A SIMULATION STUDY ON CHOPPER TRANSIENT EFFECTS IN J-PARC LINAC

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Abstract

J-PARC linac has a chopper system to reduce uncontrolled beam loss in the succeeding ring. The chopper system is located in MEBT (Medium Energy Beam Transport line) between a 3-MeV RFQ and a 50-MeV DTL, and consists of two RFD (Radio-Frequency Deflection) cavities and a beam collector. During the rising- and falling-times of the RFD cavities, the beams are half-kicked and cause excess beam loss downstream. In this paper, the behavior of these half-kicked beams is examined with 3D PARMILA simulations, and resulting beam loss and beam quality deterioration are estimated.

INTRODUCTION

J-PARC linac [1, 2] has a chopper system to reduce uncontrolled beam loss in the succeeding RCS (Rapid Cycling Synchrotron). While we are preparing two-stage chopping system utilizing both LEBT and MEBT choppers [2], we are considering to start beam commissioning only with MEBT chopper, taking account of the following circumstances, namely; we decided to start beam commissioning with lower peak current of 30 mA [1], which eases the heat load problem of the chopper target (collector), and we have experimentally confirmed that surviving ratio in the chopper-on period is less than 10^{-4} only with MEBT chopper [3]. While the experimental data is for the case with 5 mA, it encourages us to seek the possibility of "one-stage chopping" in which the combined transient effects of LEBT and MEBT choppers are avoided. In this paper, we focus on the transient effects in one-stage chopping where only MEBT chopper is used.

The chopper system is located in MEBT between a 3-MeV RFQ and a 50-MeV DTL, and consists of two 324-MHz RFD (Radio-Frequency Deflection) cavities and a beam collector [2, 4]. With this RF chopper system, an intermediate-pulse (or pulse-train) structure is generated as schematically shown in Fig. 1. In the intermediate-pulse structure, the beam-on period continues for ~ 500 nsec followed by the beam-off (chopper-on) period of ~ 500 nsec. The repetition of the intermediate-pulse structure is synchronized with the frequency of the RCS RF system. The intermediate-pulse width will be optimized to have the maximum beam power within the tolerable beam loss limit in RCS. In the beam-off period, beams are horizontally deflected by the RFD cavities and collected by the collector. During the rising- and falling-times of the RFD cavities, the beams are half-kicked and can cause excess beam loss downstream.

Survived half-kicked beams can also cause a beam loss problem in RCS, exceeding the transverse dynamic aperture limit. We have a requirement for the transverse emittance at the injection to RCS to enable effective painting, namely; the normalized transverse emittance should be less than 4πmm·mrad. To achieve the requirement for the transverse emittance, we have transverse halo collimators in the beam transport line between linac and RCS [2]. The collimator edge position is supposed to be set to satisfy the requirement for the transverse emittance, and it is practically important to estimate the collimator load, i.e., the fraction of a beam that must be eliminated with the halo collimators. One of our aims in this simulation study is to estimate the increase of the collimator load during chopper transient.

In this paper, the behavior of these half-kicked beams is examined with 3D PARMILA[5] simulations, and resulting excess beam loss and halo-collimator load are estimated.

SIMULATION CONDITIONS

As discussed in a separate paper [1], we plan to start beam operation with the lower linac energy of 181-MeV. In this paper, simulations are performed with PARMILA from the exit of RFQ to the injection point to RCS for the 181-MeV case. In the simulations, we assume the peak current of 30 mA, which is the design value for 181-MeV operation. The initial distribution at the exit of RFQ is obtained with PARMTEQM [6]. The number of simulation particles is 95,322 and the number of meshes is set to 20x20x40.

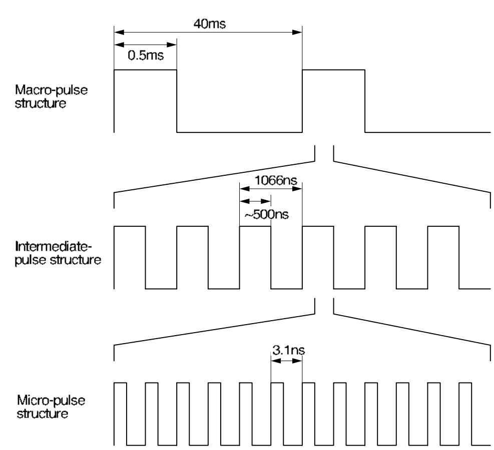

Figure 1: Pulse structure for J-PARC linac (181-MeV injection).

The quadruple magnets in DTL and SDTL sections are set to satisfy the equipartition condition. No halo collimation has been assumed.

In this paper, the RFD cavities are modeled as thin elements which provide transverse kick, and the collector as a rectangular aperture. The collector edge position is set to 12 mm from the beam axis.

In this paper, we consider the following four cases:

- Case-I: No error is assumed.
- Case-II: Run#18 of the reference [7].
- Case-III: Run#9 of the reference [7].
- Case-IV: Run#17 of the reference [7].

In the reference [7],we tried 20 cases with realistic errors. Case-II is a typical case in those 20 cases. Case-III corresponds to the case with the largest horizontal emittance growth. Case-IV corresponds to the case with the largest beam loss in DTL. In Case-IV, a simple beam orbit collection is assumed at the exit of MEBT to minimize beam loss, but it still has the beam loss of about 2 % mostly localized in DTL1.

SIMULATION RESULTS

Figure 2 shows the dependence of the transmission ratio through the linac on the deflection angle provided with the RFD cavities. In Fig. 2, the horizontal axis is the sum of deflection angles given by the two RFD cavities. Figure 2 shows that the required deflection angle in the beam-off period is around 18 mrad.

Figure 3 shows the dependence of the downstream beam loss on the deflection angle. The downstream beam loss is defined as the ratio of the number of particles lost after the collector to that at the entrance of MEBT. Figure 3 shows that the downstream beam loss maximizes at the midst of the rising- or falling-times. The loss is mostly localized in the low energy part of DTL as illustrated in Fig. 4. Beam loss increase is not observed after DTL1 except for Case-III, where the excess loss of 0.5-0.7 % has been observed in the midst of rising- and falling-times at the DTL-SDTL transition.

Figure 5 shows the dependence of the collimator load on the deflection angle. The collimator load is the fraction of the particles which must be eliminated to satisfy the requirement for the transverse emittance. The halo collimator edge position is supposed to be set to satisfy the requirement in the beam-on period (where the RFD cavities provide no deflection). Here, we define the collimator load for deflected beams as the fraction of the particles located outside the 4πmm·mrad ellipse of the un-deflected beam. The situation is illustrated in Fig. 6 where the phase-space distributions at the injection to RCS are shown for Case-I. In Fig. 6, only the transverse phase-plane is shown. The blue ellipses in Fig. 6 show the 4πmm·mrad ellipse for the undeflected beam. The halo collimator edge is supposed to be set to eliminate the particles outside this boundary. Then, we label the particle outside this boundary as the particle supposed to hit the halo-collimator. The collimator load is found as the ratio of the number of the labeled particles to that at the entrance of MEBT.

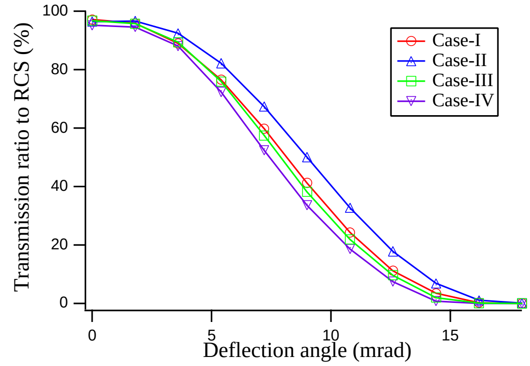

Figure 2: Transmission ratio vs deflection angle.

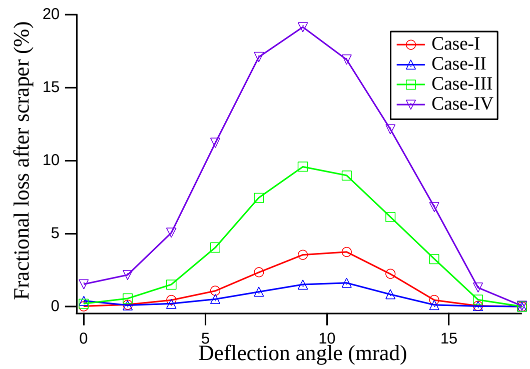

Figure 3: Downstream beam loss vs deflection angle.

DISCUSSIONS

With the beam test of the RF chopper system, we have confirmed that the rising- and falling- times of the chopper system is around 10 nsec [4], which means six micro-bunches are half-kicked in one intermediate-pulse cycle (three in the rising time and three in the falling time). Supposing that these six micro-bunches, respectively, have 20 %, 20 %, 50 %, 50 %, 80 % and 80 % of the design deflection angle (18 mrad in this case), total charge lost downstream becomes 8.9 % of a micro-bunch in Case-I. As an intermediate-pulse typically consists of 150 micro-bunches, the averaged excess beam loss due to beam chopping is estimated to be 0.059 %. Similarly, the excess beam losses are estimated to be 0.024 %, 0.19 %, and 0.41 % for Case-II, III, and IV, respectively. The excess halo-collimator load can also be estimated in a similar way, in which we find they are 0.18 %, 0.30 %, 0.18 %, and 0.11 % for Case-I, II, III, and IV, respectively.

These estimates depend on the initial supposition on the

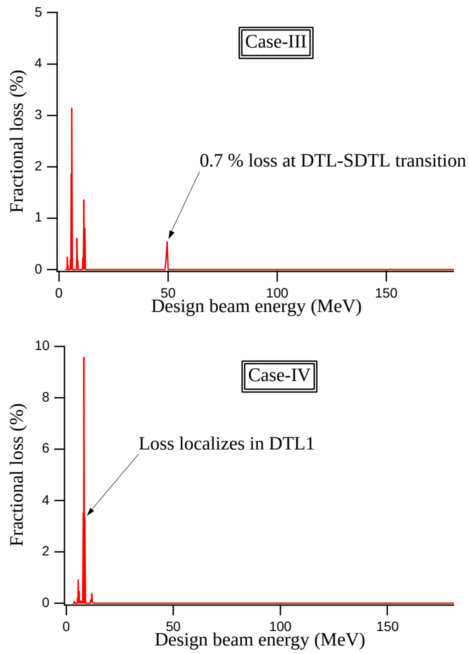

Figure 4: Loss profiles along the linac with the deflection angle of 9.0 mrad for Case-III (top) and Case-IV (bottom).

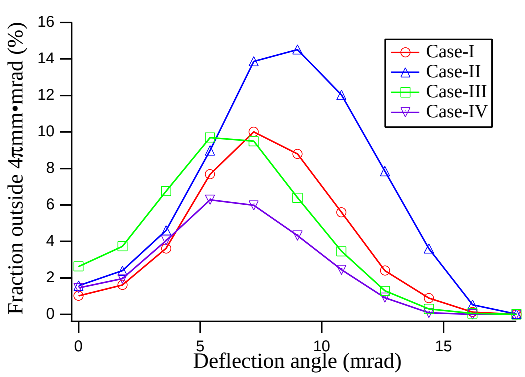

Figure 5: Halo-collimator load vs deflection angle.

fractional kicks for six half-kicked bunches. For example, supposing 10 %, 10 %, 40 %, 40 %, 70 % and 70 % of the design deflection angle, the excess-loss estimates decreases by 0.063 %, and the excess-collimator-load estimates increases by 0.19 % for Case-I.

To be noted here is that the excess beam loss is mostly localized in DTL1. While some excess beam loss after DTL1 is also anticipated, it is expected to be localized at the DTL-SDTL transition region and its amount is around 0.01 % level in average, which corresponds to around 2 W in 181-MeV operation.

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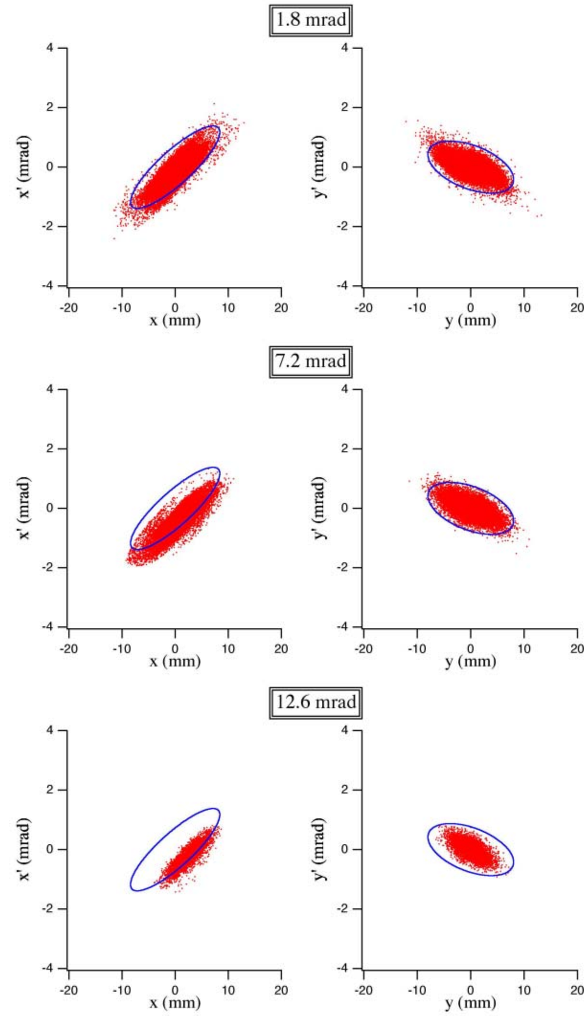

Figure 6: Phase-space distributions at the injection to RCS (Case-I). Phase-space distributions for three different deflection angles at the RFD cavities, i.e., 1.8 mrad (top), 7.2 mrad (middle), and 12.6 mrad (bottom), are shown. Blue ellipses show the 4πmm·mrad ellipses for the case without deflection.

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