EFFECT OF LARGE DTQ ALIGNMENT ERROR FOR J-PARC LINAC

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Abstract

In J-PARC linac, we are making efforts towards recovering beam operation after the Tohoku Earthquake in Japan on March 11, 2011. One of our primary concerns in the efforts is a possible large misalignment for DTQ's (Drift Tube Quadrupole magnets) in drift tube linacs that could be caused by the earthquake. In this paper, we have performed a simulation study on the effect of possible large alignment error for DTQ's. We also discuss on the reasonable limit for the tolerable alignment error in this peculiar situation.

INTRODUCTION

J-PARC (Japan Proton Accelerator Research Complex) [1] locates in Ibaraki Prefecture in Japan, which is about 270 km far from the epicenter of the Tohoku Earthquake (or the 2011 off the Pacific coast of Tohoku Earthquake) on March 11, 2011. At the earthquake, we experienced a severe tremor with an intensity of "6 lower" on the ten-stage JMA (Japan Meteorological Agency) Seismic Intensity Scale [2]. The accompanying ground movement resulted in a significant deformation of the linac tunnel which will be discussed in another literature [3].

J-PARC linac has three DTL (Drift Tube Linac) tanks and 32 SDTL (Separate-type DTL) tanks. All of these tanks have drift tubes inside, each of which is supported with a vertical stem fixed at the ceiling of the tank. The drift tubes for DTL have embedded quadrupole magnets called DTQ's (Dfirt Tube Quadrupoles), whereas no DTQ is in the drift tubes for SDTL. The SDTL has external quadrupole magnets at inter-tank spacings, with which the transverse focusing is provided. Drift tubes in both DTL and SDTL are assumed to be structurally susceptible to vibration to some extent, and we anticipate some misalignment of drift tubes caused by the earthquake. In particular, misalignment of a drift tube in DTL is expected to have more significant effects on the beam quality because of its embedded DTQ.

As it would take months to disassemble the tank and re-alignment the DTQ's for one DTL tank, it has a definitive effect on the recovery schedule if we assume it. As the other facilities in J-PARC are expected to recover by the end of 2011, it could restrict the timing of resumption for the beam operation. Meanwhile, we have not found critical misalignment of drift tubes in the initial survey utilizing an alignment microscope. Considering these situations, we decided not to assume re-alignment of DTQ's in the recovery schedule unless we find a critical misalignment of drift tubes hereafter.

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We have been trying to measure the alignment of DTQ more accurately [4]. However, the accuracy of the measurement is expected to be limited, because we assume to measure it without disassembling the tank. The limited accuracy has motivated us to be prepared for larger DTQ misalignment than actually measured to date. In parallel with the alignment measurement, we should study the effect of alignment errors which are larger than those usually assumed in a linac design. It is especially important in this peculiar situation so as to evaluate the risks and to prepare cures for them. In this paper, we perform a 3D Particle-In-Cell simulation for J-PARC DTL to study the effect of larger alignment error of DTQ's. We adopt the IMPACT code [5] for the particle simulation. In this paper, we focus on the effect of misalignment for the DTQ's in DTL, because we expect usual realignment of quadrupole magnets in SDTL and downstream sections.

DESIGN PARAMETERS OF J-PARC DTL

Before discussing on the simulation, we here present the relevant design parameters of J-PARC DTL. J-PARC DTL operates with 324 MHz, and consists of three tanks. The main parameters for each tank is summarized in Table. 1. In this table, the average accelerating field and synchronous phase are denoted as E_0 and ϕ_s, respectively. To be noted here is that DTL1 has the aperture radius of 6.5 mm in the upstream side, and it is enlarged to 9 mm at the end of 57th cell. This narrow section in the upstream portion of DTL1 has a significant effect on the transmission efficiency as discussed later.

All the drift tubes for DTL are embedded with an electromagnetic quadrupole magnets. The transverse focusing is provided with FODO lattice with the period length of $2\beta\lambda$. Here, β and λ denote the particle velocity scaled by the speed of light and the RF wave length respectively. The inter-tank spacing is $1\beta\lambda$ without any optical element. We have current transformers to monitor the beam current and beam phase at the inter-tank spacings but no beam position monitor. We have no steering magnet in the DTL section including the inter-tank spacings.

DTL1 and upstream RFQ (Radio Frequency Quadrupole linac) is connected with a 3-m long beam matching section called MEBT (Medium Energy Beam Transport). MEBT has eight quadrupole magnets and two buncher cavities. Each quadrupole magnet in MEBT has additional wiring to excite dipole field for beam orbit correction. Then, the transverse beam position and angle at the DTL1 entrance can be adjusted with these steerings.

After the DTL3 exit, we have steering magnets and various beam diagnostics including beam current monitors,

Table 1: Main parameters for DTL tanks.

	DTL1	DTL2	DTL3
Injection energy (MeV)	3.0	19.7	36.7
Extraction energy (MeV)	19.7	36.7	50.1
E_0 (MV/m)	2.5	2.5	2.5
ϕ_s (deg)	-30	-26	-26
Number of cells	76	43	27
Length (m)	9.9	9.4	7.3
Bore radius (mm)	6.5, 9	11	13

beam position monitors, and transverse beam profile monitors. Then, the beam tuning is assumed to be performed with the information from the limited beam monitors in the DTL section and that from the monitors in the upstream MEBT and downstream SDTL section.

SIMULATION CONDITIONS

We have only performed the simulation from the RFQ exit to the DTL3 exit in this paper. Assumed peak current is the final design value of 50 mA, and the initial distribution is provided with PARMTEQM. The initial horizontal, vertical, and longitudinal normalized rms emittance are 0.205 πmm·mrad, 0.206 πmm·mrad, and 0.115 πMeV·deg, respectively. The number of mesh points is $32 \times 32 \times 64$, and 94,720 simulation particles are employed. The integration step width is about $0.01\beta\lambda$, and the Lorentz integrator is used. We assume alignment errors for DTQ's generated with a uniform random number generator. No other error is assumed.

In the simulation, we have assumed three different degrees of DTQ alignment errors, namely, ± 0.1 mm, ± 0.2 mm, and ± 0.3 mm. Then, we have performed 30 runs with different random seeds for each case. Each case has a different set of random seeds. Namely, the random seed for the run no. 1 for the ± 0.1 mm case is different from that for the run no. 1 for the ± 0.2 mm case.

To model the alignment error, we have employed a thin kick element inserted at the middle of each DTQ instead of using the standard function of a DTL element. Similarly, we model the aperture with a thin circular aperture element inserted at the middle of each DTQ. The center of the aperture is shifted according to the DTQ alignment error.

It should be noted that we assume the DTQ alignment error of ± 0.1 mm in the design.

SIMULATION RESULTS

Figure 1 shows the simulated emittance at the exit of DTL3. Only 28 data are shown for the ± 0.3 mm case, because we have had complete beam loss in two runs. As seen in this figure, a larger DTQ misalignment does not result in a larger emittance at the DTL3 exit. Instead, it causes a significant reduction in the transmission efficiency as seen in Fig. 2. Therefore, our primary concern should be the transmission efficiency through DTL rather than the emittance growth.

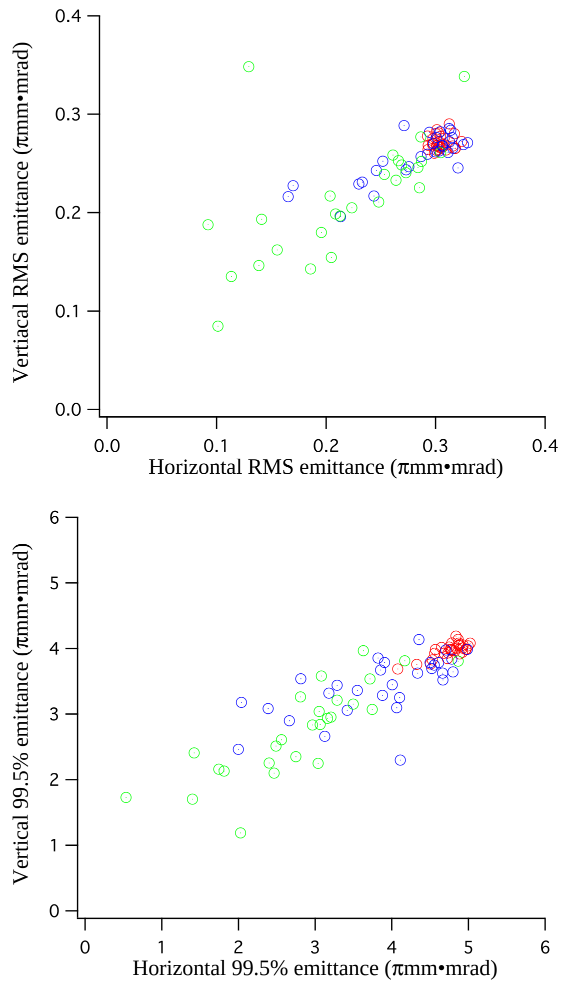

Figure 1: The simulated horizontal and vertical emittance at the DTL3 exit. Red, blue, and green circles, respectively, denote the results with the DTQ alignment error of ± 0.1 mm, ± 0.2 mm, and ± 0.3 mm.

In Fig. 2, both of the transmission efficiency through the entire DTL section and that through the narrow section at the upstream portion of DTL1 are shown. The overall similarity of these two plots indicates that the most beam loss occurs in the narrow section in DTL1. Closer look reveals that we also have some beam loss after the narrow section in some cases with larger DTQ misalignment. It means that the particles survived at the narrow section usually reach the DTL3 exit. While the orbit distortion may grow along the DTL, the increase of the aperture usually exceeds the increase of the orbit distortion. However, in some cases with larger misalignment, the increase of the orbit distortion catches up the increase of aperture and causes some beam loss in the downstream portion of DTL.

The transmission efficiency shown in Fig. 2 are for the case without beam steering. However, we would try to maximize the transmission efficiency by adjusting the

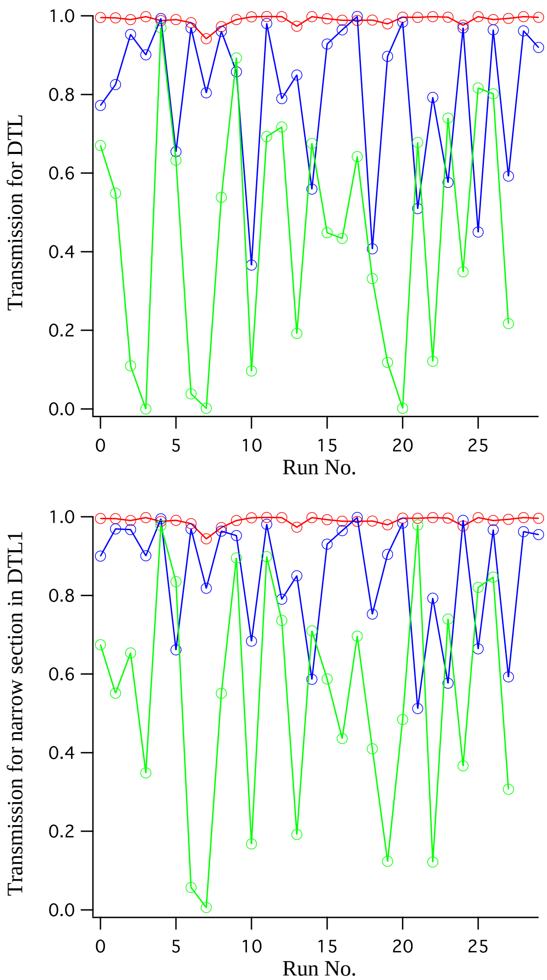

Figure 2: The simulated transmission efficiency. Red, blue, and green circles, respectively, denote the results with the DTQ alignment error of ± 0.1 mm, ± 0.2 mm, and ± 0.3 mm.

beam steering in MEBT in an actual operation. This orbit tuning is modeled by combining IMPACT simulation with an optimization routine utilizing a downhill simplex method [6]. We pick up some cases with lower transmission efficiencies in the ± 0.2 mm case, and try to increase the transmission efficiency by adjusting the last two steerings in MEBT using the above-mentioned model. The optimization is performed to maximize the transmission through the entire DTL. The obtained result is shown in Fig. 3. As seen in this figure, the transmission efficiency is increased in all cases to above around 0.85 which may not be satisfactory but may be in a tolerable range. However, we need to have a beam steering of as large as XX mrad in some cases, which is significantly larger than the present specification of 8 mrad. We are presently considering to increase the steering capacity, and we suppose that the DTQ alignment error of around ± 0.2 mm would be the reasonable limit we can handle in an actual operation.

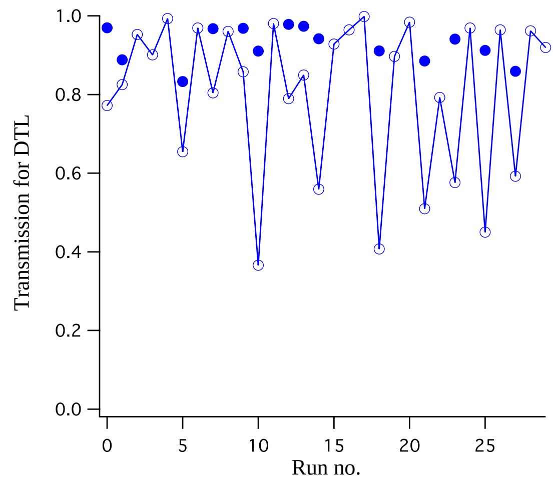

Figure 3: The simulated transmission efficiency for the DTQ alignment error of ± 0.2 mm. Open circles: without beam steering, and filled circles: with steering.

SUMMARY & DISCUSSIONS

A simulation study has been performed on the effect of DTQ alignment error for J-PARC DTL, in which larger misalignment than usual has been assumed for the peculiar situation after the Tohoku earthquake. The simulation has shown that a large DTQ alignment error could result in a significant reduction in the transmission efficiency rather than an increase in the emittance. According to the simulation, it may be marginal whether we can tolerate the DTQ alignment error of ± 0.2 mm. We need to increase the capacity of MEBT steerings to accommodate the ± 0.2 mm error. While the result has not been shown in this paper, measured alignment error to date has not resulted in a significant reduction in the transmission efficiency in the simulation. However, it may be reasonable for us to prepare for the error of ± 0.2 mm level, considering the expected accuracy for the DTQ alignment measurement without disassembling the tank.

REFERENCES

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[2] The intensity of “6 lower” ranks third in the scale after 7 and “6 upper”, with which it is difficult to remain standing and many unsecured furniture moves and may topple over. For more detailed information on this seismic intensity scale, refer to http://www.jma.go.jp/jma/en/Activities/inttable.html.

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