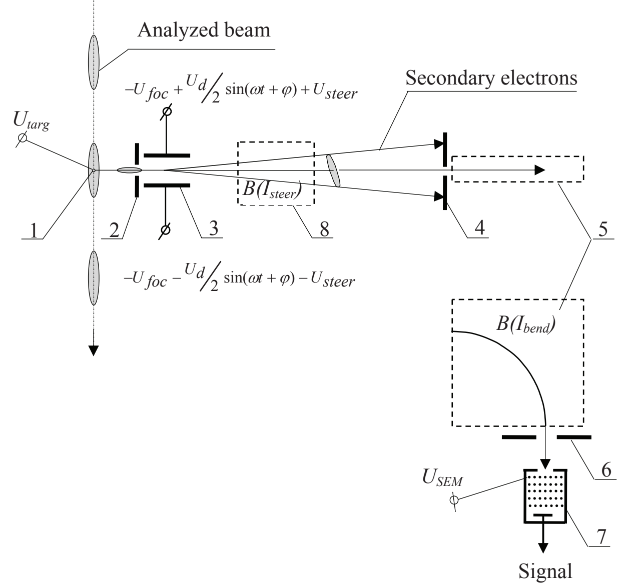

Figure 1: Principal of BSM (1: target, 2: input collimator, 3: RF deflector combined with electrostatic lens, 4: output collimator, 5: bending magnet, 6: collimator, 7: Secondary Electron Multiplier, 8: steering magnet)

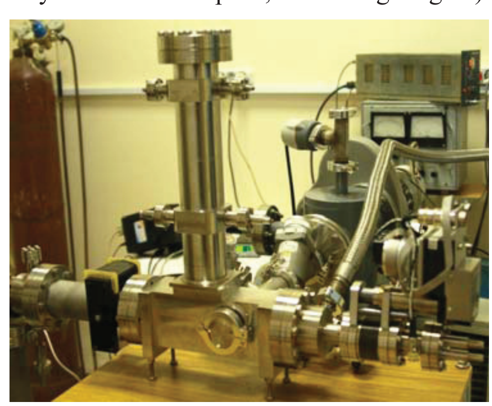

Figure 2: View of BSM in a test bench.

Installation and Layout

Three BSMs were assembled and laboratory tests which included vacuum tests, HV tests, RF deflector tuning, electron optics tests and tuning were completed.

After completion of the laboratory tests the BSMs have been transported to the accelerator tunnel and installed in prescribed positions (fig. 3). After installation, the deflector resonant frequencies were minutely adjusted.

After successful vacuum tests the electron optics of all BSMs has been tested by supplying high voltages and target heating current by permanent cables.

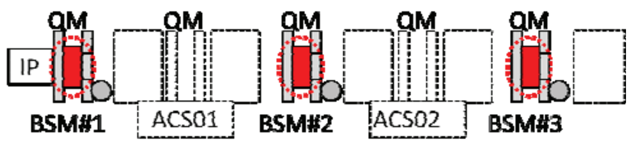

Figure 3: Bunch shape monitors (BSM) layout in the beginning of ACS section. Dotted circles are BSMs, QMs are quadrupole magnets (dotted QMs will be installed) and IP is an ion pump.

Defocusing by Quad Fringe Field

Visual observation of focusing of thermal electrons with the turned on doublet quads immediately revealed a strong influence of the quads fields. Increasing of the quads current resulted in increasing of electron beam size at the output collimator.

It became clear that BSMs cannot work with the recent nominal doublet current to say nothing of higher currents needed in future.

It was decided to decrease quads fringe field by adding magnetic shields which are the 0.4 mm thick steel plates mounted on the BSM box and 1.0 mm steel plates installed vertically near the coils (fig. 4). After installation of the shields, the focusing of thermal electron was reproduced. In order to evaluate the influence of the magnetic shield on the quad field near beam axis, we measured the beam profile at downstream beam transport with wire scanners. The results given in table 1 indicate minor difference of RMS beam dimensions with and without shields thus enabling a conclusion to be made about a possibility of working with the installed shields.

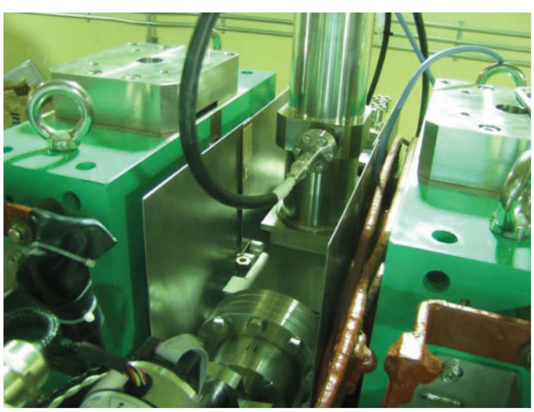

Figure 4: View of magnetic shield installed between the body and coil and on the body surface.

Table 1: RMS Beam Size Measured With And Without Magnetic Shields Using Downstream Transverse Profile Monitors. Difference from the reference case in brackets.

WSM ID	W/ Mag. Shield	W/O Mag. Shield
L3BT 6X		1.6071
L3BT 6Y	1.4682 (+0.0155)	1.4527
L3BT 10X	1.5912 (+0.0172)	1.5740
L3BT 10Y	1.1858 (+0.0106)	1.1752
L3BT 12X	1.4086 (+0.0083)	1.4003

BEAM COMMISSIONING

Parameter Survey

Before starting the measurements the BSMs must be tuned to find proper settings (target potential, focusing potential, secondary electron multiplier voltage, steering voltage, bending and steering magnet currents). BSMs settings were found in laboratory tests and preliminary tests in beam line. Target position was finally adjusted using beam with observing downstream beam loss.

Vacuum Aggravation

Under the test measurements, several problems connected with the influence on the vacuum were found. The first problem was aggravation of vacuum in case of multipactoring in the RF deflector at the operating mode. This discharge arises when the HV potential is not applied to the deflector electrodes. The software was modified to avoid switching on RF without applying HV. RF is switched on with the delay of 100 µs after applying HV and only during the measurements. The second effect is an influence of a dark electron current from the target. The electrons are accelerated and bombard the surfaces resulting in desorption of the absorbed gas molecules. The effect was observed in all three BSMs immediately after applying HV target potential. The effect was completely removed by conditioning with HV.

Initial Check

Test measurements were done with beam energy 181 MeV, beam pulse current 15 mA, pulse duration 100 µs and pulse repetition rate 1 Hz.

We estimated that the consistency of the RMS phase width among BSM's could be seen with turning off the cavity in front of the BSM's. We change the SDTL15 amplitude while setting its synchronous phase to -90 deg. We measure the response of each monitor with respect to the SDTL15 amplitude. In this situation, the larger beam width was estimated at the downstream monitor positions using 3D-PIC simulation.

Figure 5 shows the measured dependence and simulation results. It is readily seen in this figure that the experimentally obtained phase width dependence agrees with the simulation for the BSM#1 and #2. However, the result for the BSM#3 shows some discrepancy. To understand this difference more studies are needed.

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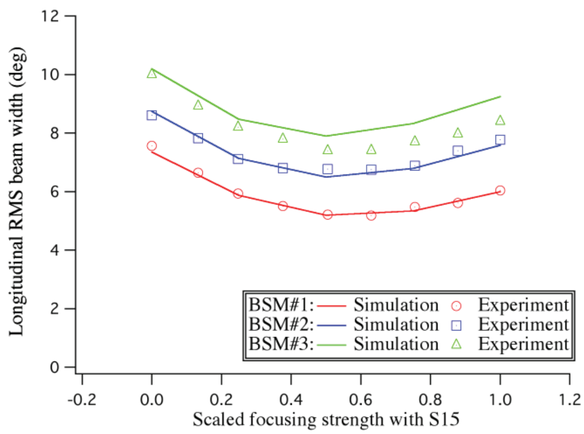

Figure 5: Measured longitudinal RMS beam width with changing focusing strength of last SDTL cavity (S15) and corresponding simulation results [5].

Phase Resolution

The most important characteristic of BSM is phase resolution. Not all the constituents contributed to the resolution can be checked experimentally, but the main component due to focusing and deflecting properties of the secondary electron optical channel of BSM can be found experimentally with the beam. This component has been estimated to be about 0.5°÷0.6°.

RMS Beam Size

Because of the pulse duration as 100μs, the measurement range for the preceding 5μs and 20μs more after the pulse was set. Because the feed forward is slightly delayed from the pulse head, measured shape would not be uniform. And the noisy electrons are coming to the secondary electron multiplier, sometimes large background appears. When RMS beam width is calculated, they would be effective. We discussed the methods to calculate the RMS beam width.

Last half of the pulse will be picked up and to neglect the feed forward delay and suppress the half of large background. And the RMS width is calculated time by time and took averaging. And we compare with the method by the Gaussian fit using the efficient signals above threshold. The methods are still discussed to find the most suitable definition.

First Data Acquisition

First data of bunch length of H^- exited from fifteen SDTL cavities were successfully obtained (fig. 6). Primary data was rigorously discussed with the beam simulation and the monitors started to be employed for the beam dynamics study. In the space charge driven transverse-longitudinal coupling resonance study, we measured the longitudinal emittance with BSMs. The results will be contributed to the design of the beam operational parameters for the energy upgraded Linac.

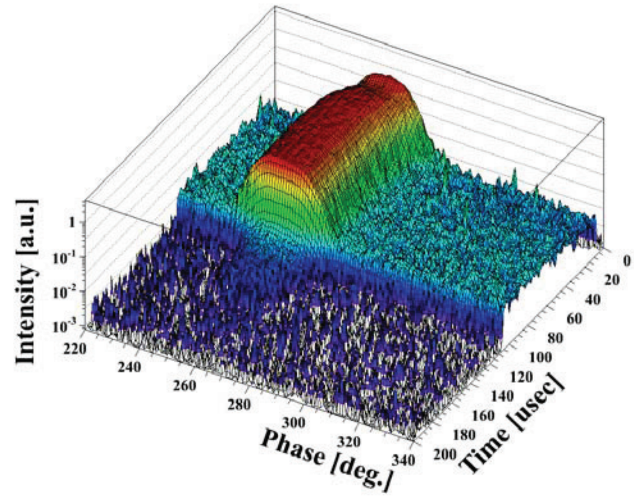

Figure 6: Data acquisition of BSM#1. These will be employed for the beam dynamics study and design for the energy upgraded Linac.

SUMMARY

Three Bunch Shape Monitors (BSMs) have been developed and fabricated for J-PARC Linac at the Institute for Nuclear Research of the Russian Academy of Sciences. The BSMs have been assembled, installed in beam line. The BSMs have been commissioned with the beam and their operability has been demonstrated. The main BSM parameter-phase resolution was evaluated. Along with the measurement with BSM, several problems had been met. The first problem is the influence of quads magnetic fields on secondary electron trajectories. The problem has been overcome by installing magnetic shields. The influence of the shields on quads field was also estimated. The second problem is the influence of target HV potential on vacuum due to dark current resulting in absorbed gas molecules desorption in BSM#3. This effect was completely removed by the conditioning.

In the beam commissioning, BSMs were checked with the consistency and started to be used for the beam dynamics study.

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