ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPTY003

MEASUREMENT OF MOMENTUM SPREAD OF THE INJECTION BEAM WITH LONGITUDINAL TOMOGRAPHY METHOD IN THE J-PARC RCS

Masahiro Yoshimoto#, Hiroyuki Harada, Hideaki Hotchi, Pranab Kumar Saha,
Fumihiko Tamura, Masanobu Yamamoto, Michikazu Kinsho
JAEA/J-PARC, Tokai-Mura, Naka-Gun, Ibaraki-Ken, JAPAN

Abstract

In the J-PARC RCS, the beam tuning toward the design output beam power of 1MW were started after the completing of the beam energy and beam current upgrades in the LINAC. One of the important issues to achieve the 1MW beam operation is the optimization of the injection beam. Due to the longitudinal beam tuning in the LINAC, we adopted the Longitudinal Tomography algorism to measure the momentum spread after the beam injection into the RCS. At first we confirmed the validity of our measurement tool developed with the Longitudinal Tomography algorism. And then longitudinal beam tuning with this tool were carried out.

INTRODUCTION

In order to observe two-dimensional (2D) beam distributions in the longitudinal phase space, the simple reconstruction tool had been developed with the Longitudinal Tomography (LT) algorithm for the 3-GeV rapid cycling synchrotron (RCS) at Japan Proton Accelerator Research Complex (J-PARC) [1]. Our reconstruction tool is adopted the Convolution Back-Projection (CBP) method [2] for the LT algorithms. This tool has some limitations to apply the beam measurement. However it is very simple enough to accelerate processing speed and achieve the on-line analysis. The reconstructed longitudinal 2D distribution has much useful information. It can diagnose not only the longitudinal beam dynamics in the RCS but also the longitudinal beam parameters from the LINAC.

In the J-PARC RCS, the beam tuning toward the design output beam power of 1MW were started after the completing of the beam energy and beam current upgrades in the LINAC. One of the important issues to achieve the 1MW beam operation is the optimization of the injection beam from the LINAC [3]. Due to the longitudinal tuning of the LINAC beam, the momentum spread ($\Delta p/p$) was measured with this reconstruction tool after the beam injection into the RCS.

MOMENTUM SPREAD MEASUREMENT WITH LONGITUDINAL TOMOGRAPHY

In order to apply the reconstruction tool with the simple LT algorism to the $\Delta p/p$ measurement of the LINAC beam, there are some issues that we have to confirm, namely the reproducibility of the 2D distribution, the accuracy of the measurement quantity, and the expansion to the Acceleration mode. Thus our reconstruction tool has to be evaluated before the high power beam tuning.

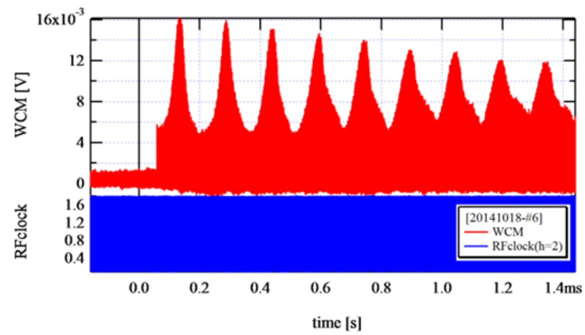

Figure 1: The typical beam bunch shape acquired by the WCM and the RF-clock generated by the LLRF.

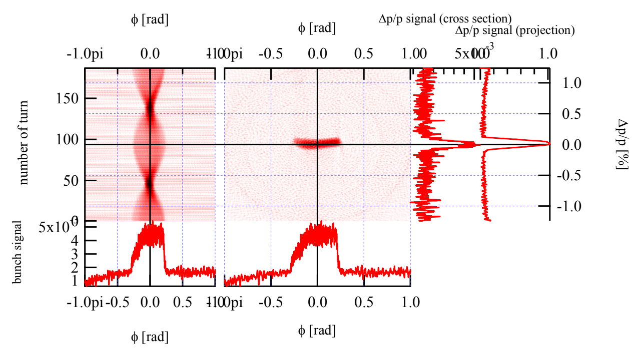

Figure 2: The reconstructed beam distribution in the longitudinal phase space with the CBP method.

Reconstruction Two-Dimensional Distribution in the Longitudinal Phase Space

The RCS adopted the multi-turn H^- charge-exchange injection scheme [4]. After the all bunched beams were injected, the longitudinal information of the LINAC beam was smeared out. Thus single intermediate bunched beam had to be injected and rotated in synchrotron phase-space. Figure 1 shows the typical measurement results of the circulating bunch signal by the WCM and the RF-clock signal generated by the low level RF (LLRF) system after the single intermediated bunched beam injection. A set of projected histograms for the Longitudinal Tomography can be obtained by cutting out from the WCM signal at the every rise timing of the RF clock. Figure 2 shows the results of the reconstruction. Left figures show the mountain plot during one synchrotron oscillation period and the first projected histogram. Right figure shows the reconstructed 2D distribution in the longitudinal phase

#E-mail address: yoshimoto.masahiro@jaea.go.jp

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPTY003

space, the bunched beam profile, and two measured Δp/p profiles. The Δp/p profile can be obtained by projecting the reconstructed 2D distribution onto the vertical axis. However this projection method has a risk of overestimating it because of the deformation of the 2D distribution from the filamentation in phase space. Thus Δp/p profile is redefined as the cross section of the 2D distribution on the vertical axis.

Validity of the Longitudinal Tomography

The accuracy of the Δp/p measurement depends on the accuracy of the reconstruction by the simple LT algorism. Therefore, we have to evaluate the validity of the simple LT algorism.

At first, we confirmed the reproducibility of the 2D distribution. Even if the synchrotron oscillation frequency shifts by changing the RF bucket height, the reconstructed longitudinal 2D distribution should not be changed. In the experiment, the bucket height can be controlled by the number of the driving RF cavities. By changing from 6 cavities to 12 cavities, one synchrotron oscillation period was reduced as shown in Fig.3. After the reconstruction with the simple LT algorism in two cases, two measured Δp/p profiles were normalized and compared. Two Δp/p profiles completely correspond to each other as shown in Fig. 4.

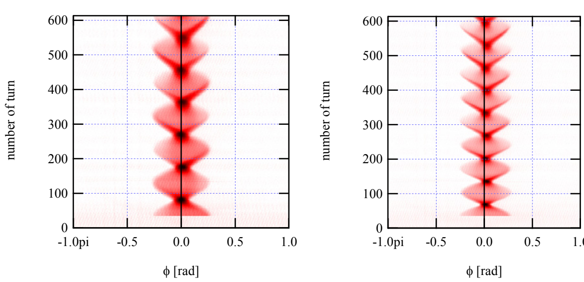

Figure 3: Left figure shows the mountain plot on the low RF bucket height operation with 6 cavities driving, and right figure shows the one with 12 cavities.

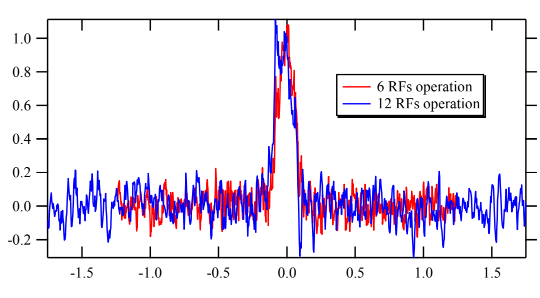

Figure 4: The comparison of the measured momentum spread profiles between 6 cavities with 12 cavities.

Next, to confirm the accuracy of the Δp/p measurement, we compared and evaluated the quantities of the measured Δp/p with two different measurement methods. One is the Gaussian fitting to the Δp/p profile obtained from the reconstructed 2D distribution. In this analysis, the quantity of the Δp/p is defined as single σ of the Gaussian fitting. The other is the estimation of the debunching time in RF switched off. Figure 5 shows the beam spread without the RF capture in the mountain plot. The debunching time can be estimated from the slope in this graph. The measured Δp/p summarised in Table 1. However the Δp/p measured from the debunching time should be divided by 2 to compare the single σ of the Gaussian fitting. The quantities of the Δp/p measured by two different methods are consistent.

From all above results, it was found out that the simple LT algorism has the high reproducibility and the accuracy of the measurement quantity. We can confirm the validity of the Longitudinal Tomography.

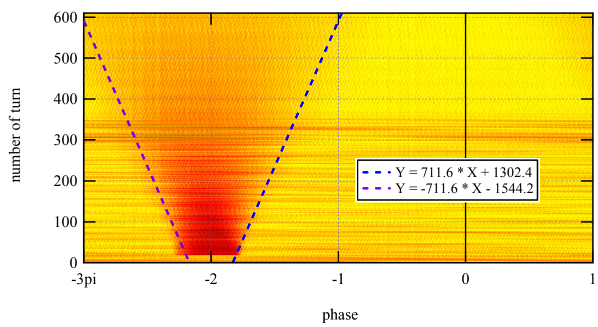

Figure 5: The spread of the beam debunching in mountain plot due to the RF switched off.

Table 1: The Measured Δp/p Comparison

(1) RF ON	cross section	projection
	0.070 %	0.071 %
(2) RF OFF	ΔT/T	Δp/p (half)
	0.000703	0.073 %

Expansion to the Acceleration Mode

This simple LT algorism is developed for the beam storage mode where the synchronous phase (ϕ_s) is constant. On the other hand, in the beam acceleration mode, the ϕ_s is shifted, but its variation is very small at the beam injection period. Then we expect the effect of the ϕ_s shift during the first one period of the synchrotron oscillation is negligibly small.

In order to concern the effect of the ϕ_s shift, we curried out the particle tracking simulation and reconstructed the longitudinal 2D distribution from the simulation results with the simple LT algorism. The longitudinal particle behaviour is simulated in the storage mode and the acceleration mode with same initial beam condition: number of particles is 500, the bunch length is 228ns, and the Δp/p is about 0.8% as shown in Fig. 6(a). Figure 6(b-1) shows the mountain plot which is fabricated from the simulated particle distributions for every turn in the

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPTY003

storage mode, and the ϕ_s is fixed. Figure 6(c-1) shows the one simulated in the acceleration mode, and the ϕ_s shifts clearly but it is very small. And then, longitudinal 2D distributions reconstructed from these two mountain plots are shown in Fig. 6(b-2) and 6(c-2) respectively. Both accurately reproduced the initial distribution. Thus we can apply the same simple LT algorithm to the acceleration mode for the Δp/p measurement of the LINAC beam.

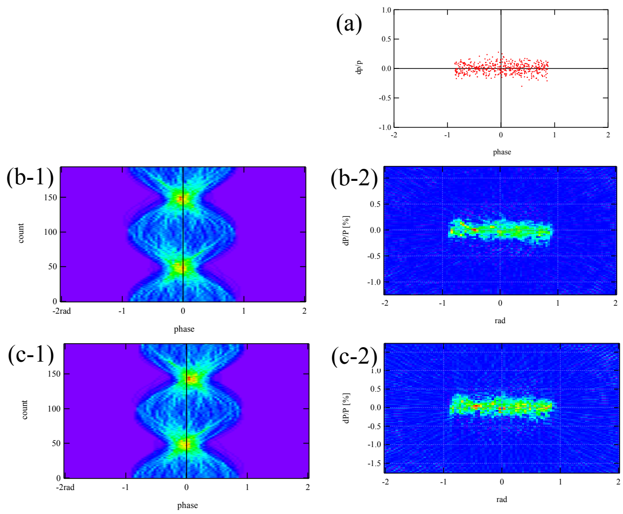

Figure 6: The particle tracking simulation and the reconstruction with simple LT algorism. (a): the initial particle distribution. (b,c-1): the mountain plot fabricated from the simulated particle distributions in the storage mode and acceleration mode respectively. (b,c-2): reconstructed two-dimensional distributions.

HIGH INTENSITY BEAM TUNING WITH LONGITUDINAL TOMOGRAPHY

To achieve the high intensity beam operation in the RCS, the optimization of the injection beam from the LINAC is essential. Key issues for the optimization are the transverse twiss matching and the longitudinal Δp/p matching. The longitudinal beam parameters were tuned by using the Debuncher (DB1, 2) installed in the LINAC to 3GeV RCS Beam Transport (L3BT). Figure 7 shows the measured Δp/p as a function of the tank level of the DB2, and Fig. 8 shows the measured Δp/p profiles in the buncher mode. In the debuncher mode, the beam was defocused and the Δp/p increases. On the other hand, the beam was changed from under-focus to over-focus in the buncher mode. Therefore the Δp/p decreases at first and next increases. Moreover the peak of the profile was reduced and flattened, but the center momentum shifts to left and the shape changes asymmetrically as shown in the Fig. 8. These results found out that the phase of the DB2 was set in non-linear field region. Therefore we fed back to the LINAC momentum tuning scheme, and successfully found the optimal focus operation point of DB2.

SUMMARY

Our simple Longitudinal Tomography algorism with Convolution Back-Projection method is very useful tool for the reconstruction of the longitudinal two-dimensional distribution. In order to measure the momentum spread of the LINAC beam, we confirm the validity of the Longitudinal Tomography. It found out that the tool has the high reproducibility and the accuracy of the measurement quantities.

This reconstruction tool is utilized for longitudinal tuning of the LINAC beam at the high intensity beam test in the RCS. By changing the tank level of the Debuncher 1 and 2, the optimal longitudinal condition was found out in on-line analysis. As a result, the RCS successfully demonstrated a full beam power acceleration of 1MW on 10 Jan. 2015. Moreover measurement results are utilized for the RCS high intensity beam tracking simulation as initial input parameters for the detailed investigation.

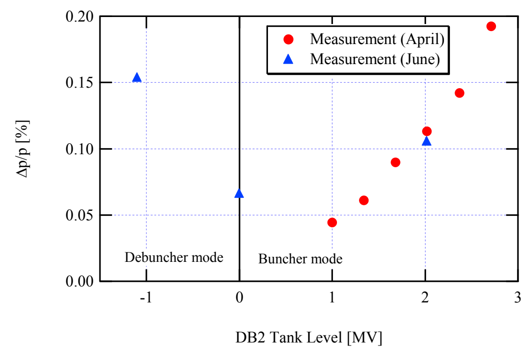

Figure 7: The measured momentum spreads as a function of the tank level of the DB2.

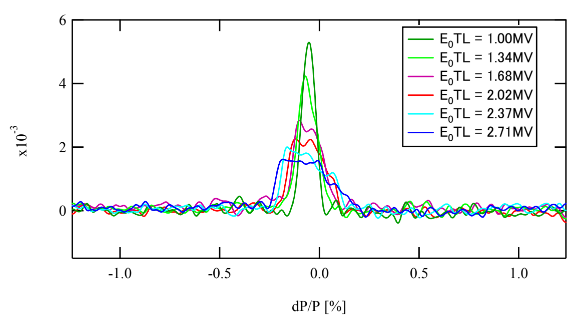

Figure 8: The measured momentum spread profiles.

REFERENCES

[1] M. Yoshimoto et al., “longitudinal phase space tomography at J-Parc RCS”, Proc. PAC09, Vancouver, pp. 3358 – 3360, 2009. (TH5PFP067).
[2] A. C. Kak, M. Slaney, “Principles of Computerized Tomographic Imaging”, IEEE Press, 1979.
[3] H. Hotchi et. al., “Recent Progress of the J-PARC RCS Beam Commissiong”, Proc. IPAC15, Richimond. (TUBB3).
[4] M. Yoshimoto, et. al., “HBC Foil Beam Study and Long-term Observation at the 3-GeV RCS in J-PARC”, J. Phys.: Conf. Ser. 417 (2013), 012073.