POSSIBILITY OF LONGITUDINAL PAINTING INJECTION WITH DEBUNCHER SYSTEM IN J-PARC LINAC

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Abstract

For J-PARC to achieve the design beam power of 1 MW from the synchrotron, we plan to upgrade the linac beam energy from 181 MeV this moment to 400 MeV. The debuncher system between the linac and synchrotron will be upgraded also. Especially an individual power supply – a new klystron will be support for the last debuncher. Depends on this, we are studying the possibility of actively controlling the center momentum with debuncher cavities to enable longitudinal painting injection into the succeeding ring as a potential new feature. If it finds feasible, it would provide an additional tuning knob to mitigate the beam loss in the synchrotron. In this paper, we show a beam dynamics design of the new debuncher system with emphasis on the possibility of its application for the longitudinal painting injection.

INTRODUCTION

In current stage, For longitudinal painting of J-PARC RCS, the momentum offset injection and applying the second harmonic rf voltage made by RCS rf system are used to improve the bunching factor, which is defined as the ratio of average and peak current. Currently, 80% second harmonic and the momentum offset of 0.2% were selected as optimization [1]. Somehow, the debuncher system in transport line just before injection can be used to make momentum offset also, which can reduce the tasks on RCS rf system. However, for current debuncher in J-PARC linac, the rf power is not enough for momentum offset 0.1%. But for future J-PARC power upgrade to 1 MW, a new klystron will be installed for debuncher system so that the injection momentum offset may possible be made by debuncher system [2]. And for current design of debuncher system after upgrade, injection momentum jitter reduction and momentum spread control will be managed by 2 debunchers of this debuncher system separately. The second debuncher is used for momentum spread control in design. By this case, it may also be used for injection momentum offset by changing rf amplitude and phase independently.

UPGRADE OF J-PARC LINAC AND NEW DEBUNCHER SYSTEM

J-PARC linac is planned to have an upgrade, including increase of both beam peak current and energy. As shown in Figure 1, the output energy is to be upgraded from current 181 MeV to 400 MeV by adding an ACS (Annular Coupled Structure linac) after SDTL. Meanwhile new ion source and RFQ will be installed for beam peak current increase also [3].

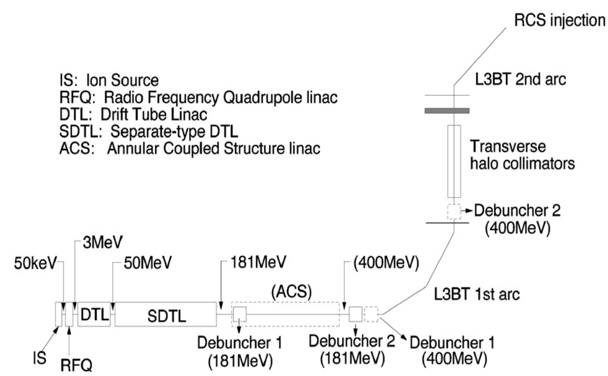

Figure 1: Schematic layout of J-PARC Linac upgrade, especially for debuncher system (dashed: ACS and new debuncher system for 400 MeV upgrade)

A new debuncher system was made for the linac upgrade [4]. Debuncher system is a key component to control the momentum spread and centroid momentum jitter at the RCS injection, which consists of two RF cavities placed after the exit of the linac with adequate spacing. Some parameters are shown in Table 1. Here We devised a two-cavity debuncher system with so-called "separate-function configuration", which means the first debuncher mainly used to deal with momentum jitter at the exit of ACS, as well as the other one to control momentum spread at the RCS injection. Due to simulation result, momentum jitter at the RCS injection can be reduced to 21.5 % as the jitter at the exit of ACS. And with elastic setting of the second debuncher, momentum spread from 0.19 ‰ to 3.1 ‰ can be selected for attaining less beam loss in the RCS after upgrade.

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Table 1: Parameters for the Debuncher System in J-PARC Linac for 181-MeV Case and 400-MeV Upgrade

	181-MeV linac	400-MeV linac
Energy at the end of linac	181.0 MeV	400.0 MeV
Peak current	30 mA	50 mA
Transverse emittance (RMS, normalized)	0.3 π mm-mrad	0.3 π mm-mrad
Longitudinal emittance (RMS, normalized)	0.1 π MeV-deg	0.27 π MeV-deg
RF freq. for debunchers	324 MHz	972 MHz
$\tilde{l}_1$	33.9 m	15.5 m
$\tilde{l}_2$	122.7 m	75.7 m
$\tilde{l}_3$	164.6 m	100.2 m
E_0TL of 1st debuncher *(Up: used; Down: Max;)*	1.431 MV 1.5 MV	3.793 MV 3.8 MV
ϕ_1	-90°	
E_0TL of 2nd debuncher *(Up: used; Down: Max;)*	0.28 MV 0.46 MV	1.8 MV 2.5 MV
ϕ_2	90°	
Reducing ratio of momentum jitter	72.4 %	79.5 %
Minimum momentum spread at the end of linac*	0.13 %	0.13 %

*: 99.5% beam particles, 15 mA due to beam operation

LONGITUDINAL PAINTING BY THE LAST DEBUNCHER AFTER UPGRADE

How Can Debuncher Give Help to Longitudinal Painting

For the J-PARC operation those years, RCS rf system with 80% second harmonic and the momentum offset of 0.2% were optimized for longitudinal painting. And it may possible to do the momentum offset by debuncher system when rf amplitude and phase was adjust. This method can reduce the burden of RCS rf system. However limited by power support of last debuncher in current situation, as shown in Table 1, the maximum effective gap voltage (E0TL) of the last debuncher is only 0.46 MV. Such small E0TL is not enough to make the momentum offset of 0.2% for longitudinal painting. Even for centre momentum adjust for beam injection to the RCS, the first debuncher was used in beam commissioning. And after the rf tuning of the first debuncher for centre momentum adjust, there should be another adjust with the last debuncher, so called 'phase scan'.

Fortunately, after linac 400 MeV upgrade, power support for the debuncher system will increase for several times, about 2.5 MV for E0TL, as shown in Table 1. With such higher value, the momentum offset may be done by the last debuncher. To make momentum offset, there should be three steps to do research.

- Get basic setting point for normal injection;
- Adjust the rf amplitude and phase to make certain momentum offset.
- Simulation should be done to check the result especially for the nonlinear effect of rf cavity.

About the basic setting point, we can see from Figure 2, which also be mentioned in reference [4]. In old design, lowest momentum spread was wanted at the injection point of the RCS. So a green circle was marked that setting point with momentum spread of 0.019 % for 99.5 % beam at injection point. However, the commissioning results showed that optimal momentum spread about 0.13 % for 99.5 % beam gave lowest beam loss in the RCS. Thus two setting points can be selected due to this information, which are red circle and blue circle in Figure 2, one with lower rf E0TL and the other a little higher E0TL.

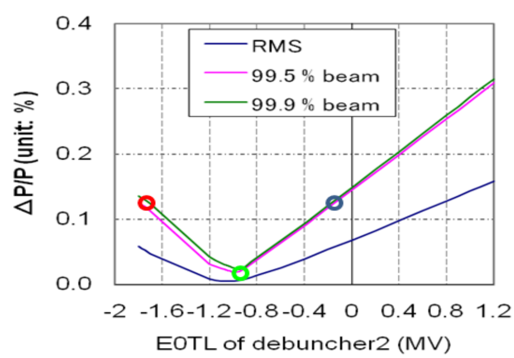

Figure 2: ΔP/P at RCS injection with elastic setting of the second debuncher (For horizontal scale, minus: rf phase of -90°; plus: rf phase of 90°). And green circle for setting point in old design to get lowest ΔP/P, red circle and blue circle for two setting points to get optimal ΔP/P according to commissioning results.

After basic setting points are selected, the rf amplitude and phase should be adjust to make certain momentum offset. Simply thinking of rf field of debuncher system, equation (1) and (2) can be used make momentum offset (δP).

$$V_{painting}\cos(\varphi_{painting}) = 0.68\frac{\delta P}{P_0} \tag{1}$$

$$V_{painting}\sin(\varphi_{painting}) = -V_0 \tag{2}$$

Here V0 is rf amplitude of basic setting point, P0 basic beam centre momentum, Vpainting , φpainting are the rf amplitude and phase setting for momentum offset (δP).

Equation (1) is used to get momentum offset (δP) for beam centre. And Equation (2) is used to make same focusing force in longitudinal direction of beam in order to have the same momentum spread at the RCS injection point.

Then the final step of beam simulation should be done to check the result with real rf electronic field of last debuncher.

Simulation Condition

To confirm the expected performance of the momentum offset by the last debuncher system, particle simulations are performed with code IMPACT. The simulations have been studied from the RFQ exit to the RCS injection point assuming the design peak current of 50 mA. The 3D space–charge routine, Particle-In-Cell, is adopted for these simulations, and 32×32×64 meshes are employed in solving the Poisson equation. The initial distribution at the RFQ exit is generated with a PARMTEQ simulation, where the number of employed simulation particles is 98 572.

Simulation Result

According to the basic setting points, we performed the simulation of momentum offset with 0.1 % to the based momentum of 400 MeV. The rf amplitude and phase can be calculated follow the equation (1) and (2), which shown in Table 2.

Table 2: Cases of Momentum Offset

Setting points	***Low*** E_0TL	***High*** E_0TL
Basic rf E_0TL (MV)	0.09	1.8
Basic rf *phase*(degree)	-90	-90
Offset rf E_0TL (MV)	0.69	1.93
Offset rf *phase*(degree)	-7.6	-69.3

The simulation results of particle distribution can be seen in Figure 3, including results of basic case with high E0TL and three offset cases.

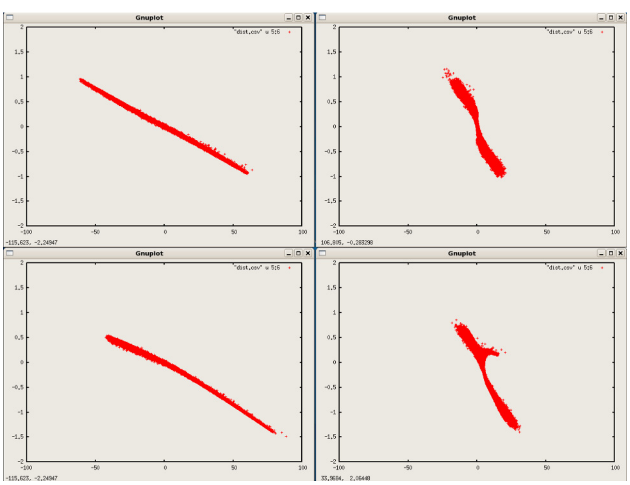

Figure 3: Longitudinal particle distribution at the RCS injection (left-up: basic case with low E0TL; right-up: basic case with high E0TL; left-down: offset case with low E0TL; right-up: offset case with high E0TL;)

Large nonlinear effects can be seen in the case for momentum offset with the basic setting points in old design and low E0TL case. Also there are some particles not so regular in the case with high E0TL, but those are not core part according to the colours. By the same way, we also did the simulation for the case from 0.01 % to 0.09 % of momentum offsets which shown in Figure 4. Due to this nonlinear effect, the basic case with high E0TL should be selected for beam tuning, especially for momentum adjusts for beam injection.

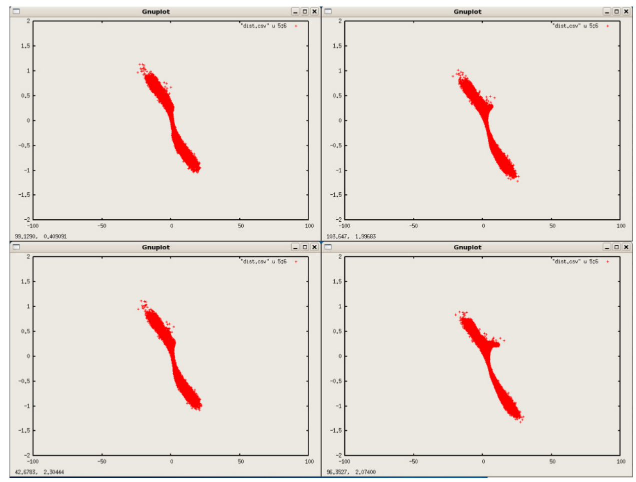

Figure 4: Longitudinal particle distribution with momentum offset at the RCS injection (left-up: 0.01 %; left-down: 0.02 %; right-up: 0.05 %; right-down: 0.08 %;)

SUMMARY

J-PARC linac will have an upgrade in the near future, including power increase for a new debuncher system. Due to this power increase, longitudinal painting of momentum offset for injection beam to the ring can be done by the last debuncher cavity. This can reduce the burden of rf system in the ring RCS. Due to simulation by the CODE IMPACT, at least 0.1 % of momentum offset for 400 MeV injection beam after upgrade can be achieved for longitudinal painting.

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