

BEAM DYNAMICS DESIGN OF THE L3BT FOR J-PARC

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Abstract

L3BT is beam transportation line from the linac to the 3-GeV RCS which is the part of the accelerators for the High-Intensity Proton Accelerator Facility Project, J-PARC. In this paper, results of the beam simulation of the injection section of the L3BT are presented. The injection section is necessary for a successful adjustment of the transported beam to the required parameters for ring injection. The matching of rms envelopes and dispersion function for high-intensity beams are also discussed.

INTRODUCTION

The accelerators for J-PARC consist of a 180-MeV linac, a 3-GeV RCS (Rapid Cycling Synchrotron), and a 50-GeV MR (Main Ring) [1].

To meet the requirement for the beam loss minimization, the L3BT does not only connect the linac to the 3GeV RCS, but also modifies the linac beam to be acceptable for the RCS. The required beam parameters at the injection point of the RCS are

Momentum spread $\leq \pm 0.1\%$ (100%) and

Transverse emittance $< 4\pi \text{ mm}^*\text{mrad}$ (100%).

To achieve these beam qualities, the L3BT should have following functions: momentum compaction, transverse halo scraping and beam diagnosis.

The L3BT consists of a straight section, an achromatic arc section, a scraper section and an injection section. Two debunchers are set up in the L3BT. The debunchers are used to obtain the momentum spread of less than $\pm 0.1\%$ at the injection point of the RCS. Another effect of the debunchers is the energy centroid correction when the beam energy is shifted from the design value due to RF errors in the DTL (Drift Tube Linac) and SDTL (Separate-type DTL) section. The vertical bump magnet for the vertical painting injection is placed at a position of π phase difference from the injection point.

PRECONDITION

PARMILA code is used for the beam simulation. The quadruple focusing strengths are determined by using TRACE3D. TRACE3D is the envelope analysis code including the space-charge effect and it has the parameter matching function [2][3].

The dispersion function calculated in TRACE3D characterizes the beam width broadening due to momentum spread, which is generally different from the central orbit distortion due to momentum deviation. At the center of the beam distribution the space charge force is cancelled and the dispersion function is the same as the case when the beam current is 0 mA. We calculate two

dispersion function for the same lattice with and without space charge and call the former “dispersion function R” and the latter “dispersion function C”. The dispersion function R means the derivatives of the rms envelope with respect to momentum p and the dispersion function C means the derivatives of the central orbit with respect to momentum p. When the beam current is 0 mA two types of dispersion functions is the same.

BEAM SIMULATION

We calculate two types of optics for the injection section of the L3BT as follows: The dispersion function R at the injection point of the RCS is 0 in one case (case 1) and the dispersion function C at the injection point of the RCS is 0 in the other (case 2).

At first, the envelope analyses of the L3BT are performed with TRACE3D for above two cases. The calculation results are shown in Fig. 1 and Fig. 2. The beam parameters at the RCS injection point are shown in Table 1.

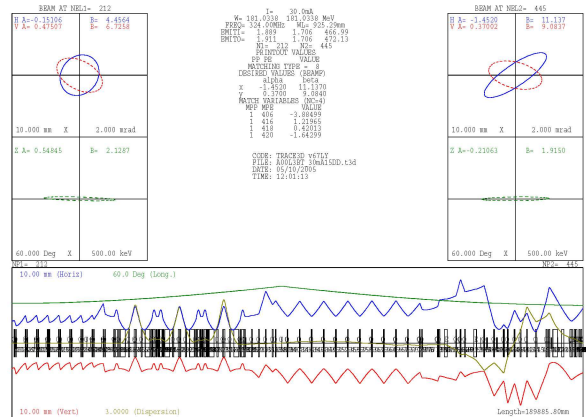


Figure 1: Beam envelope of the L3BT (case 1).

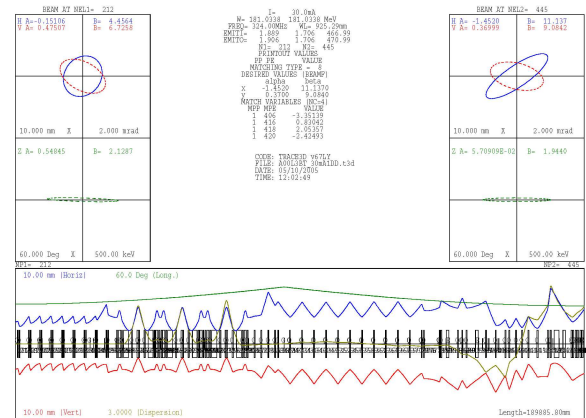


Figure 2: Beam envelope of the L3BT (case 2).

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Table 1: Beam parameters at the RCS injection point

	Unit	Case 1	Case 2
E	MeV	181.034	181.034
α_x		-1.452	-1.452
β_x	m	11.137	11.137
$\beta_{x \max}$	m	36.718	28.037
$\beta_{x \min}$	m	1.209	2.224
η_{RX}	m	0.0	-1.476
η'_{RX}		0.037	-0.136
η_{CX}	m	-0.950	0.0
η'_{CX}		-0.083	0.0
α_y		0.370	0.370
β_y	m	9.084	9.084
$\beta_{y \max}$	m	34.711	21.265
$\beta_{y \min}$	m	3.407	3.428
α_z		-0.211	0.057
β_z	deg*MeV	1915	1944
$\Delta p/p$	%	0.0022	0.0021

Table 1 shows that the maximum values of β_x and β_y of case 1 are larger than those of case 2. In case 2, the variation of the twiss parameters due to the space-charge effects is small.

Next, the simulations from the MEBT to the RCS injection point are performed with PARMILA. Assumed peak current is 30 mA and a 3D space-charge routine is adopted. The beam distribution based on the experiment and simulation result of RFQ is used as the initial beam distribution at the entrance of the MEBT [4]. Initial parameters are shown in Table 2. The calculation results of the beam parameters at the RCS injection point are shown in Table 3.

Table 2: Initial parameters at the MEBT entrance

Number of particles	95322 particles
$\epsilon_{x0}(\text{rms})$	$0.212 \pi \text{ mm}^*\text{mrad}$
$\epsilon_{y0}(\text{rms})$	$0.212 \pi \text{ mm}^*\text{mrad}$
$\epsilon_{z0}(\text{rms})$	$0.091 \pi \text{ MeV}^*\text{deg}$
$\epsilon_{x0}(99.5\%)$	$2.08 \pi \text{ mm}^*\text{mrad}$
$\epsilon_{y0}(99.5\%)$	$2.05 \pi \text{ mm}^*\text{mrad}$
$\epsilon_{z0}(99.5\%)$	$1.32 \pi \text{ MeV}^*\text{deg}$

Table 3: Beam parameters at the RCS injection point

	Unit	Case 1	Case 2
E	MeV	181.034	181.034
α_x		-1.617	-1.478
β_x	m	10.589	10.009
Δx_c	mm	0.046	0.002
ϵ_x/π	mm*mrad	4.320	3.975
α_y		0.442	0.368
β_y	m	9.750	8.934
ϵ_y/π	mm*mrad	3.647	3.469
α_z		-0.774	-0.669
β_z	deg*MeV	742.7	755.3
ϵ_z/π	MeV*deg	4.105	4.068
$\Delta p/p$	%	0.025	0.024

In Table 3, ϵ_x and ϵ_y , ϵ_z denote 99.5% transverse and longitudinal emittance, respectively. Δx_c is the distortion of the central orbit and $\Delta p/p$ is the momentum spread at the injection point which is calculated by using 99.5% emittance and β_x . In the two cases, the momentum spread at the injection point of the RCS is almost the same, which satisfies the requirement of less than $\pm 0.1\%$. Table 3 shows that 99.5% emittance of case 1 is larger than that of case 2.

We conclude from Table 1 and 3 that case 2 is more stable for the space-charge effects than case 1.

RF Errors

The simulations from the MEBT to the RCS injection point are performed assuming RF errors in the DTL and SDTL. A peak beam current is 30 mA and space charge effect is calculated with three dimensions. The same beam distribution shown in Table 2 is used as initial beam distribution at the entrance of the MEBT.

The RF field amplitude and phase errors for each tank of the DTL and the SDTL are randomly generated within the range of $\pm 1\%$ and ± 1 deg. In addition, it is assumed that there are 6 deg phase and 6 % amplitude tuning errors for the debunchers. We shall concentrate on the worst case that the energy at the end of the SDTL is maximum ($\Delta W=0.410$ MeV). [5] The calculation results of the energy and beam parameters at the RCS injection point are shown in Table 4.

Table 4: Simulation results of the beam parameters

	Unit	Case 1	Case 2
E_{ref}	MeV	181.034	181.034
E_{SDTL}	MeV	181.445	181.445
α_x		-1.802	-1.579
β_x	m	11.130	10.328
Δx_c	mm	0.672	0.003
ϵ_x/π	mm*mrad	4.132	3.934
α_y		0.514	0.403
β_y	m	11.284	9.319
ϵ_y/π	mm*mrad	3.542	3.452
α_z		-1.425	-1.443
β_z	deg*MeV	657.2	683.0
ϵ_z/π	MeV*deg	23.023	22.569
E_{RCS}	MeV	180.795	180.795
δ	%	-0.072	-0.072
$\Delta p/p$	%	0.041	0.040

In Table 4, E_{ref} , E_{SDTL} , and E_{RCS} denote the design energy, output energy of SDTL, and the energy at the injection point, respectively. δ is the momentum difference divided by the reference momentum.

Table 4 shows that even if the dispersion function R is 0 the central orbit is shifted. The distortion of the central orbit is almost consistent with the value that is calculated by using the dispersion function C in the Table 1.

We conclude from Table 1, 3 and 4 that case 2 (the derivatives of the central orbit with respect to momentum

p is 0) is better than case 1 (the derivatives of the rms envelope with respect to momentum p is 0). The beam distributions at the injection point of the RCS are shown in Fig. 3 and Fig. 4.

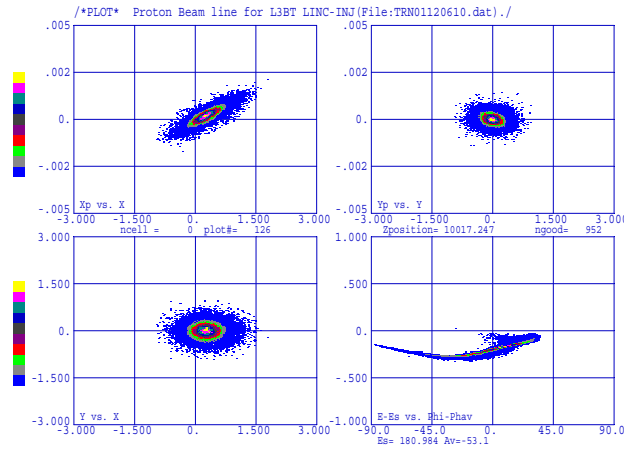


Figure 3: Beam distribution at the injection point of the RCS (case 1).

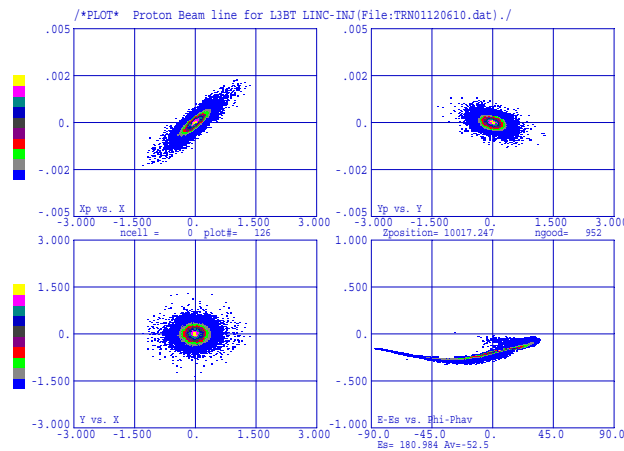


Figure 4: Beam distribution at the injection point of the RCS (case 2).

SUMMARY

We calculate two types of optics for the injection section of the L3BT, which is different in the optimisation of the dispersion function. In one case, we have optimised to eliminate the zero-current dispersion at the RCS injection point, whereas we eliminate the dispersion with space-charge in the other. We have confirmed that we should suppress the zero-current dispersion in our case to avoid excess emittance growth.

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