REDUCTION OF TRANSVERSE EMITTANCE GROWTH IN J-PARC LINAC DTL

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Abstract

In J-PARC linac DTL (Drift-Tube Linac), horizontal and vertical rms emittance at the beam current of 15 mA was reduced by 12 % and 10 %, respectively, by setting the amplitudes of the first and second bunchers to 120 % and 90 % with respect to the design settings. The resulting normalized horizontal and vertical emittance is 0.230 and 0.205 π mm mrad. At 20 mA, horizontal and vertical emittance was reduced by 17 % and 10 % by setting the buncher amplitudes to 110 % and 80 %. The resulting normalized horizontal and vertical emittance is 0.273 and 0.253 π mm mrad. At 15 mA, we further investigated dependence of emittance on quadrupole magnetic field in MEBT1 (Medium-Energy Beam Transport). With the most downstream quadruple magnet field at MEBT1 enhanced by 20 % from the designed values, the emittance is further reduced to 0.171 and 0.200 π mm mrad. These results are compared with the IMPACT simulation.

INTRODUCTION

It is very important to understand and control transverse beam transport and emittance in accelerating cavities at upstream of the linac, since beam mismatch may result in longitudinal and transverse emittance growth and halo formation, which may cause downstream beam loss. However, tt is hard to investigate beam transport inside Drift-Tube Linac (DTL), due to its complex structures for beam acceleration and luck of diagnostics devices. Due to its long length and complex electric and magnetic field, simple matrix transport calculations hardly work. Therefore, transverse matching at the exit of DTL did not work with bunchers and quadrupole magnets in upstream MEBT1 (Medium-Energy Beam Transport).

Therefore we search for a more practical solution. In IMPACT particle-in-cell model, it was found that longitudinal mismatch causes transverse match mismatch inside DTL due to space-charge effects, leading to transverse emittance growth.

Based on this calculation, we take very practical approach. We try to minimize the transverse emittance at the exit of DTL measured by 4 wire scanners, by varying amplitudes of 2 bunchers (B1 and B2) and quadruple magnets in MEBT1.

EMITTANCE MEASUREMENTS WITH VARYING BUNCHER AMPLITUDES AT MEBT1

We have measured dependence transverse emittance on B1 and B2 amplitudes at 15 mA and 20 mA. Tables 1 and 2 show the resulting dependence at 15 mA and 20 mA. For detailed procedures of transverse emittance measurements, see Refs. [1][2].

Table 1: Normalized horizontal and vertical rms emittance (π mm mrad) at the DTL exit at 15 mA with different B1 and B2 amplitudes. The ε_x and ε_y denote measured horizontal and vertical emittance. The ε_x (IMPACT) and ε_y (IMPACT) denote IMPACT horizontal and vertical emittance calculations.

	Nominal			Best
B1 amplitude	1	1.1	1.2	1.2
B2 amplitude	1	1	1	0.9
ε_x	0.264	0.253	0.246	0.231
ε_x(IMPACT)	0.257	0.251	0.258	0.240
ε_y	0.229	0.220	0.213	0.205
ε_y(IMPACT)	0.258	0.250	0.262	0.241

Table 2: Normalized horizontal and vertical rms emittance (π mm mrad) at the DTL exit at 20 mA with different B1 and B2 amplitudes. The ε_x and ε_y denote measured horizontal and vertical emittance.

	Nominal			Best	
B1 amp.	1	1.1	1.15	1.1	1.1
B2 amp.	1	1	1	0.8	0.9
ε_x	0.310	0.293	0.295	0.273	0.276
ε_y	0.288	0.275	0.274	0.253	0.256

Similar dependence of emittance on B1 and B2 amplitudes are observed. At 15 mA, by increasing the B1 amplitude by 20 % and reducing the B2 amplitude by 10 %, we obtained the best horizontal and vertical emittance of 0.231 and 0.205 π mm mrad. At 15 mA, the resulting ratios of the best emittance to that at the nominal setting are 0.88 and 0.90 in the horizontal and vertical directions. At 20 mA, by increasing B1 amplitude by 10 % and reducing B2 amplitude by 20 %, we obtained the best horizontal and vertical emittance of 0.273 and

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0.253 π mm. At 20mA, the resulting ratios of the best emittance to that at the nominal setting are 0.82 and 0.88 in the horizontal and vertical directions.

To understand the mechanism of the observed emittance reductions, we performed calculations with by the IMPACT model at 15 mA. Figs. 1, 2, and 3 show horizontal, vertical, and longitudinal normalized rms emittance as a function of the longitudinal position with respect to the ion source (m). The units of transverse and longitudinal emittance are π mm mrad and MeV deg, respectively. The DTL is located at the position from 2.9 m to 30.3 m. The wire scanner monitors at the DTL exit for the emittance measurement is around 36 m. The position at the exit of SDTL (Separated-type DTL) corresponds to 115 m. To compare with our measurements, we assume the best B1 and B2 settings with minimum emittance correspond to matched (designed) B1 and B2 setting in the simulation, and assume our nominal setting corresponds to the designed B1 and B2 amplitude divided by 120 %, and 90 % ("mismatched" setting). The "mismatched" longitudinal emittance increases significantly (by 60 %) at DTL. The transverse "mismatched" emittance at the DTL exit increases by 7 %. The enhancement tends to increase from the DTL entrance to the SDTL exit.

From these IMPACT calculations, large longitudinal mismatch may cause transverse mismatch due to space-charge effects, which causes transverse emittance growth. The calculated transverse emittance growth of 7 % is slightly smaller than the measured emittance enhancement of 12-10 %.

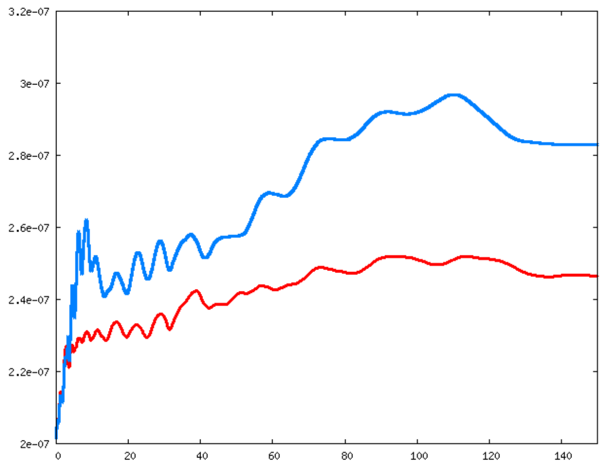

Figure 1: Calculated horizontal emittance by IMPACT at the design B1 and B2 amplitudes (red), corresponding to the best buncher settings, and the "mismatched" B1 and B2 amplitudes (blue) amplitude corresponding to our nominal buncher settings as a function of the longitudinal distance from the ion source.

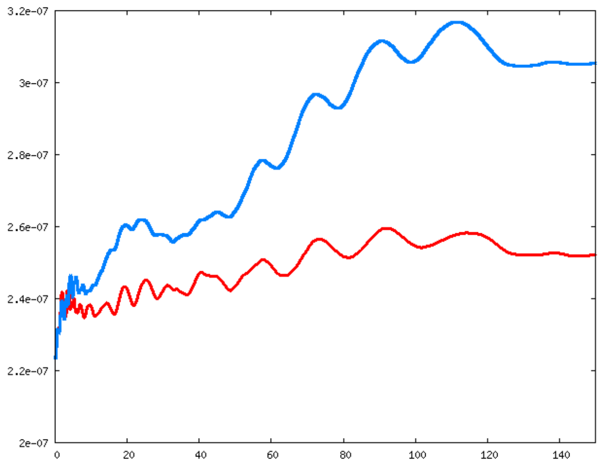

Figure 2: Calculated vertical emittance by IMPACT at the design buncher setting (red), and the "mismatched" setting (blue) as a function of the longitudinal distance from the ion source.

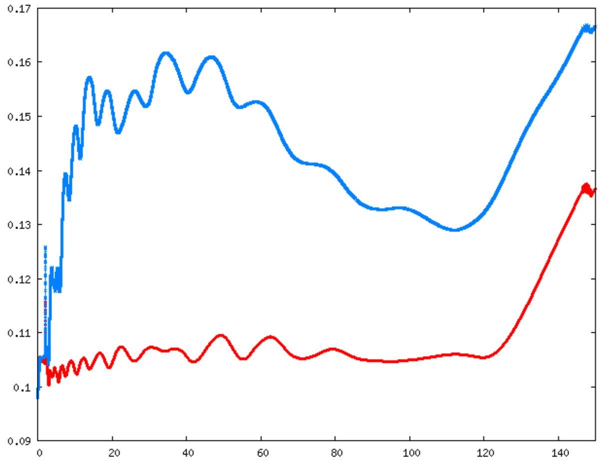

Figure 3: Calculated longitudinal emittance by IMPACT at the design buncher setting (red), and the "mismatched" setting (blue) as a function of the longitudinal distance from the ion source.

In Fig. 4, we show comparison of beam profiles measured by wire scanner monitors at the DTL exit with and without the buncher amplitudes corrections. Profile widths and tails at the ACS section are slightly reduced with the correction..

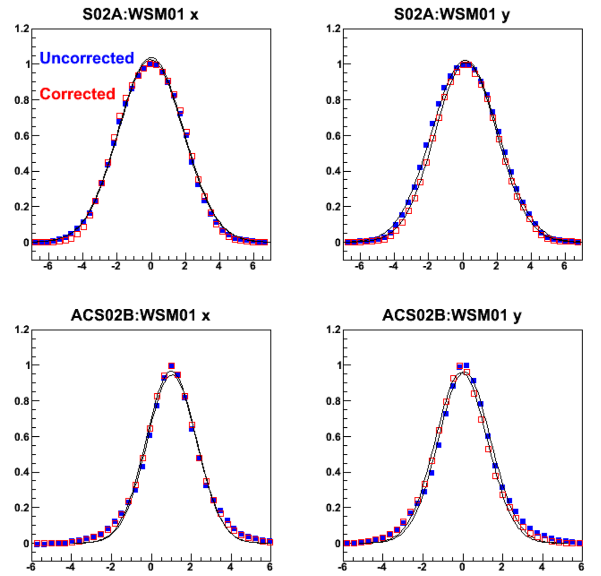

Figure 4: Comparisons of horizontal (left) and vertical (right) profiles with nominal (uncorrected) buncher amplitudes and with the corrected profiles with the minimum emittance. The top 2 plots show profiles at the DTL exit, and the bottom 2 plots show those at the entrance of the ACS (Annular-Coupled Structure linac) section.

EMITTANCE MEASUREMENTS WITH VARYING QUADRUPLE MAGNETIC FIELD AT MEBT1

At 15mA, we further tried to reduce transverse emittance at the DTL exit, by tuning quadruple magnetic field at MEBT1. The measured emittance with varying upstream 7 quadrupole magnetic field settings shows the smallest emittance with the nominal field settings. Only by varying the 8-th most downstream quadrupole (Q8) magnetic field, we measured smaller emittance at the magnetic field increased by 20 % with respect to the nominal setting, as shown in Table 3. The reduction of horizontal and vertical emittance is 29 % and 5 %, respectively.

Table 3: Normalized horizontal and vertical rms emittance (π mm mrad) at the DTL exit at 15 mA with different Q8 settings.

	Nominal			**Best**
Q8 field	1	0.9	1.1	1.2
ε_x	0.241	0.243	0.203	0.171
ε_x(IMPACT)	0.251	-	0.242	0.240
ε_y	0.210	0.222	0.207	0.200
ε_y(IMPACT)	0.248	-	0.240	0.241

For comparison, we simulated mismatched Q8 setting at the design Q8 field divided by 1.2 with IMPACT. The resulting emittance reductions from the mismatched to the design settings in the horizontal and the vertical directions are 4 % and 3 %, which are smaller than the measurements.

CONCLUSIONS

We succeeded to reduce transverse emittance at the exit of DTL by tuning amplitudes of Buncher 1 and Buncher 2 at MEBT1, and magnetic field of the most downstream quadruple magnet at MEBT1 by 10 %-20 % at the beam current of 15 mA and 20 mA. The reduction of transverse is observed in IMPACT calculations, which is slightly smaller than the real measurements.

REFERENCES

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[2] H. Sako, et al., “Transverse Beam Matching and orbit Corrections at J-PARC Linac”, LINAC 2008, Victoria, Canada, pp. 260.