SIMULATION STUDY OF DEBUNCHER SYSTEM FOR J-PARC LINAC ENERGY UPGRADE*

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Abstract

The J-PARC linac will have an upgrade from 181 MeV to 400 MeV in recent years. Considering design of 181-MeV linac, aiming to correct center energy jitter from the upgrade linac, to minimize momentum spread and adjust beam energy at ring injection, a debuncher system should be involved between linac and ring. Meanwhile, beam commissioning results show a different requirement for injection momentum spread to minimized beam loss in RCS. Based on the original design and the experimental findings with 181-MeV operation, a debuncher system has been designed for the upgrade linac.

INTRODUCTION

J-PARC linac will has an upgrade plan, whose layout is shown in figure 1. For this upgrade, an ACS accelerator section with 21 cells, 2 tanks per each cell, will be installed [1]. Beam evenlopes of designed upgrade linac can also be seen in figure 1.

According to error study of upgrade linac [2], mainly caused by RF error of amplitude ± 1% and phase ± 1 degree, beam momentum jitter at the end of linac ACS would be ± 0.37 ‰ of standard deviation and ± 1 ‰ of maximum compared with nominal momentum at 400 MeV. Meanwhile for high power operation in the ring RCS and mitigating space charge effect, longitudinal painting is used with RCS rf operation for linac beam injection [3]. Momentum offset for longitudinal painting is designed as ± 2 ‰. Momentum jitter should be small enough comparing with this momentum offset value. A momentum jitter of standard deviation ± 0.15 ‰ and maximum ± 0.3 ‰ at injection is wanted.

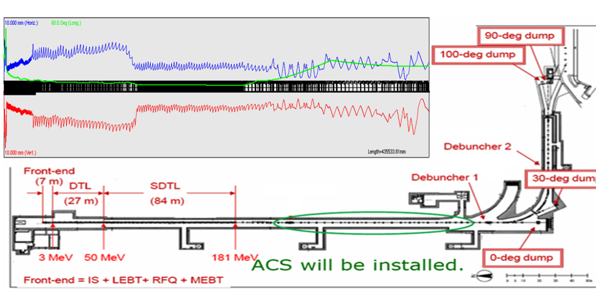

Figure 1: Layout and beam envelopes of upgrade J-PARC linac.

Beside tackle of momentum jitter, same as 181-MeV linac case [4], debuncher system for upgrade linac should consider momentum spread at injection also. But unlike the function of minimizing momentum spread in design, beam commissioning results show a different requirement for the injection momentum spread to minimize the beam loss in RCS. This point is mentioned as follow.

DEBUNCHER SYSTUM DESIGN IN 181-MEV LINAC AND ITS COMMISSIONING RESULTS

Debuncher system for 181-MeV linac [4] is shown in figure 2. There are two debunchers for debuncher system. , The first debuncher is expected to deal with center momentum jitter, while the other debuncher is utilized to minimize the injection momentum spread. Longitudinal particle distributions at injection are also plotted.

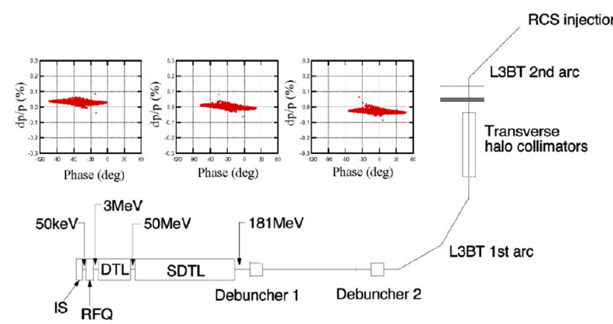

Figure 2: layout of 181-MeV linac and beam longitudinal distribution at injection (left: with +1 ‰ momentum jitter; middle: design; right: with -1 ‰ momentum jitter).

In the design for 181-MeV linac, both two debunchers are set at -90˚ for their rf phase. But beam tuning shows less beam loss in RCS for the second debuncher with rf phase of 90˚, which can be seen in figure 3.

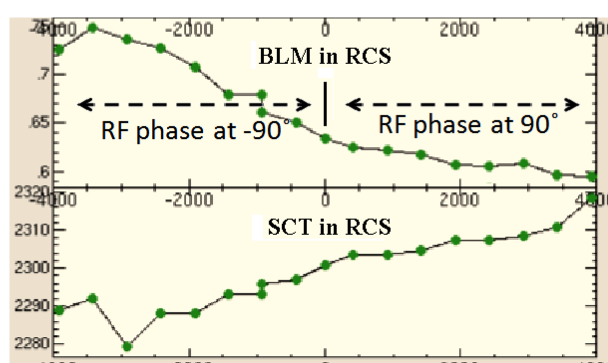

Figure 3: Beam loss and current show in RCS by the scan of last linac debuncher.

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REDUCTION OF MOMENTUM JITTER FOR LINAC BEAM INJECTION

Follow the design guides of debuncher system for 181-MeV linac [1], separate function of the first debuncher is to reduce the momentum jitter at ring injection and minimize nonlinear effect at the second debuncher. These functions are performed as shown in Figure 4. Two momentum jitters, larger and less than nominal momentum, are discussed here. δ_{P0} and δ_{P1} mean momentum jitter upstream and downstream of the first debuncher. Because phase jitter at the exit of linac has very small value and influence here, it can be ignored.

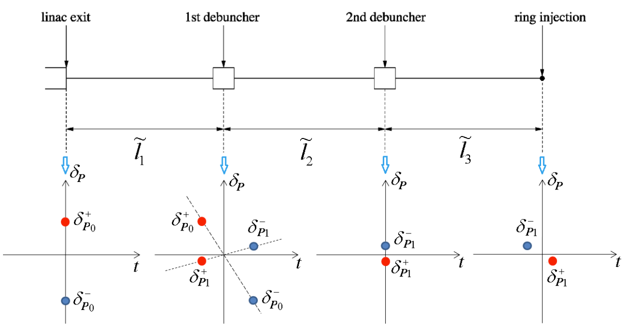

Figure 4: Depiction of function performance of first debuncher in 400-MeV J-PARC linac.

According to physical process in Figure 4, phase and energy change of beam centre can be deduced as follow.

$$\begin{bmatrix} 0 \\ \delta_{p1} \end{bmatrix} = \begin{bmatrix} 1 & l_2 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 1 \\ -\dfrac{1}{f_1} & 1 \end{bmatrix} \begin{bmatrix} 1 & l_1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ \delta_{p0} \end{bmatrix}$$

Here $\tilde{l}$ is the geometrical drift length and l is the effective drift length in the longitudinal phase-plane. These two have the relationship as $l = \tilde{l} / \gamma^2$.

So, $\begin{bmatrix} 0 \\ \delta_{p1} \end{bmatrix} = \delta_{p0} \begin{bmatrix} l_1 - l_1 l_2 f_1^{-1} + l_2 \\ -l_1 f_1^{-1} + 1 \end{bmatrix}$

Thus,

$$f_1 = \frac{l_1 \cdot l_2}{l_1 + l_2} \qquad (1)$$

$$\delta_{p1} / \delta_{p0} = -\frac{l_1}{l_2} \qquad (2)$$

Inside, $f = \left(\dfrac{2\pi |q| E_0 TL}{\beta^3 \gamma m_0 c^2 \lambda}\right)^{-1}$

Where λ is the free-space wavelength of RF, q and m_0 are the charge and the rest mass of the particle, c is the speed of light in vacuum, β, γ are the relativistic factors of the particle. The effective gap voltage E_0TL is the product of the average accelerating field E_0, the transit time factor T, and the cavity length L.

Based on equation (2), if momentum jitters of standard deviation ± 0.15 ‰ and maximum ± 0.3 ‰ at ring injection is wanted, while standard deviation ± 0.37 ‰ and maximum ± 1 ‰ is located at the exit of ACS, value of $\tilde{l}_2 / \tilde{l}_1$ should larger than 3.6. By the way, $\tilde{l}_1$ should not be too small, or the effective gap voltage E_0TL of the first debuncher would be very large according to equation (1). Finally $\tilde{l}_2 / \tilde{l}_1$ is selected as 4.9 which can be calculated by parameters in Table 1. Satisfied result is attained as shown in Figure 5 according to jitter error study [2].

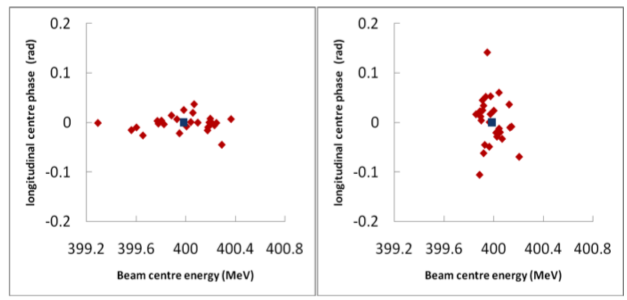

Figure 5: Centre energy and phase at exit of ACS (left) and the RCS injection (right).

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	1.431 MV	3.793 MV
$_1$	-90˚	
E_0TL of 2nd debuncher	0.458 MV	1.000 MV
$_2$	-90˚ or 90˚	
Reducing ratio of momentum jitter	72.4 %	79.5 %
Minimum momentum spread at the end of linac*	0.19 ‰	0.19 ‰

*: 99.5% beam particles

CONTROL OF ΔP/P AT RCS INJECTION

Separate function of the second debuncher is to control the injection momentum spread according to the requirements from the RCS injection. According to the commissioning results mentioned above, rf phase of 90˚

for second debuncher, which gave larger Δp/p at RCS injection, supported less beam loss in the RCS than the case of phase -90˚ in design. So here a large scale of Δp/p at injection is wanted to be made by the second debuncher for upgrade linac.

By using code IMPACT, setting of rf amplitude and both -90˚ and 90˚ phase have been studied step by step to know the momentum spread at RCS injection. Same as 181-MeV linac [1], minimum momentum spread was found as 0.19 ‰ at rf phase setting of -90˚. While rf phase setting at 90˚ and 120 % amplitude setting of the second debuncher based on minimum momentum spread case, a large Δp/p of 3.1 ‰ can be attained for RCS injection. Here 99.5 % beam particles were mainly considered because about 0.5 % beam halo would be dumped by collimation system in linac before injection.

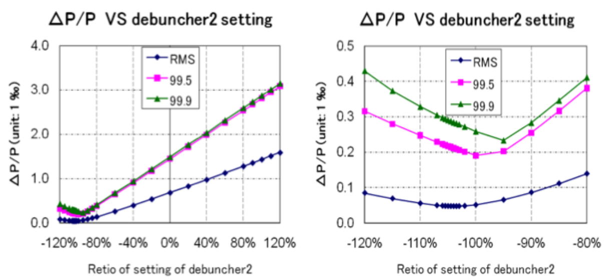

Figure 6: ΔP/P at RCS injection with elastic setting of the second debuncher (minus: rf phase of -90˚ ; plus: rf phase of 90˚;).

SIMULATION RESULT AND DISCUTION

Mentioned above, momentum jitter is caused mainly by rf error on amplitude and phase. Here 27 runs with random error of amplitude ± 1% and phase ± 1˚ have been studied by using code IMPACT. Figure 5 shows the energy jitter at the exit of ACS and RCS injection for these 27 runs. Energy jitter of standard deviation ± 0.13 ‰ and maximum ± 0.3 ‰ is attained at the injection which meets the requirements from energy offset for injection longitudinal painting. Compared with energy jitter at the exit of ACS, centre phase jitter seems become larger. But on one hand, these phase jitter at injection point are not beyond ±0.16 rad, about ±10 degree; on the other hand, longitudinal painting is used for injection with a RCS rf system of 1 MHz, much lower than 972 MHz of linac rf frequency. Thus those phase jitter can be ignored.

Longitudinal phase space plots for design and two error runs with large momentum jitters are shown in Figure 7. Those phase space plots are located at the exit of ACS, entrance and exit of two debunchers, and RCS injection point. Those three cases are for minimum momentum spread at injection. The functions of two debunchers can be seen very clear in these plots. And beam distributions at injection for design case and two jitter runs look similar from each other.

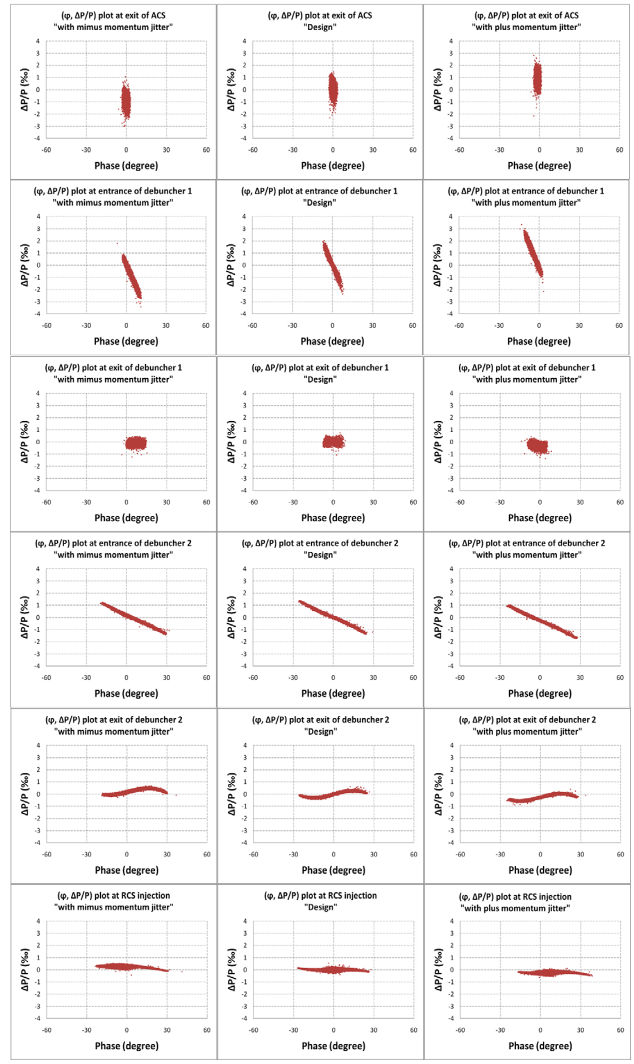

Figure 7: Longitudinal beam distributions in design and the cases of with plus and minus momentum jitters.

SUMMARY

Based on 181-MeV J-PARC linac design and beam commissioning results, debuncher system for upgrade linac has been studied. Suitable positions for 2 debunchers and rf amplitude of the first one are selected to meet the requirement of energy jitter for energy offset in longitudinal injection painting. Meanwhile 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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