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IMPROVEMENT OF THE CHOPPER SYSTEM FOR RF DEFLECTOR AT THE J-PARC LINAC

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Abstract

In the J-PARC linac, the RF deflector (RFD), which is called a chopper, has been operated to kick the wasted beam and to shape the intermediate-pulse beam with the comb-like structure. The wasted beam is about 50% in the normal condition and the rest beam is accelerated by the linac and injected to the downstream synchrotron ring, RCS. In this chopping system, the faster rising time and falling time of the RF field on the RFD are required to decrease the amount of the incomplete kicked beam because its transient time influences the rising time and the falling time of the intermediate-pulse beam. The chopper controllers, which has the fast RF-switch to generate the particular RF pulse according to the intermediate-pulse beam, were improved for the faster RF falling time by outputting a few pulses with anti-phase. The beam study for the new system was successfully done and the rising time of the intermediate-pulse beam was improved to 10 nsec from 17 nsec.

INTRODUCTION

In the J-PARC linac, a RF deflector (RFD) was installed as a chopper in Medium Energy Beam Transport (MEBT) line between 3-MeV RFQ and 50-MeV DTL [1]. RFD plays an important role in the chopper system generating the intermediate-pule beam [2–6]. On the normal operation, the approximately half beam, which is kicked by RFD shown in Fig. 1, is led to a scraper and the residual one goes straight ahead as usable beam. On the other hand, there is always incomplete kicked beam for the transient time of the rising and falling on the RF field. It has the different trajectory comparing with one of the usual beam and can cause the beam loss and the radio-activation on the downstream [7]. Therefore, a very low loaded-Q cavity and a RF source with the high-speed response are required as the chopper system.

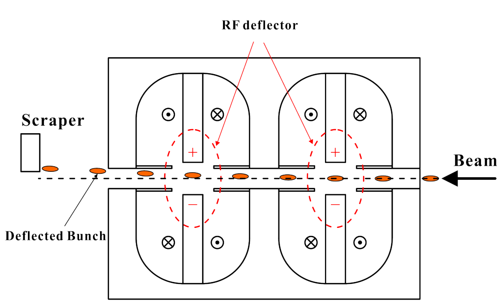

Figure 1: Schematic view of RFD. The wasted beam is kicked and led to a scraper.

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RF SYSTEM FOR RFD

The particular RF pulse, which has the repetition of RF-ON and RF-OFF with the cycle of about 815 nsec on a macro-pulse, is formed by the special module with the fast RF-switch called a chopper controller. For the faster rising time of the beam, the chopper controller was improved to output the short RF pulse with anti-phase in the timing to change from RF-ON to OFF. The characteristics of the short RF pulse can be adjusted with two parameters, attenuation and number of pulses. Figure 2 shows the output of the chopper controller with anti-phase function. The actual falling of the RF field has the ringing associated with the reflection from the cavity and characteristic of the solid-state amplifiers. The new function of the chopper controller is expected to chancel the ringing effect and the faster rising time of the intermediate-pulse beam.

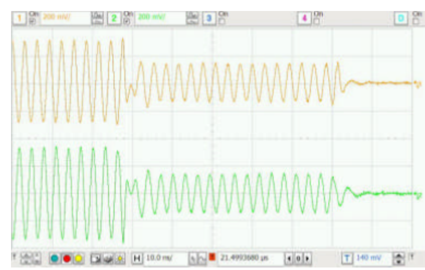

Figure 2: Oscilloscope's capture screen of the falling signal of the chopper controller. After the RF pulse falls, the short pulses with anti-phase are appeared.

The RFD system consists of individual two cavities which are called RFD_U and RFD_D. Each cavity has a solid-state amplifier and a LLRF system with a chopper controller shown in Fig. 3. The amplitude and phase, the relative timing, the new anti-phase function can be independently tuned [8].

PHASE TUNING

The RF amplitude was determined by limit of the maximum output power of the solid-state amplifier (120 kW) and design of the RFD field (2.6 MW/m). The RF phase was independently tuned by the kick-out angle, which was measured by the beam position monitor (called BPM04X) between RFD and the scraper, in the beam commissioning. When the correlation of the phase and the beam position was measured, the optimized phase was obtained from the largest kick-out angle against the beam current center. Figure 4 shows the results of the phase tuning of RFD_U in

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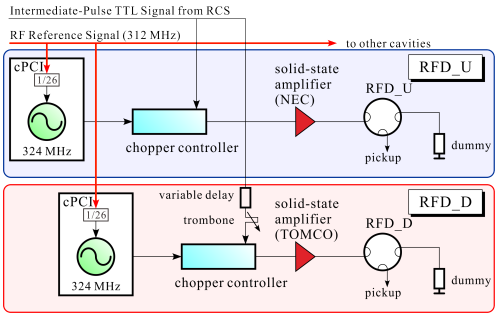

Figure 3: Schematic view of the chopper RF control system. There are two RF cavities and the parameters can be independently tuned.

the condition of zero amplitude of RFD_D. The phase of RFD_D was adjusted in the opposite method.

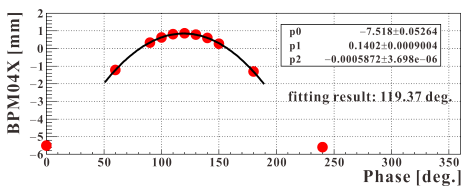

Figure 4: Results of the tune of the RF phase (RFD_U). The optimized phase can be obtained by the largest kick-put angle.

RELATIVE TIMING TUNING

The two solid-state amplifiers for RFD_U and RFD_D have a different characteristics. Additionally the waveguide lengths between the amplifier and the RFD cavity are not uniform. Therefore, the relative timing for two RFD cavities has to be tuned to the proper behavior of the beam. The RF timing of RFD_D has the 3 cycle delay of 324MHz (about 9.3 nsec) against that of RFD_D in principle, because the distance of two gap centers of RFD is $3\beta\lambda$.

In the beam commissioning, the raw signals of BPM05Y shown in Fig. 5 (a) were taken by the oscilloscope, Tektronix DPO7354C of 3.5GHz and 40 GS/s. Those signals were offline analyzed using fast Fourier transform (FFT) while drifting the time gate (b). The intensity of the component with the frequency of 324MHz could be obtained as a function of time (c).

The falling waveform of the intermediate-pulse beam was adopted to evaluate the relative timing tune because the rising one is affected by the ringing of the falling of the RF field. Figure 6 shows the falling waveform of the intermediate-pulse beam obtained by BPM05Y with various relative delay settings. It can be seen by the faster falling time with the relative delay of 22 nsec (blue dash-dot line) than one of 6 nsec (black solid line)[1]. On the other hand, when the relative delay is larger value such as 46 nsec with the cyan long-dash

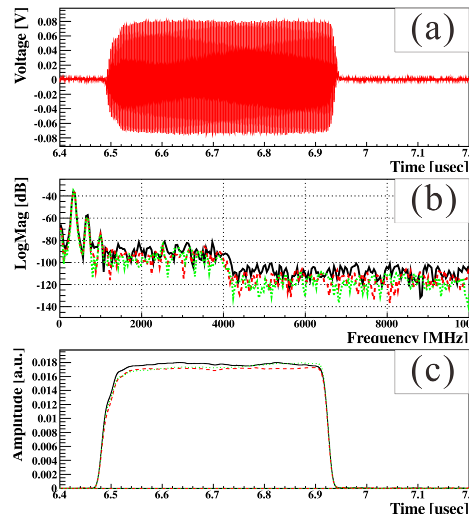

Figure 5: (a) raw signal of BPM05Y, (b) FFT analysis results and (c) intensity of the component of 324MHz, respectively.

line in Fig. 6, the shape of the falling pulse becomes blunt. The falling time was quantitatively evaluated in Fig. 7. Here, there are two amplitude settings of the LLRF system, normal operation (AMP:4000) and half (AMP:2000) because the falling waveform lessens to decidedly measure a different in the relative timing. The falling time was defined by the time period from 80% to 20% of peak. The relative delay value with the fastest falling time could be obtained to 20 nsec.

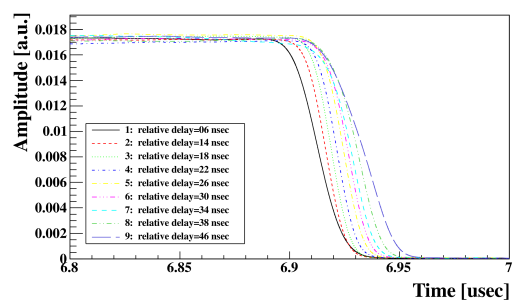

Figure 6: BPM05Y falling shape of the intermediate-pulse beam depending on the relative timing. It can be seen by the faster falling time with the relative delay of 22 nsec of the blue dash-dot line than one of 6 nsec of the black solid line and of 48 nsec the cyan long-dash line.

ANTI-PHASE FUNCTION TUNE

The effect of the ringing on the RFD_U cavity is larger than that of RFD_D because the RFD_U cavity installed on the upstream side has the larger kick-out angle. The ringing of the RFD_U RF field is louder than that of the RFD_D one to expect that the mismatch of the RFD_U system is greater. Additionally, enough time for this study was not able to be ensured in the restricted beam time. Therefore, the parameters of the anti-phase function were adjusted and used for the RFD_U system.

[1] This value means the setting value of the variable delay module shown in Fig. 3 and no actual relative time difference.

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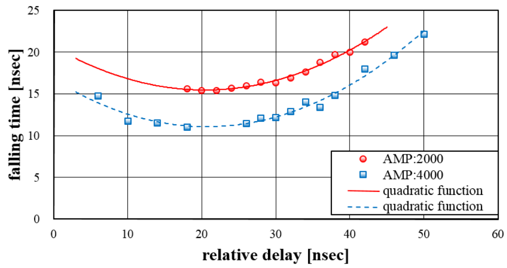

Figure 7: Results of the relative timing tune. The beam study using BPM05Y signals was performed on the two conditions with different RF amplitudes.

In the same way as the relative timing tune, the oscilloscope with the high sampling rate, DPO7354C, was used to take the data of BPM05Y. The FFT method was utilized to analyze the raw signals and to calculate the waveform of intensity.

There are two parameters, attenuator and number of anti-phase pulses, for the chopper controller. Figure 8 shows the amplitude signals of 324MHz frequency component depending on these parameters. The original waveform without the anti-phase function, which is represented by the black line, has the bump in the rising. It seems to be affected by the ringing on the falling of the RF field. When the anti-phase function implemented in the chopper controller was used, the bump was dissipated and the rising time was improved.

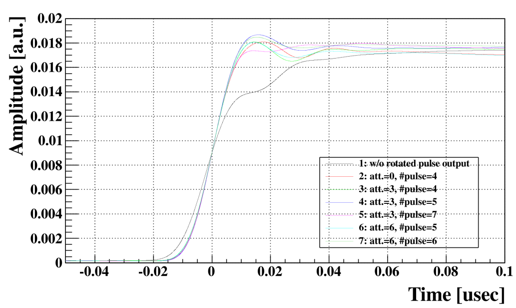

Figure 8: BPM05Y rising waveform of the intermediate-pulse beam depending on the parameters of the anti-phase function, when the only RFD_U was driven. The time of the abscissa axis was shifted to be zero in the amplitude of 0.01. To avoid the use of the anti-phase function, the waveform of the rising shown in the black solid line has the bump on the rising. It is adversely affected by the ringing on the falling of the RF field.

Figure 9 shows the rising time depending on the parameters of the anti-phase function. In the figure, the rising time was defined by the time from 20% to 80% of peak. When the function of anti-phase function was not used, the rising time became about 17 nsec. When the every parameters of the anti-phase function (<6dB, <8 pulses) were set in the region of this figure, the better results could be obtained. The rising time was improved to about 10 nsec by optimizing of the parameters of the anti-phase function. In the actual operation, the attenuation of its parameter was 3dB and the number of pulses was 6.

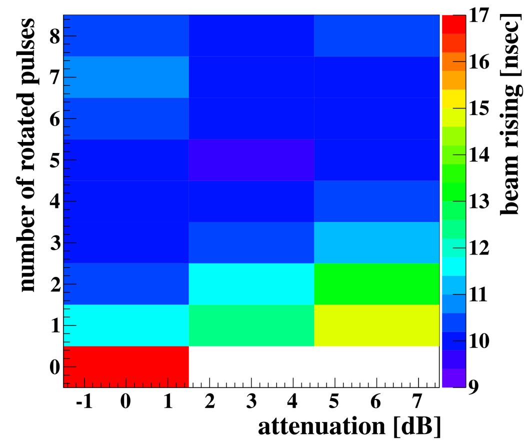

Figure 9: Results of the anti-phase function tune. When the function of anti-phase function was not used, the rising time became about 17 nsec. It was improved to about 10 nsec by optimizing the parameters of the anti-phase function.

CONCLUSION

In the J-PARC linac, the RF deflector has been utilize to generate the intermediate-pulse beam. The fast rising time and falling time of the RF field on the RFD are required to decrease the amount of the incomplete kicked beam. However, the ringing on the falling of RF field exists for the mismatch of the RF system and RFD. The chopper controller was improved to implement the function outputting the short pulse with anti-phase in changing to RF-ON from RF-OFF. The beam study for the new function was successfully done in October of 2017. The bump of the waveform in the intermediate-pulse beam dissipated and the rising time of the intermediate-pulse beam was improved.

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