CAVITY EXCITATION OF THE CHOPPED BEAM AT THE J-PARC LINAC

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Abstract

In the J-PARC linac, the beam energy injected into Rapid-Cycle Synchrotron (RCS) was upgraded up to 400 MeV by the installation of 25 Annular-ring Coupled Structure (ACS), in 2013. The initial frequency of RCS was shifted to 1.227 MHz in order to change the velocity of the injection beam. In the linac, the beam is chopped as the comb-like structure with this frequency by the RF deflector. This chopped beam excited the post-coupler mode (PC1) of DTL2 and caused the instability of the RF field. Therefore, the property of this beam excitation was investigated. Additionally, the frequency components of the beams with some thinned structures to tune the beam power and to perform the commissioning were observed to manage the risk of other mode excitation.

INTRODUCTION

J-PARC is one of the highest intensity proton accelerator facilities in the world. It consists of a H^- linac, a 3-GeV Rapid Cycling Synchrotron (RCS), and, a 30-GeV Main Ring synchrotron (MR). The accelerated beam is provided for the wide-ranging applications such as materials and life science, particle and hadron physics, and so on [1].

In the J-PARC linac, the energy of the injection beam to RCS was upgraded from 181 MeV to 400 MeV by the installation of 25 additional Annular-Coupling Structure linac (ACS) modules and 25 new 972-MHz RF systems in the shutdown of 2013 [2]. The 400-MeV acceleration was successfully achieved on January 17th, 2014 and the user operation with the 400-MeV injection energy started from February 17th [3, 4]. In this energy upgrade, the velocity (β) of the injection beam was shifted from 0.55 to 0.71.

In the normal operation of the present J-PARC linac, the width of a macro-pulse is 500 μsec and the repetition rate is 25 Hz. This macro-pulse has the internal structure like a comb, which called an "intermediate-pulse", by the RF deflector to synchronize the initial frequency of RCS. This frequency ($f_{initial}$) is expressed as

$$f_{initial} = \frac{\beta c}{L/N}. \quad (1)$$

Here L, N and βc are circumference (=348 m), number of bunches (=2 in the typical operation) in RCS and the velocity of the injection beam, respectively. Therefore, the frequency of an intermediate-pulse was shifted from 0.939 MHz to 1.227 MHz to upgrade the injection energy. Figure 1 shows the pulse structure of the J-PARC linac.

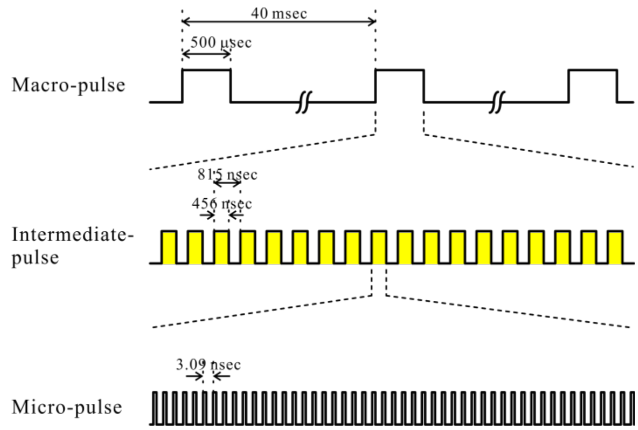

Figure 1: Pulse structure of the J-PARC linac. The frequency of an intermediate-pulse was shifted to 1.227 MHz (815 nsec) due to the energy upgrade of the linac.

DTL2 PC1 EXCITATION

RF properties for the low-level measurement

The second Alvarez-type DTL (DTL2), which consists of 42 full-size drift tubes, 42 post-couplers and 10 fixed tuners, accelerates the H^- beam from 20 to 37 MeV. In order to achieve the stabilized-uniform of the filed distribution for the accelerating mode (TM_{010}), the post-couplers were tuned [5]. Figure 2 shows the dispersion curve of DTL2 for the low-level measurement. The frequency difference of the first post-coupler mode (PC1) from 324 MHz, δf, was −1.2419 MHz.

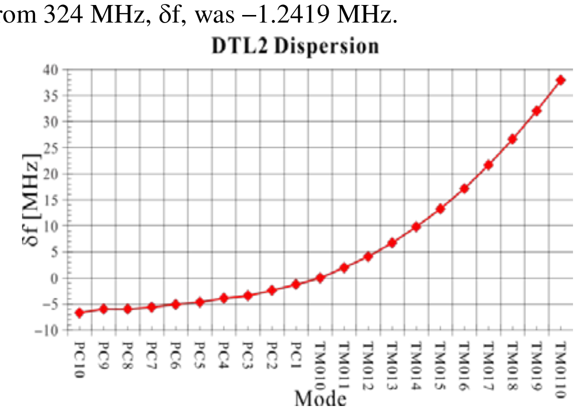

Figure 2: Dispersion curve of DTL2. The frequency of the PC1 mode is $\delta f = -1.2419$ MHz against that of TM_{010}.

Excitation by chopped beam

Figure 3 shows the result of the Fast Fourier Transform (FFT) analysis for a pickup signal of DTL2 with the chopped beam by the frequency of 1.227 MHz. Two peaks except for the driven frequency, 324 MHz, by a

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ISBN 978-3-95450-142-7

klystron could be confirmed. The frequency component of δf=−1.23MHz had the larger peak of 14.6dB than that of δf=+1.23MHz, whereas the heights of two peaks were almost equal at other cavities. That difference was expected to be caused by the excitation of the PC1 mode with δf=−1.2419 MHz by the chopped beam.

To observe the decay region after the macro-pulse, the frequency of this peak changed to δf=−1.245 MHz. This frequency means the original one of the excited mode for the free oscillation and corresponded to the results of the low-level measurement of PC1. In addition, when the chopping frequency was changed to 1.250 MHz from 1.227 MHz by the local oscillator, this peak heightened to −20.9dBm from −28.7dBm. These results mean the PC1 mode of DTL2 was excited by the chopped beam with a comb-like structure.

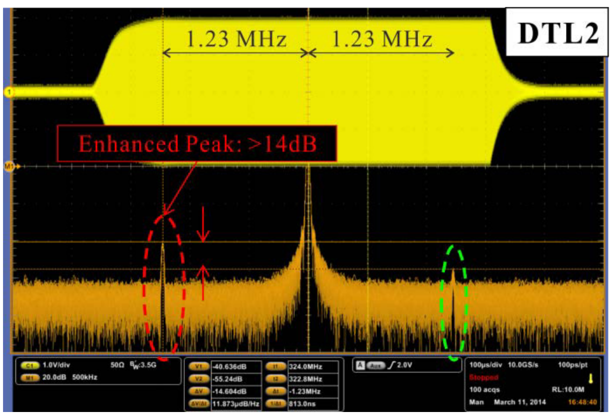

Figure 3: Result of the FFT analysis for the DTL2 field with the chopped beam. The peak of δf=−1.23 MHz is enhanced in comparison with that of δf=+1.23 MHz.

Beam Current Dependence

The relative field of the excited PC1 mode in the beam current of 16 mA and 26 mA were obtained to −32.3dBm and −28.7dBm, respectively. When the current increased $26/16 = 1.6$ times, the strength of the excited field grew up to $-28.7-(-32.3) = +3.6\,\mathrm{dB}$, 1.5 times at field. Although there are only two data points of the beam-current dependence, the strength of the excited field is thought to proportional to the beam current.

Effect of RF Field Stability Control

Figure 4 shows the amplitude of DTL2 with the chopped beam of 16 mA. The stabilities for the pickups ID#9 (yellow) and ID#4 (red) were obtained to ±0.5% and ±0.2% in peak-to-peak, respectively. The difference in these results comes from the strengths of couplings to the PC1 mode. As a comparison, the amplitude stabilities of other 324-MHz cavities are almost less than ±0.15%.

The field stabilities in the J-PARC linac are required to ±1 deg. in phase and ±1% in amplitude. Therefore, if the beam current increases to 50 mA of the design value, the expected amplitude stabilities of DTL2 at the pickup ID#9 are estimated to ±1.6% for the excitation by the chopped beam. That estimated value cannot satisfy the requirement.

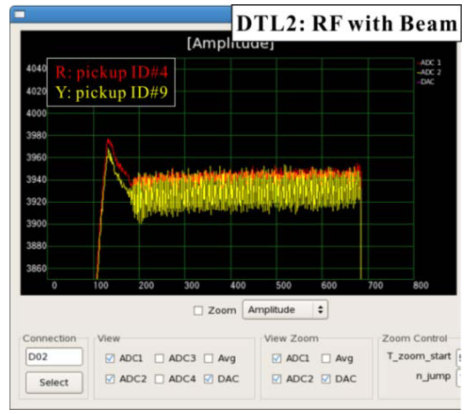

Figure 4: Amplitude stability of DTL2 with the chopped beam in the condition of 16 mA.

Tuner Position Dependence

When the accelerating frequency, TM_{010}, was detuned to ±20 deg. by the mechanical tuner, the strengths of the excited PC1 mode were changed to only ±1dB. It is thought that this weak contribution comes from not rotating the magnetic field in the outside of the cavity in a difference from the TM mode. Therefore, it is not expected that this dependence make an effective solution to realize the RF stabilities with high precision.

Pickups Dependence

The certain method to shift the frequency of the PC mode is simplistically to retune the insertion length and the rotation of the post couplers. However, to realize this retuning, we have to uninstall DTL2 to confirm the uniform of the accelerating field. This is clearly neither practical. Additionally, acceptable results can be obtained by other approaches. We concluded that the avoidance of this excitation is hard.

Therefore we will use other pickups with weaker couplings to the PC1 mode like pickup ID#5 in fig. 5 as the tentative method. It means that the effect to the field control of the RF system by the excited mode can be reduced and at least the amplitude and phase of the accelerating frequency can be stabilized.

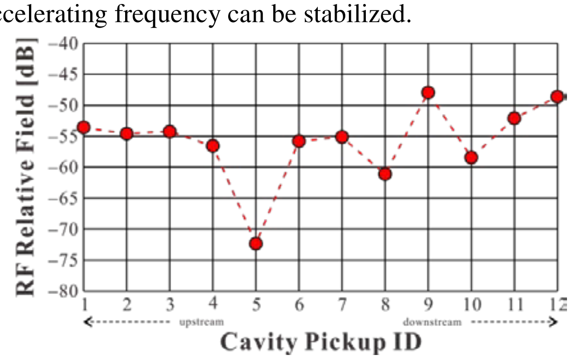

Figure 5: Pickup dependence on the couplings for the PC1 mode of DTL2. The pickup ID#9 has the largest coupling.

THINNED INTERMEDIATE-PULSE

In RCS, maximum number of buckets is two and in the typical user-operation, the beam with 2 bunches is utilized. However, 1-bunch operation can be realized to thin the intermediate-pulses by half, which condition is called "thin ratio is 16/32#". Additionally, sometimes some intermediate-pulses are thinned to adjust the beam power to users and to carry out the beam commissioning of the ring. In the latter case, there are many patterns of thinned intermediate-pulses.

The frequency components of the chopped beams with typical thinned intermediate-pulse, which was obtained by FFT for the signal of a Beam Profile Monitor (BPM), are shown in fig. 6. In the case of (a) the 1-bunch operation, the frequency was one-half of 2- bunches operation, 0.614 MHz. On the other hand, it was found that the chopped beam of (b) is produced by the overlap of many frequency components (1/2, 1/4, 1/16 of 1.227 MHz). Although the contribution of other components is smaller than that of 1.227 MHz, we already had the experiment that the other frequency component of a thinned intermediate-pulse (24/32) excited the PC1 mode of DTL1 (δf=−1.352 MHz) as the similar case. On the other hand, since the frequency component has the law depending on the thinned pattern, we can predict a certain level of the risk exciting the cavity by the thinned beam before the measurement.

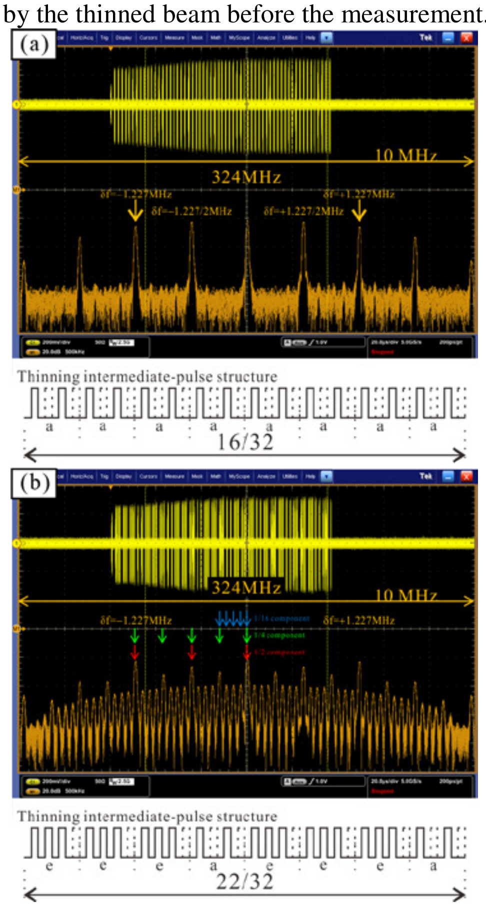

Figure 6: Frequency component of (a) the 1-bunch operation (16/32) and (b) a thin ratio of 22/32 for the thinned intermediate-pulse.

Although the thinning method is easy and useful, we should not forget the possibility of the excitation of an unexpected mode.

OTHER MODES EXCITATION

To evaluate the cavity excitation by the chopped beam, we prepared some chopped beam with a various frequency by the local oscillator and investigated the property of the cavity excitation. The cavity excitations of the PC1 mode of DTL1 (δf=−1.352 MHz in the low-level measurement) and of the TM_{011} mode of DTL2 (δf=−1.965 MHz) could be confirmed by the chopped beams with the periods of 740 nsec (1.351 MHz) and 510 nsec (1.961 MHz), respectively. These results mean every mode can be excited by the chopped beam if the chopped beam has the close frequency component to the resonance frequency. However, if we have the results of the low-level measurement, we can predict the beam excitation from that frequency component of the chopped beam.

SUMMARY

In the J-PARC linac, the frequency of the intermediate-pulse was shifted to 1.227 MHz for the injection-energy upgrade to 400 MeV in 2014. This chopped beam excited the PC1 mode of DTL2 and induced the instabilities of the RF field. The stabilities of the amplitude and the phase in the beam condition of 50 mA are expected not to satisfy the requirement. Therefore, we will use other pickups with the weak couplings to the PC1 mode as the tentative method. In addition, the thinned beam to adjust the beam power and to perform the beam study could have many frequency components and might cause the unexpected RF instability by exciting other modes of a cavity. Therefore, we need the continued and careful observation.

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N/32: The number of *N* in 32 is alive as the intermediate-pulse and (32−*N*) is thinned. The normal operation of 2-bunches without the thin becomes 32/32. There are some patterns to choice the thinned pulse in the same *N* value.

ISBN 978-3-95450-142-7