Study of Adiabatic Condition on Beam Compression with Barrier Bucket

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Abstract

A beam compression experiment by barrier buckets was performed at the HIMAC using a high-field gradient cavity which involved magnetic alloy cores. The cavity generated two barriers, the waveforms of which were improved to make a flat potential by optimizing the drive signal. So that the smooth beam distribution was achieved. In the beam compression process, the momentum spread was measured varying the sweep speed of barrier so as to study the adiabatic condition. It was found that the speed 10 times slower than the drift time of beam satisfied it.

1 Introduction

Tune shift caused by space charge, which is in inverse proportion to a bunching factor, limits the beam intensity in a proton synchrotron. In order to reduce the tune shift and the resultant beam loss, it is necessary to increase the bunching factor, that is, to decrease the peak line density. A barrier bucket injection scheme[1, 2] enables to maximize the bunching factor, which becomes almost 1, because a injected beam bunch is debunching in a flat RF potential made by two barriers. It is also possible to accumulate more bunches than the harmonic number of the ring before the RF bucket becomes full. It is a effective scheme to increase the beam intensity of a proton synchrotron.

A barrier bucket experiment[3, 4] was performed at the Brookhaven AGS during 1998 high intensity proton run[5]. Two dedicated barrier cavities were used to carry out barrier gymnastics. One is a magnetic alloy(MA) loaded-cavity [6] developed by KEK, and the other is one of the AGS accelerating cavity modified by BNL. In order to conserve a longitudinal emittance, a barrier is required to be moved adiabatically. Therefore, the adiabatic condition for the debunching process was studied in the experiment. A longitudinal emittance growth was observed during accumulation. The main causes was a longitudinal mismatching between the bunch and the RF bucket. It was also found that the RF potential distortion by an overshooting voltage of the MA cavity and the beam loading of the ferrite cavity prevented the beam from debunching smoothly.

In order to supplement the results of adiabatic condition, a beam compression experiment by barrier buckets was performed using a high-field gradient MA(HGMA) cavity[7, 8] at the HIMAC[9], where the adiabatic condition and longitudinal mismatching was studied and cancellation of a potential distortion was tried. The experimental results are described in this paper.

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2 Experimental setup

A beam compression experiment was performed at the HIMAC(Heavy Ion Medical Accelerator in Chiba) in the NIRS, where a HGMA cavity was installed for the beam test. Two barriers of the peak voltage of 1.7kV were generated by the cavity, which were triggered at a revolution frequency of 261kHz. One barrier is fixed and the other was moved by modulating the trigger frequency with a synthesizer. The adiabatic turning-off of the barrier was carried out with amplitude modulation of the drive signal by a PIN-diode attenuator.

3 Experimental results

3.1 Potential improvement

A flat potential is necessary to make a smooth beam distribution in a barrier bucket injection scheme. In the experiment at the AGS, a bump was formed in the potential well by an overshooting voltage of the MA cavity, where some particles were trapped. The bottom of the barrier potential made by the HGMA cavity was not flat as shown in Fig.1(d), because there was a small bump. It has been improved, however, by mixing harmonics of 1 and 2 into the drive signal, because an MA cavity can be driven by an arbitrary function due to its broad-band impedance. The quite flat separatrix has been achieved by the correction, which is shown in Fig.1(b). A beam compression have been performed using the waveforms. Figure 2 shows the mountain range plots of the beam monitor signal. In the case without correction, it is clearly seen that the bunch shape is distorted as same as that of potential. On the other hand, the correction makes the beam distribution smooth.

3.2 Adiabatic condition on beam compression process

In order to study the adiabatic condition, a beam bunch was spread changing the sweep speed of barrier in the experiment at the AGS, the momentum spread of which was measured. It was found that the sweep time as slow as 10 times of the drift time of beam was adiabatic there. Moreover, the simulation was performed by a multi-particle tracking code, the result of which was consistent with the experimental ones. In the debunching process, however, the potential distortion by the beam loading of the ferrite cavity induced the growth of the momentum spreads. The momentum spreads were

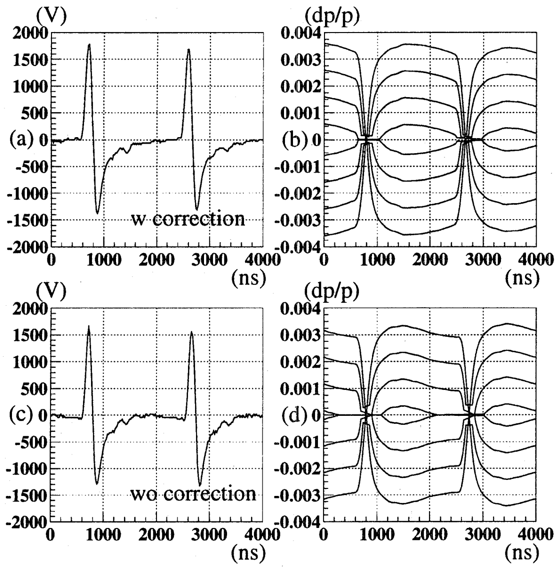

Fig. 1 Gap voltages and RF buckets: (a), (c), gap voltages; (b), (d), RF buckets. (a), (b), With waveform correction; (c), (d), without correction. One revolution period is 3826ns.

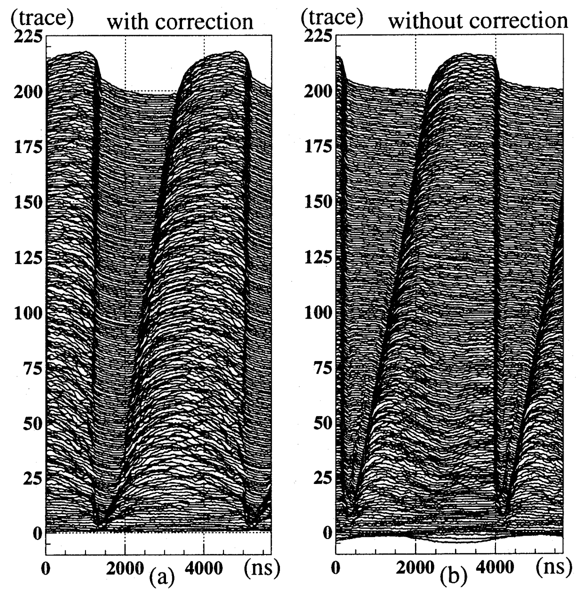

Fig. 2 Mountain range plots of beam monitor during the beam compression. (a): with correction, (b): without correction. The period between traces is 500μs. In both plots, the sweep times are 100ms/180°. One can see that the beam distribution is not flat around 10 $\sim$ 80th trace in the case without correction(b).

not decreased as same as spread phase gap.

An adiabatic condition measurement was performed during the beam compression process by barriers without any potential distortion at the HIMAC. The injected beam was coasting in the ring, where a barrier voltage was increased adiabatically. Then the barrier was divided into two barriers. While one of them was fixed at the phase, which was assumed to be 0°, the other was moved from 0° to 180°, where the one revolution period corresponded to 360°. As the barrier was moved, the width of beam was shortened as shown in Fig. 2. As soon as the barrier was moved by 180°, two barriers were turned off suddenly. After cmpletely debunching, the momentum spreads were measured by the Schottky signal while varying sweep speed of the barrier. The initial momentum spread was measured when the RF voltage was off, which was $\pm 0.1\%$ and corresponded to the drift time of 4.3ms. If the barrier is moved adiabatically, the beam emittance is conserved, the momentum spread of which should become double the initial one. The experimental results are shown in Fig. 3.

The experimental results almost agree with double the initial momentum spread, which show that the adiabatic condition is satisfied. Moreover, the simulation results are compatible with the experimental ones. When the sweep times are from 5ms to 50ms, the momentum spreads are slightly larger than the other values. Therefore, the results seem to be in agreement with the conclusion about adiabaticity which was derived from the experiment at the AGS.

3.3 Longitudinal mismatching

The longitudinal mismatching mainly caused the longitudinal emittance growth in the experiment at the AGS. In the experiment at the HIMAC, the longitudinal mismatching was caused on purpose to study the emittance growth by the mismatch, where the momentum spread of beam was measured. In the case aiming to cause the mismatching, a barrier was moved from 0° to 180° adiabatically. Then the barrier was jumped back to 0° in 0.2ms and stayed at 0° in 50ms, then turned off suddenly. In the matching case, after the barrier was moved from 0° to 180°, it was moved back to 0° adiabatically. Then it was turned off suddenly. Those patterns of the barriers are shown in Fig. 4. The measured momentum spreads are listed in Table 1. In the ordinary compression, the momentum spread was measured after the barrier was moved from 0° to 180° adiabatically.

Table 1
The momentum spreads.

	momentum spread($\pm\%$)
initial	0.10
ordinary compression	0.17
mismatching	0.18
matching	0.13

In the mismatching case, the momentum spread should become double the initial momentum spread, while its initial value should be kept in the matching case. The experimental results almost agree with the expected values. A longitudinal mismatching induced the longitudinal emittance growth.

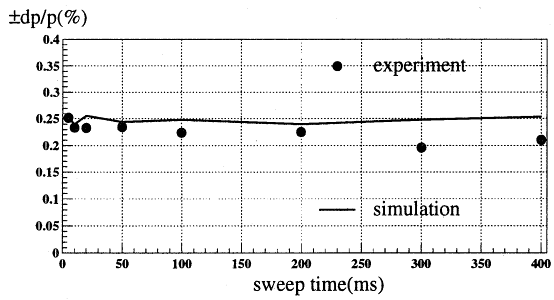

Fig. 3 Momentum spreads for the sweep time. The solid circles and lines are the experimental and simulation results, respectively. The initial momentum spread is ±0.1%.

4 Conclusion

A beam compression experiment with barriers was performed at the HIMAC. A high-field gradient MA cavity was used here, which generated two barriers. The distorted potential by the barriers was improved successfully with mixture of a few harmonics, so that the smooth distribution of beam was achieved. The momentum spreads were measured varying the sweep speed. It turned out that it was necessary for the sweep time to be slower than 10 times of drift time of the beam, which satisfy the adiabatic condition. A longitudinal mismatching between the RF bucket and the beam bunch induced the longitudinal emittance growth.

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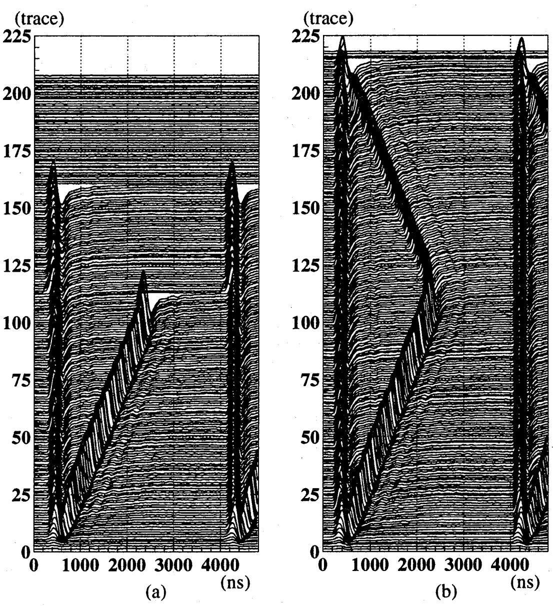

Fig. 4 Mountain range plots of gap voltage. (a): mismatching case, (b): matching case. The period between traces is 1ms.