SIMULATION STUDY OF THE RF CHOPPER

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Abstract

For the beam current upgrade of the J-PARC linac, a new RFQ (RFQ III) is developing. The peak beam current of RFQ III is 50 mA. To increase the peak current from the existing RFQ (RFQ I), the longitudinal and/or transverse emittances are expected to be increased. However, the increase of the longitudinal emittance will affect the performance of the RF chopper system. In this paper, detailed simulations of the RF chopper system are described and the effect of the longitudinal emittance of the RFQ to the chopper system is examined.

INTRODUCTION

For the beam-current upgrade of the J-PARC linac, the operating RFQ[1] will be replaced by a 50-mA-optimized one. We refer the operating 30 mA RFQ and 50 mA RFQ as RFQ I and RFQ III, respectively. RFQ II is a constructing backup one [2, 3] of the RFQ I.) The design parameters of the RFQ I and current RFQ III reference design [4] are summarized in Table 1[5].

The design of RFQ III will be refined but, as shown in Table 1, the longitudinal emittance of the RFQ III current reference design is about 1.2 times larger than that of the RFQ I. This probably affect the beam extinction after the RF chopper system [6, 7].

The RF chopper system is located in the Medium Energy Beam Transport (MEBT)[8] following the RFQ. Figure 1 shows the schematic drawing of the MEBT.

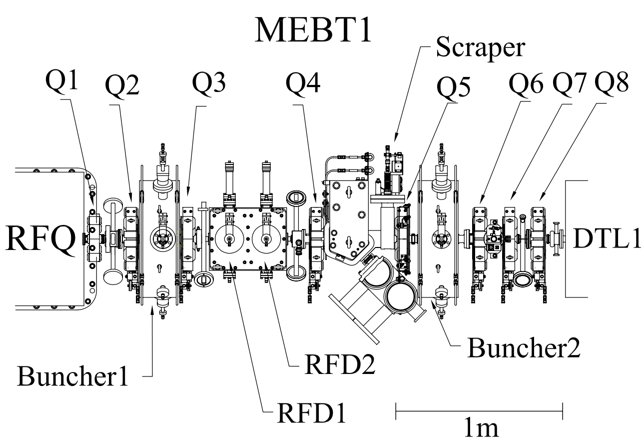

Figure 1: Schematic drawing of the MEBT. The unnecessary part of the beam is deflected by two RFDs toward the upper side of this figure. The chopped beam is dumped with a scraper.

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The RF chopper system consists of two RF deflectors (RFDs) and a beam scraper. The RFDs are 324 MHz TE11-like mode cavities, they horizontally deflect the unnecessary part of the beam by using the transverse RF electric field. The scraper is located at 720 mm downstream from the center of the second RFD and it's head is made of Carbon brazed to water cooled copper block. The rise and fall times of beam chopping are 10 ns.

With this principle, the RFDs have finite phase acceptance for the sufficient chopping. The chopper system is well operated now, however, if the longitudinal emittance is increased to be more than the acceptance of the RFDs, the extinction will become worse. Therefore, we have made a set of simulation model of RF chopper system and investigated the effect of RFQ longitudinal emittance to the RF chopper system.

MODELING OF THE CHOPPER SYSTEM

The RFD cavity is modeled with a finite element method (FEM) code, Micro Wave Studio (MWS)[9]. Figure 2 shows the MWS model of the RFD cavity.

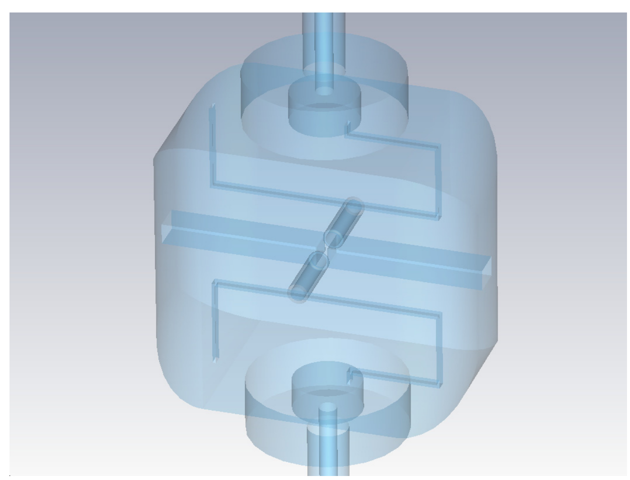

Figure 2: MWS model of the chopper cavity.

As described in reference [7], two RFDs are being operated as a coupled cavity, but in this study, the RFDs are treated as two single cavity, as the first step. Coupled cavity behavior will be investigated in further study.

Figure 3 is the calculated horizontal component of the electric field Ex(x axis is the horizontal direction) on the yz plane. This is obtained with the transient solver of MWS and the plotted distribution is the one at the frequency of 324 MHz. The obtained three dimensional electric-field distribution is used for the particle simulation.

Table 1: Design Parameters of the J-PARC RFQ I and RFQ III. The parameters of RFQ III is that of the current design and it will be refined.

	RFQ I	RFQ III
Cavity structure	4-vane	←
Vane length (mm)	3115	3874
Numbers of the cells	294	362
Inter-vane voltage (kV)	82.9	80.7
Maximum surface field (MV/m) (Kilpatrick)	31.6 (1.77)	31.5 (1.77)
Average bore radius (mm)	3.7	3.6
Vane-tip curvature (mm)	$0.89r_0$ (3.293)	← (3.204)
Synchronous phase in the acceleration section (deg.)	-30	-35
Transmission * (%)	95.7	94.5
Transverse emittance* (π mm · mrad., normalized, r.m.s.)	0.18	0.16
Longitudinal emittance* (π MeV · deg., normalized, r.m.s)	0.078	0.092

*PARMTEQM calculation (1.0 π mm·mrad. (100%, normalized, water-bag), 36 mA injection for RFQ I and 60 mA injection for RFQ III.)

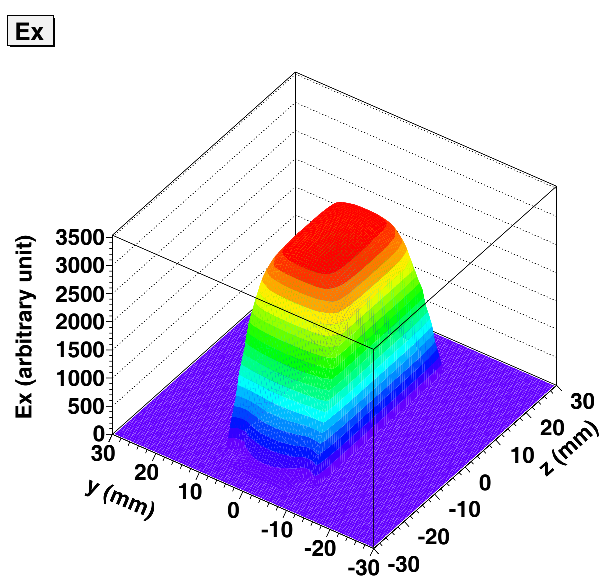

Figure 3: Horizontal electric field Ex of the RF deflector on the yz plane obtained with the MWS. The transient solver is used and the plotted electric field is the one at 324 MHz.

Particle simulations have been performed by using a particle-in-cell (PIC) code, IMPACT[10]. The start point of the simulation is the exit of the RFQ. The initial particle distribution is made with an RFQ simulation code, PARMTEQM[11]. The RFDs are modeled as travelling-wave cavities and the operation phases of each cavity are individually optimized. The three-dimensional electric-field distribution obtained with MWS is used. The magnetic field is neglected because the Lorentz force from the magnetic field is very small compared to that from the electric field for this cavity.

RFQ LONGITUDINAL EMITTANCE DEPENDENCE

Using the simulation model described above, the effect of the RFQ longitudinal emittance to the extinction of the chopper system have been studied. The beam current in this study is 30 mA.

For the nominal case, the distribution at the exit of the RFQ described in reference [12] is used. The number of the particles is 95322.

To examine the effect of phase length and energy width separately, two cases are studied. One is that only the phase width of the initial distribution is enlarged by a factor of 1.2 and the other is energy width is enlarged by 1.2. We refer these two cases as case P and case E, respectively. Figure 4 shows the phase and energy profile of each case. Upper figure of Figure 4 shows the phase distribution of the case P (hatched area) and the nominal case, and the lower figure represents the energy distribution of the case E (hatched area) and the nominal case.

In this study, all the beam is chopped to investigate the extinction. The kicking field strength is set the value corresponding to the 30 kW input power for each RFD. Then, the particles are tracked to the scraper position. Figure 5 is the beam profile plot along the horizontal axis. Upper figure is the horizontal profile of the case P (hatched area) and the nominal case, and the lower shows that of the case E (hatched area) and nominal case.

From these figures, the horizontal profile of the chopped beam at the scraper position is broadened for the case P. On the other hand, for the case E, the profile is not significantly changed.

CONCLUSION

We have developed a simulation model of the RF chopper system of the J-PARC linac. Using this model, the effect of the RFQ longitudinal emittance to the chopper sys-

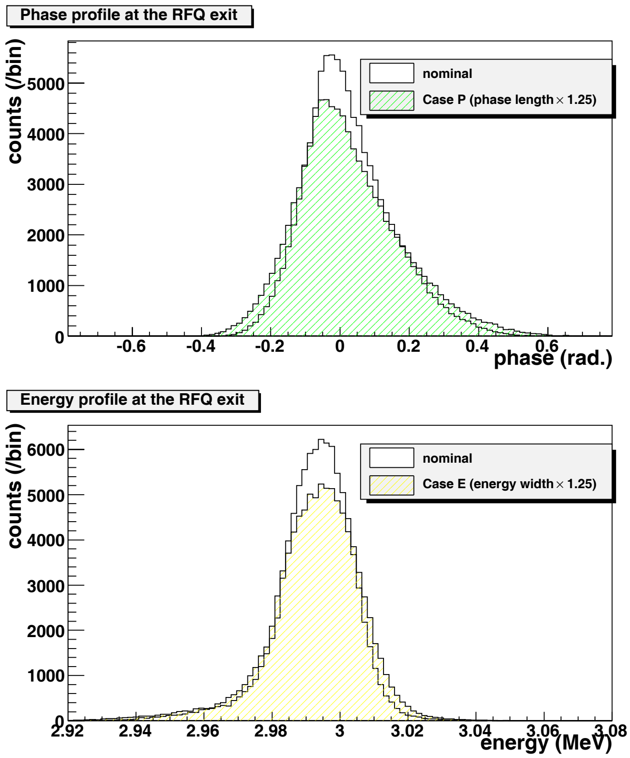

Figure 4: Phase and energy profiles at the RFQ exit. Upper: RFQ phase width is 1.2 times enlarged from the RFQ I phase width (case P). Hatched histogram is the profile of the case P. Lower: RFQ energy width is 1.2 times enlarged (case E). Hatched histogram is the profile of the case E.

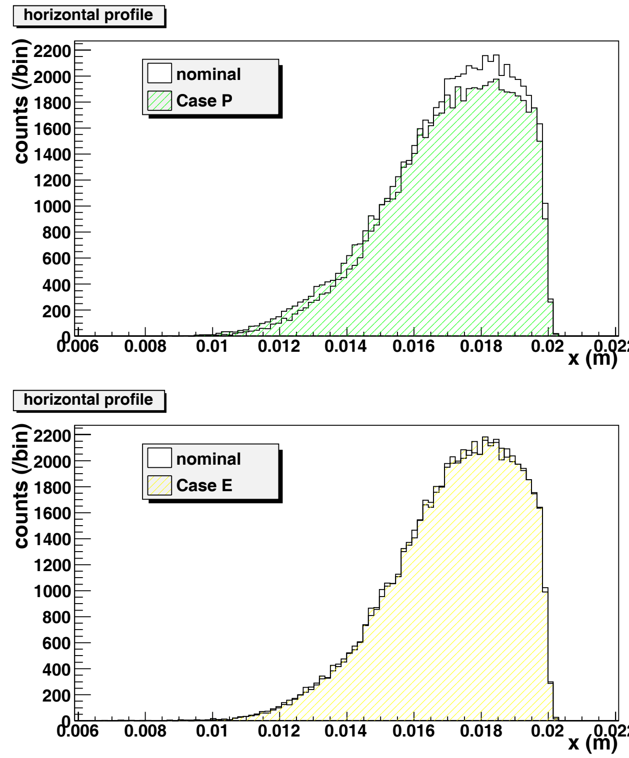

Figure 5: Horizontal profile at the scraper. Upper figure represents the profile of the case P and nominal case. Hatched histogram is the profile of the case P. Lower one shows that of the case E and the nominal one. Hatched histogram is the profile of the case E.

tem has been studied.

The phase width of the output beam from the RFQ directly affect the performance of the RF chopper system. The study described above is a very ideal case (the RFDs are two single cavities and the phase is tuned individually), thus the profile at the scraper position will be worse under the more realistic conditions.

To perform more realistic simulation is the remaining issue, however, it can be concluded that the phase width of J-PARC RFQ III should be designed not to exceed that of RFQ I.

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