# OPTIMIZATION OF J-PARC LINAC BEAM FOR INJECTION TO RCS

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*Abstract*

An optimized momentum spread is predicted for best bunching factor and RF capture at RCS injection. A sufficiently wide range of output momentum spread was successfully achieved from J-PARC linac for the verification. It is found that not only momentum spread, but also transverse emittance, Twiss parameters and dispersion play import roles. Series of theoretical and experimental tests were carried out for improving J-PARC linac output beam for mitigating beam loss at injection to RCS.

## INTRODUCTION

The Japan Proton Accelerator Research Complex (J-PARC) is a high-intensity proton accelerator, which consists of a linac[1], as shown in Fig.1, a 3GeV synchrotron (rapid cycling synchrotron, RCS), and a main ring synchrotron (MR).

The J-PARC linac consisted of a 3MeV RFQ, 50MeV DTL (Drift Tube Linac) and 181/190 MeV SDTL (Separate-type DTL) before 2013.

The J-PARC linac was upgraded from 181 MeV to 400MeV in Jan., 2014, with new annular-ring coupled structure (ACS) installed during the summer shutdown in 2013. The present nominal operation current is 15mA. The designed peak current of 30 mA was applied for beam studies.

A new RF ion source and a new RFQ (RFQ3) are being installed in the summer shutdown this year with designed current of 50mA. The commissioning is scheduled in this October.

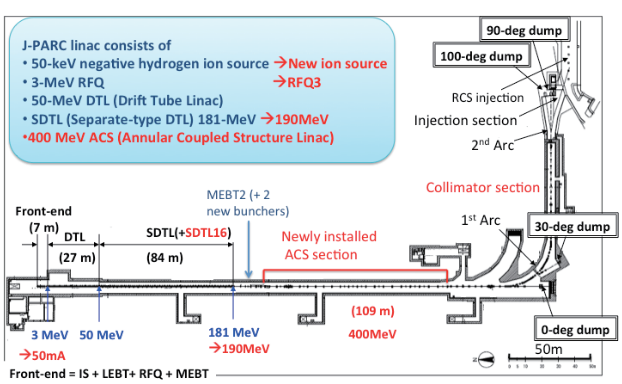

Figure 1: Layout of J-PARC linac.

Due to the increase of energy and current and the change of the setup, the linac should be optimized for minimal beam loss both in linac and RCS injection.

The key points of linac optimization for RCS injection consists longitudinal tuning for best output momentum spread using the debuncher system, and transverse matching. The condition of dispersion-free at the injection foil should be kept for any tuning.

The optimization of linac for RCS injection requests the following steps,

1. Achieve dispersion-free at injection foil
2. Find requested center energy for RCS
3. Get optimal momentum spread
4. Check Twiss parameter at injection foil
5. Transverse match at injection foil

A satisfying result for minimized beam loss at RCS injection was finally achieved, after high-power beam studies with 30mA in Jan., April and June this year.

This paper mainly focuses on the works with linac longitudinal tuning, i.e. steps 1~4.

## SCHEME OF LONGITUDINAL OPTIMIZATION

An optimized momentum spread is predicted both for best bunching factor and RF capture at RCS injection, based on simulations and experiences from previous beam studies.

A separate-functioned debuncher system [2] is applied at J-PARC linac, for longitudinal tuning. Fig.2 sketches the debunchers (DB) in the post-linac beam line L3BT.

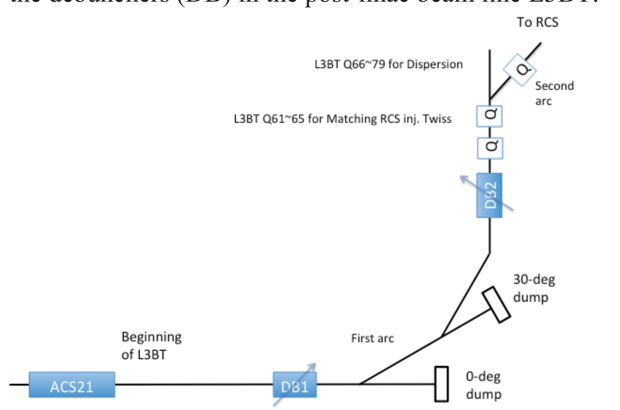

Figure 2: Sketch of J-PARC L3BT used for linac optimization for RCS injection.

The main functions of DB1 are to eliminate the energy jitter due to random RF errors and to control the bunch length. The main function of DB2 is achieved the optimized momentum spread for RCS injection.

A beam energy offset is often requested for the optimal RCS longitudinal painting. It is obtained with the debunchers, singly or jointly, depending on the amount of offset.

The two-debuncher system is designed such that a minimum output momentum spread at the injection could be achieved with DB2, typically with small amplitude at the focusing phase. With the amplitude, equivilently the focusing strength of DB2 decreased or increased, a curtain range of momentum spread could be available for minimizing the RCS injection beam loss. It is straightforward to believe both sides are equivalent.

## FIRST EXPERIMENTS

The first beam studies of linac longitudinal tuning were carried out in Jan. and April this year.

The basic setting is as follows.

RCS requested an energy offset of -0.52MeV from ACS output. It was handled by DB2 solely. Therefore DB1 served as design and DB2 was responsible both for the deceleration and focusing/defocusing.

8 points were tested in Jan., as shown as dots in Fig.3. The simulation was done with 3D PIC code IMPACT.

According to the simulation, the tuning range of the Δp/p| rms was about 0.01~0.15%. An optimal momentum spread was found with DB2 voltage at 1.9MV at focusing side.

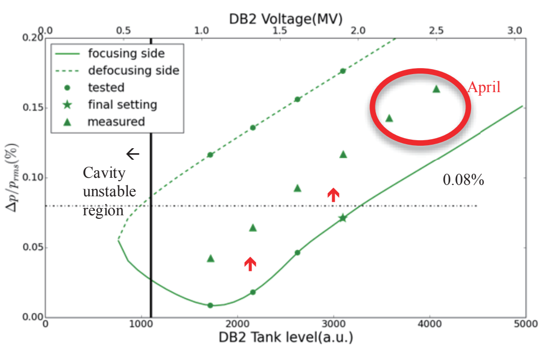


Figure 3: Simulation for DB2 amplitude tuning with simultaneous deceleration by 0.52MeV, together with measurement results in Jan. and April for the focusing side.

There were some questions left open. First, the optimal setting was the highest DB2 amplitude tested, and the predicted optimal Δp/p (0.08%) was still higher; Second, the defocusing side offered higher Δp/p, but no benefit was found. Third, compared with previous 181MeV case, the measure beam profiles showed as if there was no adiabatic damping for the 400MeV. Fourth, the measured momentum at RCS with tomographic method was larger than the simulation.

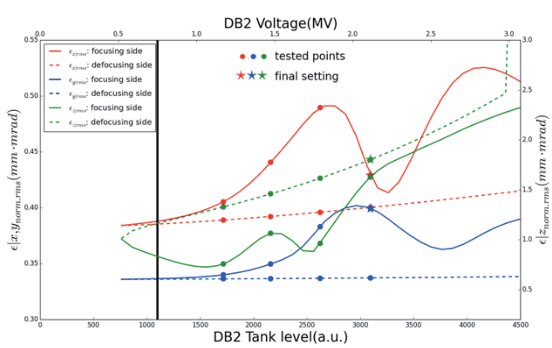


Figure 4: Simulated emittance for DB2 amplitude tuning with simultaneous deceleration by 0.52MeV.

The simulated emittance, as shown in Fig.4, helped to understand the third question. Transverse emittance growth was found at the focusing side.

In early simulation studies there were also emittance growth in the defocusing side due to mistake of remained dispersion at the injection. After correction it was found that there is almost no emittance growth in the longitudinal defocusing side.

Questions No.1 and 2 pointed out it is possible to find better optimal with bigger Δp/p, and there were two ways. The first is to carefully try higher amplitude at focusing side. The second is to try lower amplitude. DB2 was conditioned for about 0.6~2.2MV. Below 0.6MV needs long-time conditioning to be stable. ACS group agreed to try up to 2.5MV.

Therefore in the high-power beam study in April, two more points, as shown in red circle in Fig.3, were tried. But they were worse than the previous optimal.

There was only one direction left, i.e. the lower amplitude.

## FINAL EXPERIMENT

It is not easy to touch the unstable region of DB2 without hardware preparations. So there are two simple ways. One is to try the lowest stable amplitude. The other is to set DB2 to 0, using DB1 deceleration. Simulation results for this new setting are shown in Fig.5 and Fig.6.

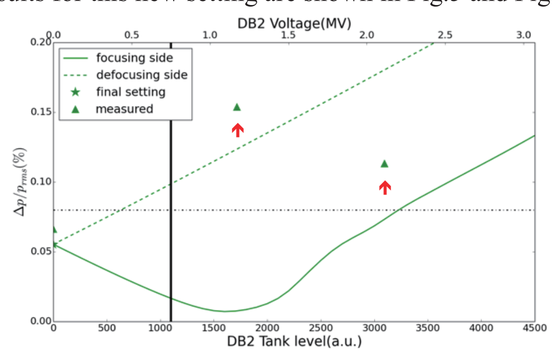


Figure 5: Simulation for DB2 amplitude tuning with DB1 deceleration, together with measurement results in June.

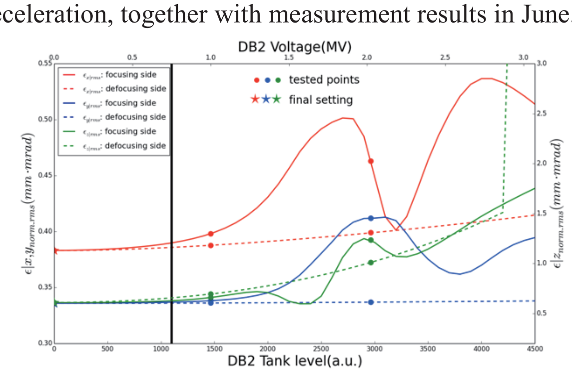


Figure 6: Simulated emittance for DB2 amplitude tuning with DB1 deceleration.

In the high-power beam study in June this scheme was realized and final optimal is found to be with DB2 set to 0. For this setting the momentum spread is less but comparable with the optimal for the setting of DB2 deceleration. Almost no transverse emittance growth was found both in simulation and experiment.

Together with transverse matching and optimization of RCS tune, the RCS injection beam loss was reduced to the ideal level, which only includes loss due to stripping foil. Linac optimization for RCS was satisfyingly solved.

## TRANSVERSE EMITTANCE

A very interesting phenomenon found in the longitudinal tuning is the different behavior of transverse emittance growth for focusing side and defocusing side.

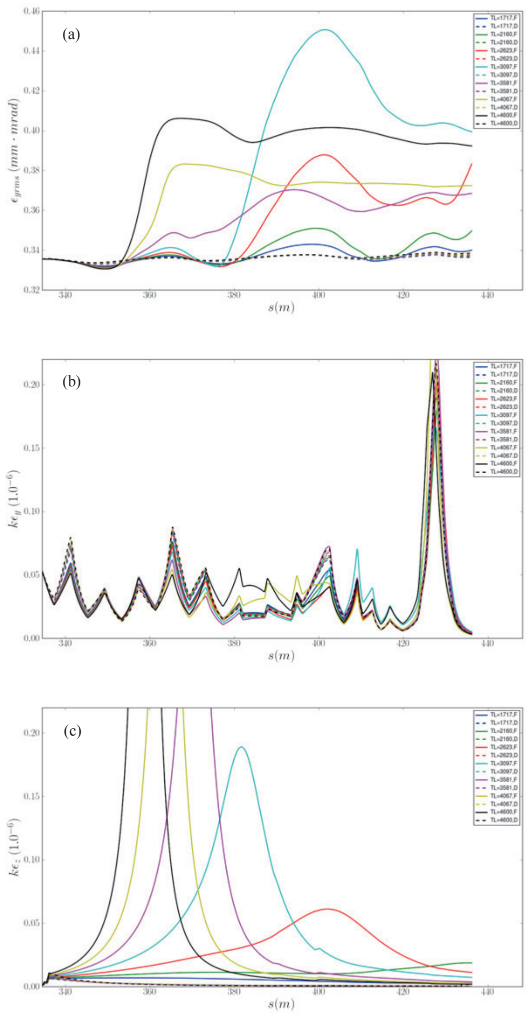


Figure 7: Simulation for experimental tested points for DB2 amplitude tuning with simultaneous deceleration by 0.52MeV. (a) vertical emittance; (b) vertical "setting temperature"; (c) longtudinal "setting temperature".

Fig.7 and Fig.8 show some simulated evolution of emittance and etc. for the longitudinal tuning with the setting 1: DB2 amplitude tuning with simultaneous deceleration by 0.52MeV, and the setting 2: DB2 amplitude tuning with DB1 deceleration.

In Fig.7a and Fig.8a it is clear to see the vertical emittance growth in the longitudinal focusing side (the solid lines), but not in the defocusing side.

This phenomenon could be understood by looking at the "setting temperature", defined as $T = k\epsilon$, where k is the wave number representing the total focusing strength from applied and space charge field, ε is the emittance (unnormalized). The "setting temperature" T stands for the free energy in each plane. In the longitudinal focusing side, the $k\epsilon_z$ becomes larger than $k\epsilon_y$, so that the emittance exchange from plane z to y happens.

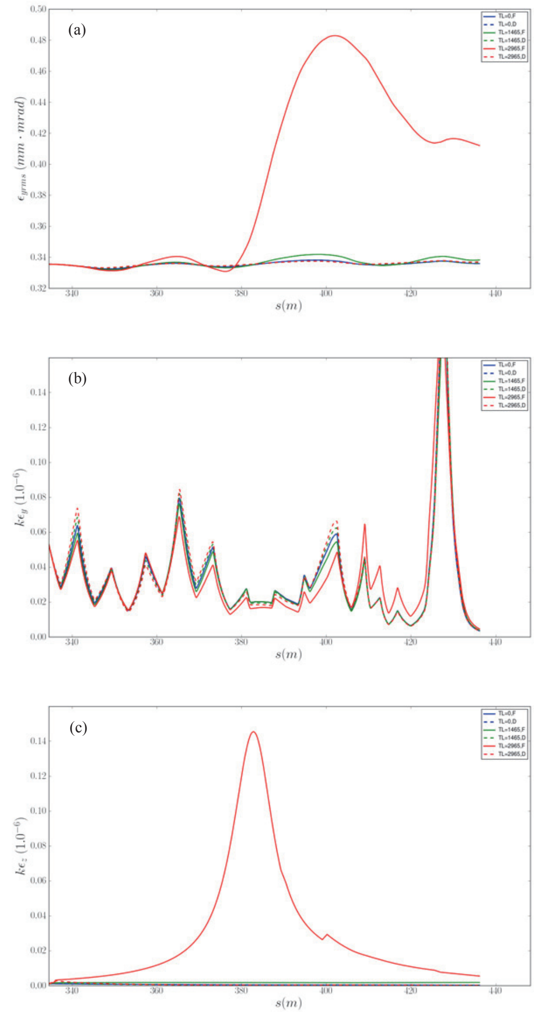


Figure 8: Simulation for experimental tested points for DB2 amplitude tuning with DB1 deceleration. (a) vertical emittance; (b) vertical "setting temperature"; (c) longtudinal "setting temperature".

## ACKNOWLEDGEMENT

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