TUNING STRATEGY FOR TRANSVERSE COLLIMATOR IN J-PARC L3BT

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Abstract

A transverse collimation system is installed in a beam transport line between J-PARC linac and the succeeding 3-GeV synchrotron. Planned tuning strategies for the transverse collimator are presented together with the relevant beam monitor layout. Maintenancibility and continuous monitoring of the tuning are also discussed.

INTRODUCTION

We will start beam commissioning of J-PARC linac [1] and the succeeding beam transport line in December 2006 with the reduced beam energy of 181 MeV. The beam transport line, to which we refer as L3BT, has two key functions to satisfy the requirements for the RCS (Rapid Cycling Synchrotron) injection [2, 3]. One is to reduce the momentum jitter and momentum spread, and the other is to eliminate a transverse tail or halo. To realize the latter function, we have a transverse collimation system in L3BT. The normalized transverse emittance should be kept below 4π mm·mrad for the effective painting injection for the RCS.

In this paper, we focus on the tuning strategy for the transverse collimation system and the relevant beam diagnostics. Hardware details and simulation results for the collimator system will appear somewhere else (refer to [3] for some preliminary simulation results).

TRANSVERSE COLLIMATOR

As shown in Fig. 1, the transverse collimation system in L3BT are located after a 90-deg achromatic arc section. The collimation system consists of four horizontal and four vertical collimators which are placed with a fixed interval in the collimator section. The collimator section has eight quadrupole magnets, which constitutes four FODO cells with the period length of 8 m. The zero-current phase advance per cell is set to 45 deg, and each collimator is placed just after each quadruple magnet. (A horizontal collimator is placed after a focusing quadrupole magnet.) In the transverse collimator, the tail portion of the beam is charge-exchanged from a negative hydrogen ion to a proton, and transported to a dedicated dump named 100-deg dump about 40 m downstream from the end of the collimator section. To enable the simultaneous transport of negative hydrogen ions and protons with tolerable beam losses, a large aperture radius of 60 mm is secured for this section. Each collimator has two collimator jaws, or blades, on both sides of the beam which are independently movable with stepping motors. For the collimator blade, we have adopted a thin carbon plate with the thickness of 0.2 mm. This concept was originally proposed by K. Hasegawa [4], and developed by M. Matsuoka and K. Yamamoto [5].

A collimator is accommodated with a WS (Wire Scanner) and a BPM (Beam Position Monitor) in its vicinity for its tuning as shown in Fig. 2. The roles of the monitors are described in detail in the following sections. Figure 3 shows a typical beam profile simulated at the collimator location, where typical collimator edge locations are shown with vertical lines. If the gap width is deviated from the design value, the final emittance and the removed beam current will be deviated. If the gap center is deviated from the beam centroid, the beam centroid after the collimation will be deviated from the center of the beam ellipse and the eliminated beam current will be increased. In principle, the beam centroid deviation from the ellipse center causes effective emittance growth. After an optimization consideration, we have decided to keep both of the excess elimination current and the effective emittance growth below 10 %. To meet these goals, the gap width deviation should be

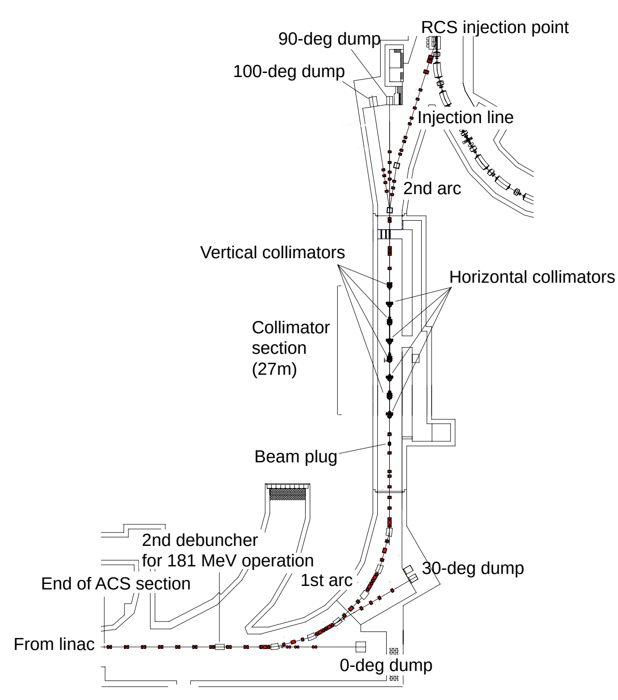

Figure 1: L3BT layout.

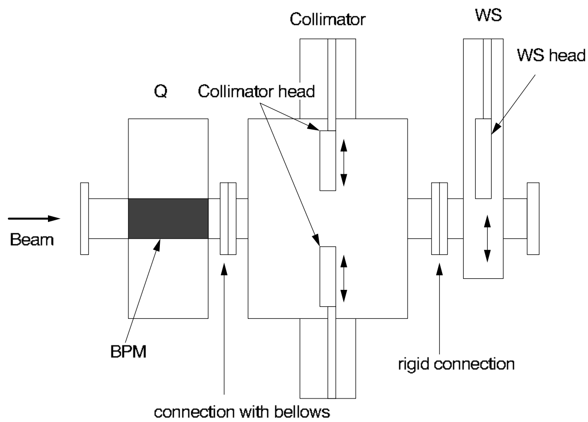

Figure 2: Monitor layout around a collimator.

less than 0.1 mm, and the gap center shift with respective to the beam centroid should be less than 0.3 mm.

BEAM DUMPS

We have four beam dumps in L3BT as shown in Fig. 1. The capacity of the straight dump, or 0-deg dump, is rather small to secure the possibility for future extension of the linac. To compensate the small capacity of 0-deg dump, we have 30-deg dump which has the largest capacity of 5.4 kW. The roles of the remaining two dumps are closely related to the transverse collimation system. In a nominal operation where the transverse collimation system is utilized, the main beam (negative hydrogen ions) is injected into RCS, but the tail portion is charge-exchanged to protons by the collimators and led to 100-deg dump. In addition, some neutral hydrogen atoms generated by the collimation and collision with residual gases is dumped to 90-deg dump. The capacity for 100-deg and 90-deg dumps are 2 kW and 0.6 kW, respectively, which correspond to 5.8 % and 1.7 % of the nominal beam power in 181-MeV operation and 1.6 % and 0.48 % after the energy upgrade to 400 MeV.

It is a key requirement in the collimator tuning to keep the dumped beam powers under these limitations. Because the resolution for a conventional CT (Current Transformer) is supposed to be around 1 % (and it is not sensitive to neutral beams), we decided to measure the dumped beam current by monitoring the temperature rise of the beam windows for 100-deg and 90-deg dumps. We plan to calibrate the dumped beam power measurement with a conventional CT injecting a main beam into these dumps, in which weak beam current is simulated reducing the beam duty factor and increasing the chopping ratio. We expected that the beam power can easily be reduced to less than 0.3 % of the nominal one, securing an enough accuracy for CT measurements. The accuracy of the CT measurements are ensured by securing a certain peak current. The polarity of the first bending magnet in the second arc can be reversed to guide the main beam into 100-deg dump for this calibration.

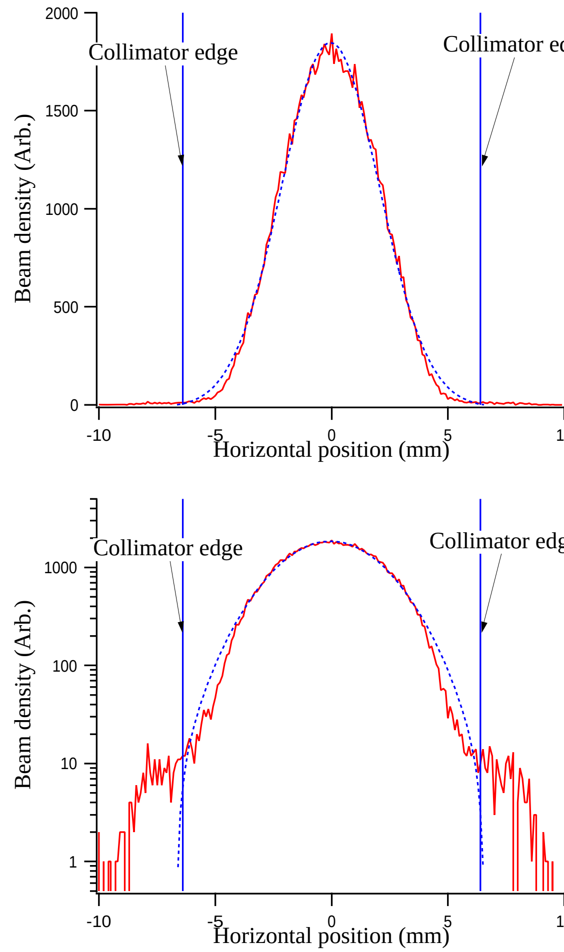

Figure 3: Typical beam profile at a collimator location (simulation). Top: linear, bottom: logarithmic. The dotted line shows the Gaussian fit.

BEAM LOSSES

Another key requirement in collimator tuning is to keep uncontrolled beam losses below the beam loss limit of 1 W/m in the collimator section to allow hands-on maintenance. The beam loss is monitored with 12 beam loss monitors of the gas-filled proportional counter type [6] which are attached to the wall of the collimator section and the 100-deg dump line. We plan to calibrate the loss monitors with dosimeters and the measurement of the residual radiation level. Particle simulations shows that only around 1 % of the charge-exchanged protons are failed to be led to the dedicated dump, and the resulting uncontolled loss level is below the tolerable limit with a reasonable margin [3]. The energy deposition at the collimator blades is estimated to be less than 2-3 W in total.

COLLIMATOR EDGE POSITIONING

In the collimator tuning, the gap between two collimator blades is gradually narrowed monitoring the dumped beam powers and the beam losses. The target gap width can easily be calculated supposing that the quadrupole strength error is small enough. The accuracy of the gap width is guaranteed by the offline calibration of the collimator. In the collimator edge positioning, we shift the gap center according to the orbit distortion. For this purpose, we have installed a WS (Wire Scanner) after each collimator as shown in Fig. 2. The relative position between the wire and collimator edge can be calibrated with an alignment telescope placed on the beam line. However, we should not assume this on-site measurement after the commencement of beam commissioning to mitigate human exposure to residual radiation. An alternative calibration scheme should be established to handle possible wire breakage and collimator failure. Then, we have planned the following three schemes for the relative position calibration and the relative position reproduction;

- Scheme-I: Both the collimator and WS are equipped with reference bases which are compatible with a laser tracker and a theodlite measurements. The relative position between the wire and the base is calibrated offline with a theodlite, and so is that between the collimator edge and the base. The assembling accuracy for the collimator and the WS is guaranteed by a laser tracker measurement.
- Scheme-II: The beam centroid position at the WS can be calculated from neighboring two BPM readouts. The offset between zero-points for BPM and WS is calibrated with the beam centroid measurement with the WS. The new wire position is calibrated with BPM outputs after WS replacement using a beam.
- Scheme-III: The relative position is calibrated with an alignment telescope at an offline test bench where the collimator and WS are assembled in the same way with that in the beam line. After the calibration, the collimator and WS are installed to the beam line together.

The overall accuracies for the calibration are estimated to be 0.3, 0.2, and 0.15 mm for Scheme-I, -II, and -III, respectively. These three schemes have their advantages and disadvantages, namely; Scheme-I is the most conservative, but its reproducibility is marginal to satisfy the requirement. Scheme-II is simple and attractive, but it can not be adopted for collimator replacement. It also depends on the resolution of BPM measurements, which might be poorer than expected due to the large aperture radius of 60 mm. Scheme-III is the robustest, but the most demanding at the same time. It is assumed in Scheme-III that the collimator is replaced with a spare module every time the neighboring wire is broken. Considering those pros and cons, we will choose the optimum calibration scheme after examining the actual operation situations, such as the frequency of wire breakage and the residual radiation level.

The WS's are utilized to perform precise transverse matching also [7], and we plan to use them to examine the beam profile in advance of inserting the collimator blades. It also should be noted that the collimator section is an optimum location to evaluate the emittance and Twiss parameters before injected into RCS. While an array of four WS's are installed in the injection line after the second arc, the phase advance in the array is much smaller and the section is not dispersion free.

CONTINUOUS MONITORING

Once the collimator tuning is established, the continuous monitoring of the tuning becomes important. The BPM installed in each quadrupole magnet just before a collimator is used to monitor the drift of transverse beam position at the collimator. If the position drift becomes notable, we will perform re-tuning of the collimator edge positions. In addition, the collimator has capability of detecting collimator blade current, which enable us to detect an anomalous increase or decrease of the collimated current. It might be useful to adjust the gap center to the beam centroid also by keeping the balance between signals from two opposite blades. The loss monitors and the dumped beam current monitors also provide us with indispensable information for the collimator tuning monitoring.

SUMMARY

Planned tuning strategies for the transverse collimation system in L3BT are described in detail. The position calibration between the wire and the collimator edge is a key to the accurate tuning. In the planning, maintenancibility has been considered for WS wire breakage and collimator failure. We have planned three calibration schemes for the wire position and the collimator edge location, from which an optimum scheme will be selected depending on the operation circumstances.

REFERENCES

[1] Y. Yamazaki ed., “Accelerator Technical Design Report for J-PARC”, KEK-Report 2002-13.

[2] T. Ohkawa et. al., “Beam Dynamics Design of the L3BT for J-PARC”, PAC'05, May 2005, Knoxville, p. 3091.

[3] T. Ohkawa et. al., “Present Status of L3BT for J-PARC”, EPAC'06, June 2006, Edinburgh, p. 1756.

[4] K. Hasegawa, unpublished.

[5] M. Matsuoka et. al., “Design of Beam Transport System between JKJ-Linac and 3-GeV Synchrotron” (in Japanese), The 27th Linear Accelerator Meeting in Japan, July 2002, Kyoto, p. 243.

[6] S. Lee et. al., “The Beam Loss Monitor System of the J-PARC Linac, 3 GeV RCS, and 50 GeV MR”, EPAC'04, July 2004, Lucerne, p. 2667.

[7] M. Ikegami et. al., “Transverse Tuning Scheme for J-PARC Linac”, PAC'05, May 2005, Knoxville, p. 2750.