ERROR STUDIES FOR J-PARC LINAC UPGRADE TO 50MA/400MEV

Y. Liu, M. Ikegami, KEK/J-PARC, Tokai, Japan

Abstract

The J-PARC linac is to be upgraded from present 181 MeV to 400 MeV and the peak current to 50mA. This paper presents results of machine errors studies performed with 3D simulation code IMPACT. It is intended to validate the design, to predict possible beam situations at the RCS injection point and to be helpful for the coming commissioning.

INTRODUCTION

The Japan Proton Accelerator Research Complex (J-PARC) is a high-intensity proton accelerator facility that aims at 1 MW beam power [1][2]. The J-PARC accelerator consists of a linac, a 3GeV synchrotron (rapid cycling synchrotron, RCS), and a main ring synchrotron (MR).

The J-PARC linac consists of a 3MeV RFQ, 50MeV DTL (Drift Tube Linac) and 181/190 MeV SDTL (Separate-type DTL). The J-PARC linac is currently operating with output energy of 181 MeV and designed peak current of 30 mA (nominally operated at 15mA). The 50mA/400MeV linac power upgrade program is now in progress. The power upgrade includes a new ion source and a third RFQ designed for 50mA, and a 190-400 MeV annular-ring coupled structure (ACS) linac. The ACS tanks are to be installed during the shutdown in 2013.

In the design phase, error studies are necessary to verify the lattice design and help to define the machine tolerances. For the commissioning, it is helpful to foresee the worst cases to evaluate the risk, and to foresee the range of beam parameters.

Simulations were made using the 3D particle-in-cell code IMPACT [3], starting with the new J-PARC RFQIII output with 95322 particles.

Quadrupole transverse alignment error, RF amplitude and RF phase error were included in the simulation study, which are the most effective ones. The quadrupole alignment error mainly causes the beam orbit distortion, which will be locally corrected in the operation. The RF errors will cause the beam phase and energy error, and mismatch. All the errors combine and cause emittance growth and beam loss.

The orbit distortion is not corrected in the simulation studies. The beam phase and energy error were compensated by the debuncher system with fixed setting in the simulation.

SIMULATIONS OF BASELINE DESIGN WITH NO ERROR

Equi-partitioning (EP)[4] setting is both applied for the present 181MeV operation and for the baseline design of the coming upgrade to 50mA/400MeV.

There is a 3-fold frequency transition between 324 MHz SDTL and 927 MHz ACS section. The longitudinal focusing in the ACS part increases proportionally to the jumped frequency, with acceleration gradient and synchronous phase equivalent to the SDTL part.

EP condition is namely the equal oscillation energies in all planes. Given the ratio of oscillation energies between x (horizontal) and z (longitudinal),

$$\frac{T_x}{T_z} = \frac{r_x^2 k_x^2}{r_z^2 k_z^2} = \frac{\epsilon_x k_x}{\epsilon_z k_z},$$

where r stands for the beam rms envelop, ε the rms emittance, focusing is represented by the wave number k, EP condition for x and z planes is,

$$\frac{T_x}{T_z} = 1\,.$$

It is clear that in order to keep the EP condition the transverse focusing should increase with the increased longitudinal focusing with frequency jump assuming the emittance unchanged. It can be also deduced that the transverse envelope will shrink. The simulated envelope and rms emittance for the baseline design of the J-PARC linac are shown in Fig. 1 and 2.

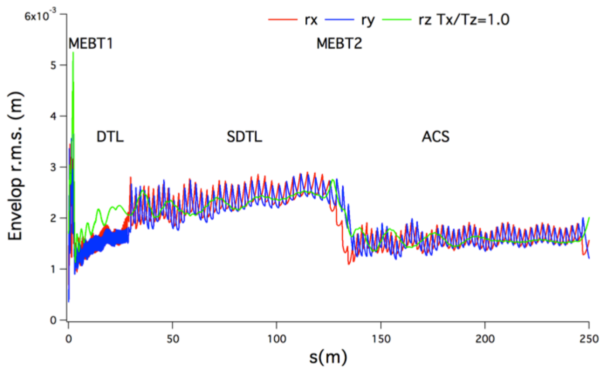

Figure 1: Simulated rms envelope for the baseline design of the J-PARC linac .

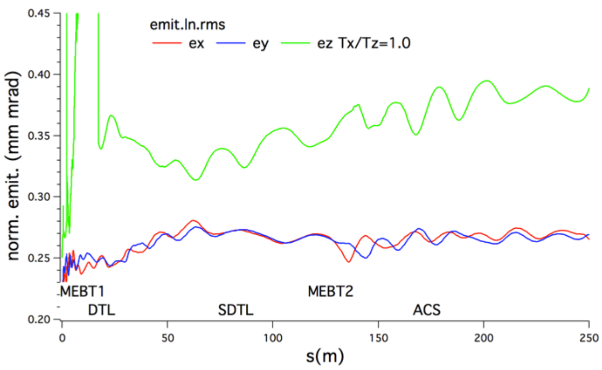

Figure 2: Simulated rms emittance for the baseline design of the J-PARC linac .

It is found that in the previous simulation studies [5] the ACS setting with EP setting is more stable than the non-EP ones. On the other hand, the sharply shrunk transverse envelopes increase the interactions in the beam, and require a more complicated medium energy beam transport line, MEBT2.

For the transition from the SDTL to the ACS, the MEBT2, which consists of 6 doublets and 2 bunchers, is used for the transverse and longitudinal matching of the transition.

STATISTICAL RESULTS WITH SIMULATIONS WITH ERROR

Error study is done giving ~100 uniform random seeds for quadrupole transverse alignment error of ±0.1mm, RF amplitude error of ±1% and RF phase error of ±1 degree, with no tank-to-tank field/phase error.

Transverse emittance

Transverse emittance at the RCS injection is one of key parameters for such a high-power linac-injector. Considering the collimation before the injection, the 99.5% normalized transverse emittance before the RCS septum is used to describe the output emittance of the J-PARC linac.

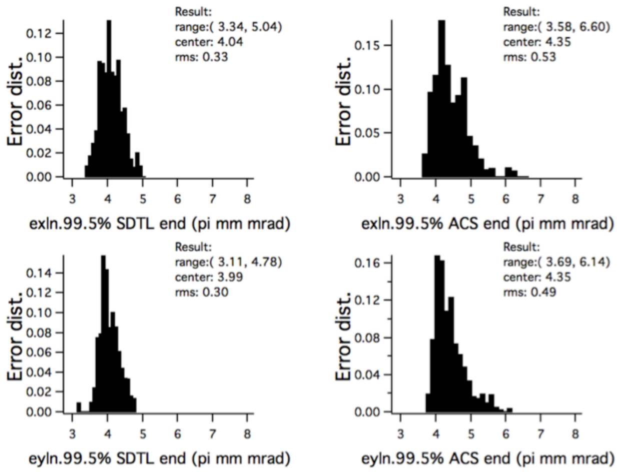

Figure 3: Statistical results of simulated transverse emittance at entry and exit of new ACS part with errors for the baseline design of the J-PARC linac upgrade.

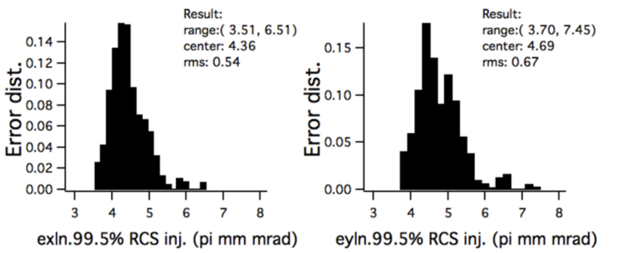

Figure 4: Statistical results of simulated output transverse emittance with errors for the baseline design of the J-PARC linac upgrade.

The simulated 99.5% transverse emittance statistics at the ACS entry/exit are shown in Fig. 3. About 10% emittance growth in the ACS part was found from the statistical results. Fig. 4 and 5 shows the final output emittance.

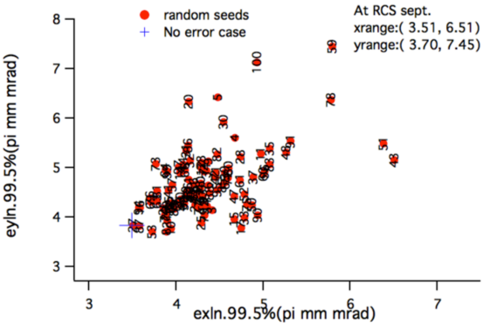

Figure 5: Simulated output transverse emittance with errors for the baseline design of the J-PARC linac.

Longitudinal output

2-Debuncher system [6] is designed to minimize the output momentum spread and energy jitter in J-PARC linac. The first debuncher, which is 15.5m downstream of ACS, is set to compensate most of the energy jitter and suppress the longitudinal emittance growth due to long drifting. The second debuncher is to minimize the momentum spread at the injection. The longitudinal output momentum spread, emittance and jitters are shown in Fig.6 and 7.

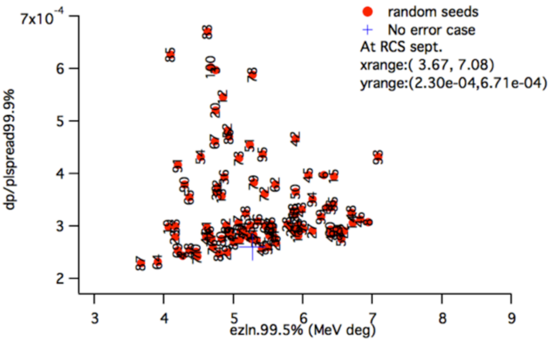

Figure 6: Simulated output longitudianl emittance with errors for the baseline design of the J-PARC linac.

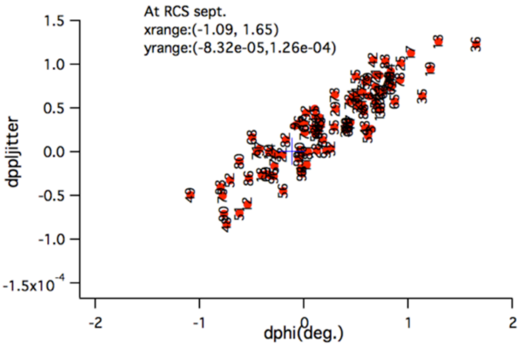

Figure 7: Simulated energy and phase jitter of output beam with errors for the baseline design of the J-PARC linac, with the 2-debuncher system.

Beam loss

In the simulation for all random error seeds, the most of the beam loss happened before end of DTL. Beam loss at SDTL is less than 5.0×10^{-4}. No beam loss is found in the downstream of SDTL.

Orbit distortion

The beam orbit distortion could accumulate to a big value due to large number of quadrupoles and the long distance. Practically the orbit distortion should be locally corrected in the operation. It is not corrected in the main calculation because it is better to take a worse situation. If the orbit distortion corrected is included, it is found that the output emittance does not change significantly. The main effect is some mitigation of beam loss mainly at the low-energy DTL part. Fig. 8 shows the beam orbit distortion in the range from MEBT1 to end of ACS.

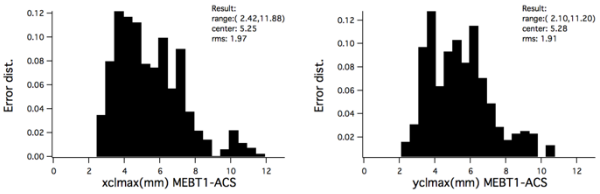

Figure 8: Simulated beam maximum orbit distortion, without correction, from MEBT1 to end of ACS.

Twiss at MEBT2

It is helpful to foresee the range of the initial mismatch at the ACS entry considering the errors. As mentioned in the previous section, the MEBT2 should perfectly match in the presence of frequency jump and envelop shrink. Fig. 9 shows the mismatch factor vs. all simulated errors at the MEBT2, assuming the no error case as the perfect matching. The mismatch factor defined by [7] is,

$$M = \sqrt{1 + \frac{\Delta + \sqrt{\Delta(\Delta + 4)}}{2}} - 1$$

where Δ depends on the differences of the Twiss parameters

$$\Delta = -\left\| \begin{bmatrix} \Delta\beta & -\Delta\alpha \\ -\Delta\alpha & \Delta\gamma \end{bmatrix} \right\|$$

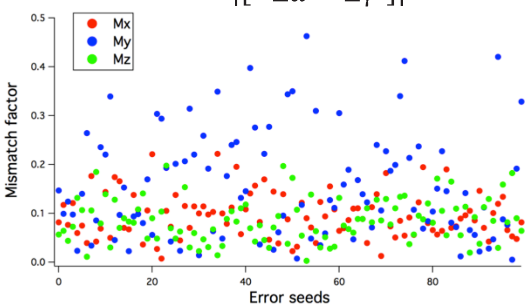

Figure 9: Simulated mismatch factor vs. errors at MEBT2.

It is clearly shown that with the assumed errors, the Twiss parameters at ACS entry have considerable deviations. Based on the experience of J-PARC linac commissioning, it will be possible to reduce the mismatch factor from the simulated initial values of ~0.5 to <0.1, with the matching procedures at MEBT2.

THE WORST CASES

If the statistic is sufficient, the bad error seeds, which have biggest output emittance, beam loss and so on could be found, like the error #59, 43, 100, 78 and 51, for example, in Fig. 5. They lie at the "unlucky" tails faraway from most of the error seeds. It might be important to check the stability of these edged cases, for instance if there is current fluctuation. Fig. 10 shows the stability for the worst seed (#59), of the emittance with current. 5% growth of the 99.5% transverse output emittance is found in case of current fluctuation of ±2mA of 50mA.

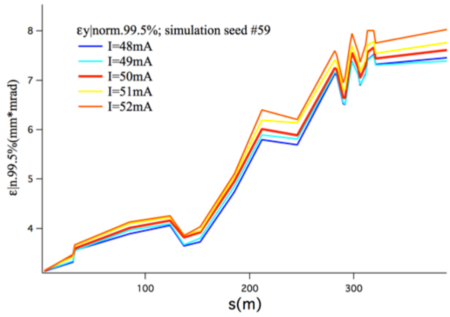

Figure 10: Simulated horizontal 99.5% emittance for error seed #59.

CONCLUSION AND DISCUSSIONS

Error studies with IMAPCT simulation were done for the baseline design of the J-PARC linac 50mA/400MeV upgrade. Statistical results of emittance, beam loss, orbit distortion, range of Twiss parameters at MEBT2 and properties of the worst cases were studied. The results confirmed that for the baseline design of J-PARC linac upgrade the beam loss at the high energy is minimized and output transverse 99.5% normalized emittance is controlled within 8 π mm*mrad. The matching condition at MEBT2 is also predicted. And stability of emittance with current fluctuation is also checked.

REFERENCES

[1] M. Ikegami, "Recent Progress in Beam Commissioning of J-Parc Linac", proceedings of IPAC2013.
[2] H. Oguri, "Power upgrade of J-PARC linac", proceedings of IPAC2013.
[3] J. Qiang, R. Ryne, S. Habib, and V. Decyk, J. Comput.Phys. 163, 434 (2000).
[4] I. Hofmann et al., Phys. Rev. ST Accel. Beams 6, 024202 (2003).
[5] Y. Liu and M. Ikegami, "Lattice and error studies for J-PARC linac upgrade to 50mA/400MeV", proceedings of IPAC2013.
[6] G. Wei and M. Ikegami, "Simulation Study Of Debuncher System For J-Parc Linac Energy Upgrade", proceedings of LINAC2010.
[7] T. P. Wangler, "RF Linear Accelerators", p223, Wiley-VCH; 2nd.