COMPARISON OF TRAJECTORY BETWEEN MODELING AND EXPERIMENT FOR J-PARC LINAC

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Abstract

In the beam commissioning of J-PARC (Japan Proton Accelerator Research Complex) linac, three simulations codes are used to model the accelerator. We have compared the modeling with the experimental results obtained in the beam commissioning to date, where a basic agreement has been confirmed between the modeling and the actual beam behavior.

INTRODUCTION

The accelerators for J-PARC consist of a 181-MeV linac, a 3-GeV RCS (Rapid Cycle Synchrotron), and a 50-GeV MR (Main Ring) [1]. In the 181-MeV linac, the negative hydrogen ions accelerated with a 3-MeV RFQ (Radio Frequency Quadrupole linac), 50-MeV DTL (Drift Tube Linac), and 181-MeV SDTL (Separate-type DTL) are transported to the succeeding RCS with a beam transport line called L3BT (LINAC-to-3-GeV RCS Beam Transport) (See Fig. 1). The beam commissioning of J-PARC linac has been started since November 2006, and to be continued until the end of June 2007 [2].

In the beam commissioning of a high intensity accelerator, it is of essential importance to avoid a trial-and-error tuning, because even a temporal beam loss in a commissioning stage can cause a long-standing residual radiation which deteriorates the maintenancibility of the accelerator. Then, an accurate accelerator modeling is indispensable to realize a systematic beam commissioning where excess beam losses are eliminated as possible. From this point of view, we have performed a comparison between the modeling and the experimental results in the beam commissioning of J-PARC linac to evaluate the achieved accuracy in the modeling.
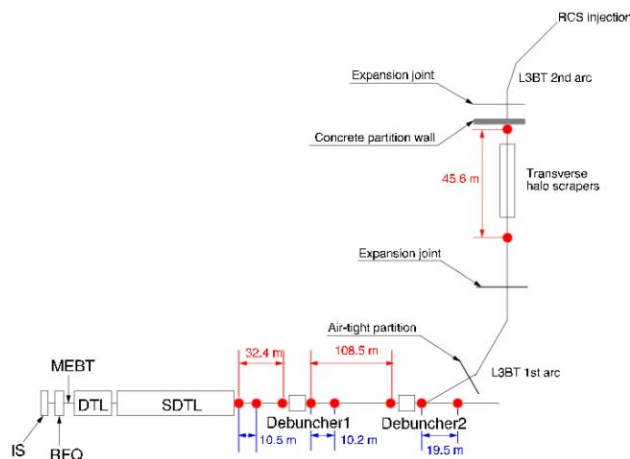

Figure 1: Schematic layout of J-PARC linac and L3BT

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In this paper, we briefly describe the modeling used in the beam commissioning, and we also present the results in the comparison between the modeling and the measurement performed in the beam commissioning to date.

As the beam commissioning so far is mainly performed with lower peak current of 5 mA (30 mA in design), we limit the discussion in this paper to the 5 mA operation

MODELING

In the beam commissioning of J-PARC linac, we use three different simulation codes for accelerator modeling to suit the required capacity, which includes TRACE3D [3], XAL online model [4], and PARMILA [5].

TRACE3D

TRACE3D is mainly used to find the initial configuration of quadrupole magnets and buncher cavities utilizing its "matching" capability. The base configuration of the quadrupole strength is generated to satisfy the equipartitioning condition [6]. However, we can not use the equipartitined setting as it is because the actual lattice is not ideally smooth, but we need to perform matching in advance at some transitions along the linac. Then, J-PARC linac has 10 matching points in the straight line, where the quadrupole strength is to be adjusted to smoothly connect the beam envelope. These 10 matching points are divided into two categories. For the matching points in the first category, a beam-based matching is assumed and proper beam diagnostics are prepared for the tuning. Meanwhile, no beam-based matching is assumed for those in the second category because the assumed adjustment is so subtle and it is difficult to accommodate sufficient beam diagnostics for beam-based matching. The first category includes five of the 10 matching points, which includes DTL1 (the first DTL tank) entrance, DTL3 exit, the SDTL entrance, and the exit of the future ACS section [7]. The remaining five matching points are grouped in the second category, which correspond to the end of each DTL tank and transitions of the DTQ (Drift Tube Quadrupole) thickness in the DTL section. All the matching points in the second category are in the DTL section, and the accumulated mismatch at these matching points is to be corrected at the exit of DTL3 with a beam-based matching.

The initial configuration of the quadrupole strength and buncher strength is determined from a TRACE3D calculation (or "pre-matching"), and beam-based matching is performed with this configuration as a starting point. The correctness of this "pre-matching" is important to realize effective tuning, where the beam-

based matching is converged with fewer iterations. Moreover, excess discrepancy of the pre-matching from the actual beam behavior may result in a sever beam quality deterioration in DTL section. To realize the accurate pre-matching, the initial Twiss parameters are determined from an experiment [8] and the quadrupole magnets are modeled with "PMQ" elements in the TRACE3D calculation. The "PMQ" element is used to model fringing field, while the actual DTQ's for the J-PARC DTL are electro-magnetic.

XAL online model

XAL online model has been used for the transverse matching and the orbit correction. The high-level application software for J-PARC linac commissioning is developed with JAVA or a JAVA-based SAD script interpreter called JCE (J-PARC Commissioning Environment) [9]. Both these frameworks have a capability to connect with XAL onlilne model. Then, XAL online model is predominantly used in cooperation with commissioning application software. The benchmark between XAL online model and TRACE3D has carefully been performed, and a good agreement in order of 0.1% has been confirmed [4].

PARMILA

PARMILA is mainly used to model phase-slip effects in a phase-scan tuning [10-12]. Each cell geometry of DTL and SDTL is designed to have the same synchronous phase for the design particle which has the design beam energy all along DTL and SDTL. If a beam has the energy higher or lower than its design, the arrival phase at each cell slips away from the design synchronous phase. In the phase-scan tuning, the beam energy is deviated from the design value, and the above phase-slip effects should be correctly modeled to analyze the experimental data. Although XAL online model also has a capability to handle phase-slip effects, we have been temporally using PARMILA because in-house benchmark on the phase-slip effects between PARMILA and XAL online model has not been completed yet.

COMPARISON BETWEEN MODELING AND EXPERIMENT

TRACE3D

TRACE3D is mainly used to determine the initial configuration for quadrupole magnets and buncher cavities as described in the above section. If the pre-matching in DTL is insufficient, halo development is supposed to be observed at DTL3 exit. To examine the beam halo development, the beam profile is measured with wire scanners located at upstream sections in SDTL [13]. Without any adjustment in MEBT, we have observed no clear halo developed at SDTL entrance with the peak current of 5 mA. In addition, the transverse mismatch at DTL3 exit is around 5 % without any transverse matching [14]. It suggests that the modeling

with TRACE3D describes the beam behavior with sufficient accuracy.

Another observation suggesting the accurate modeling is the successful beam transport of lower energy beams. During the RF tuning of the DTL and SDTL, we need to deliver the lower energy beam to a straight beam dump located about 300 m downstream. The lowest beam energy to be transported is 19.7 MeV. The beam transport of such a low energy beam has been successfully performed by scaling the downstream quadruple strength with the magnetic rigidity, and performing the pre-matching in DTL section with TRACE3D.

Meanwhile, the measured betatron wavelength shows a slight discrepancy from that obtained with TRACE3D calculation as shown in Fig. 2. In this figure, the beam centroid positions are measured with BPM's (Beam Position Monitors) with two different settings of steering magnets, and the difference of the BPM readouts is plotted as a function of the monitor location. The difference in the beatatron wavelength suggests a small residual error in the evaluation of effective quadrupole length or the conversion factor of the quadrupole excitation current to its field gradient. This scheme of benchmark is adopted in SNS also to avoid the influence of the BPM offset.
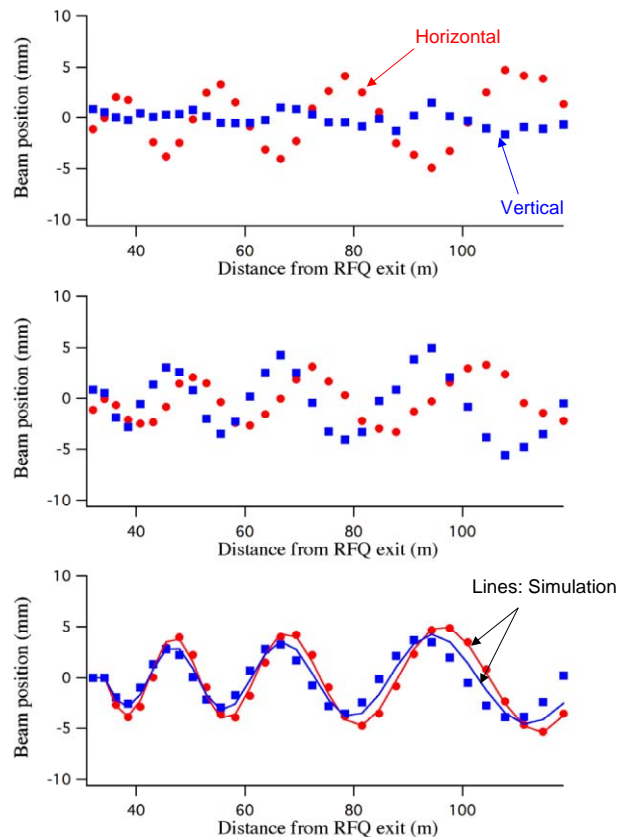

Figure 2:Beam centroid positions in the SDTL section

XAL online model

XAL online model is mainly used in the beam-based transverse matching and the orbit correction. In both transverse matching and the orbit correction, the response

matrices are obtained from the modeling, and then the optimum setting is determined from the response matrices. This procedure usually needs some iterations due to a nonlinear response or a measurement error. The tunings are converged with only a few iterations in the beam commissioning [14], which shows a reasonable agreement between the model and the actual beam behavior. However, the tuning becomes ineffective if you use a tuning knob far upstream from the targeted beam monitor. This behavior is supposed to be related to the discrepancy in the betatron wavelength observed in Fig. 2.

PARMILA

PARMILA is used to evaluate the phase-dependence of the output beam energy during the phase-scan tuning of DTL and SDTL. In the phase-scan tuning, the phase-scan curves (which shows the phase-dependence of the output beam energy) are obtained by scanning the RF phase monitoring the output beam energy. Then, the RF set-points are determined by comparing the phase-scan curves obtained with the measurement and the modeling. Figure 3 shows the comparison of the phase-scan curves, where we can see an excellent agreement between them [12]. It illustrates that the phase-slip effects are modeled in PARMILA simulations with a sufficient accuracy.

In the meantime, the phase-scan curve tends to deviate from modeling with lower tank level for DTL1 and DTL2 [11]. The reason for this discrepancy is open for further studies.
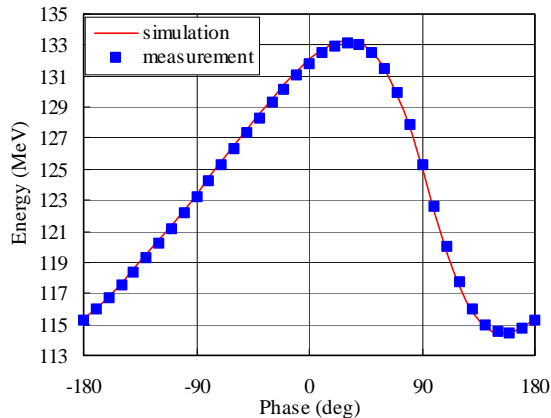

Figure 3: Comparison of the phase-scan curves obtained with the measurement and the modeling at the SDTL10.

SUMMARY

It is crucial to establish an accurate modeling so that we can avoid a trial-and-error approach in the beam commissioning. We use TRACE3D, XAL online model, and PARMILA for the beam commissioning of J-PARC linac. Then, we have compared the modeling with the experimental results obtained in the beam commissioning so far. While all three simulation codes show basic agreements with the experimental results, we need further studies on the discrepancy in the betatron wavelength and the phase-scan curves for lower tank levels.

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