BEAM TEST OF THE ACCELERATION SYSTEM WITH THE DDS IN HIMAC SYNCHROTRON

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Abstract

We have examined the acceleration efficiency as a function of B-clock step size from 0.1 to 2.0 Gauss/pulse at HIMAC synchrotron. The result showed good acceleration efficiency with 0.2 Gauss/pulse, even if we haven't used feedback. Larger width case shows significant loss, suggesting a limitation due to stepwise change of acceleration frequency.

1 INTRODUCTION

Accurate and stable operation of the acceleration system of the synchrotron is very important in the medical accelerator like the HIMAC[1]. Further the quick and easy operation for beam energy switch is also required. To obtain these required performances, we have moved to the digital acceleration system[2] with a direct digital synthesizer (DDS) at the design stage of the HIMAC synchrotron[3]. The rapid development of digital technology permit the utilization of the DDS as an RF signal generator of the acceleration system of the synchrotron. With the DDS, control of the acceleration frequency can be as precise as below 10^{-5} in $\Delta f/f$. This comes from the clock accuracy with a crystal in the DDS, whose frequency accuracy is sufficient enough for the acceleration system of the synchrotron. To maintain this precision in the acceleration frequency, the DDS is controlled with digital data directly. There is no analog signal between the programmed frequency data in the pattern memory and the controlling data of the DDS. When the feedback loop of the acceleration frequency is required with the phase and radial position of the accelerated beam, these beam signals must be digitized. In spite of these advantage of frequency accuracy, the output frequency of the DDS is swept with step wise function. In the analog system with the voltage controlled oscillator (VCO), it is easy to make smooth the step wise frequency function with a low pass filter for the controlling signal of a VCO. If the frequency step is large, it may deteriorate an adiabatic condition of the acceleration process, and make longitudinal emittance growth, consequently the acceleration efficiency may become worse. To see these effect, we have tested the effect of the step height in the acceleration frequency.

2 ACCELERATION SYSTEM AND ITS PARAMETERS

In the HIMAC synchrotron, injected beam of 6 MeV/u can be accelerated up to 800 MeV/u for ion with charge to mass ratio of 0.5. Corresponding acceleration frequency is from 1.05 MHz to 7.9 MHz with harmonic number of 4. Acceleration period is 1.0 second to the maximum energy with maximum ramp speed of 1.7 T/s in the main dipole field. The momentum spread of the injected beam is 0.1%. Acceleration voltage of 6 kV can be obtained, whose value is enough to accelerate the beam with above momentum spread. In this condition filling factor of rf bucket is 60% at beginning of the acceleration with maximum ramp speed. In the pattern operation of the acceleration system, the data are generated by use of clock pulse (50kHz) at flat base and top. During acceleration period, the frequency data is given as a function of the magnetic field of the main dipole magnet. This frequency pattern is generated by use of the field clock (B-clock). The single clock corresponds to 0.2 Gauss increment or decrement in the magnetic field of the main magnet in the current system. This single clock changes acceleration frequency 204 Hz and 56 Hz at the beam energy of 6 MeV/u and 800 MeV/u, respectively. In figure 1, ratio of above jump step versus rf bucket height is shown as a function of beam energy, where the step width of the field clock is 0.2 Gauss. This shows that the relative frequency jump is large at low energy.
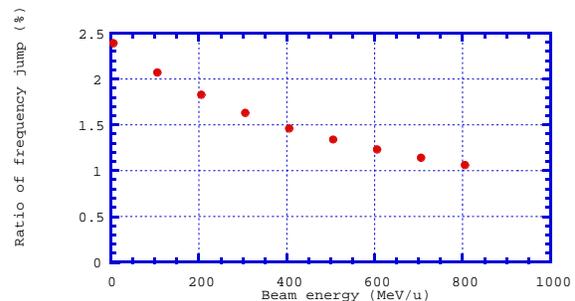

Figure 1   Ratios of the frequency jump height with 0.2 Gauss field clock to rf bucket half height as a function of beam energy. The acceleration voltage is 6 kV and the ramp speed of the dipole field is 1 T/sec.

3 BEAM TEST

To see the effect of the B-clock step on the acceleration performance, we have tested acceleration efficiency with several step widths from 0.1 to 2 Gauss/pulse. For each step width we have made corresponding pattern data of the acceleration system i.e. acceleration frequency, ferrite bias current, acceleration voltage. Concerning the other patterns such as the current pattern of main dipole magnets, quadruple magnets, we haven't changed during this experiment. The test was performed with the flat top energy of 230 MeV/u, and maximum ramp speed of 0.9 T/s. We have used the constant acceleration voltage of 6 kV. With this low maximum ramp speed, we can test with B-clock step of 0.1 Gauss. In figure 2-1 accelerated beam intensity is shown with 0.2 Gauss B-clock step, where we haven't used beam phase feedback. Bunch shape at flat base is shown with same condition in figure 2-2.

Increasing the B-clock step width, beam loss occurred at low energy region as shown in figure 3. If we turn on the beam feedback the acceleration efficiency can be improved. In figure 4, acceleration efficiencies, as defined by beam intensity ratio of flat top and just after injection, are shown for various B-clock step widths in both the cases with and without the feedback. This shows deterioration of acceleration efficiency at larger B-clock step width than 0.2 Gauss/pulse without feedback. When we use the feedback we can improve the efficiency. With the condition of 0.4 Gauss/pulse, beam loss become large especially in the case that there is no feedback of beam phase. If there is the phase feedback the situation is improved very much. This will indicate that the frequency jump excite the synchrotron oscillation which can be damped with the phase feedback loop. If the jump becomes large, higher harmonics of the beam oscillation will be excited strongly. For this higher component the phase feedback can't work, and this is the reason of large beam loss with large B-clock step even if there is the feedback. The bunch shapes at flat top without feedback are shown in figure 5-1, and with feedback in figure 5-2. To see the emittance growth of the accelerated beam with different B-clock step, bunch widths(FWHM) are shown in figure 6 with and without the phase feedback. If we increase the B-clock step, we can observe the increment in the bunch width in the case of no feedback. At the flat base this value is 106 degree. If we assume adiabatic damping in the acceleration, this bunch width will decrease to 88 degree. This value is consistent with the observed value in the case of 0.1 Gauss/pulse. With the feedback, the bunch width is same to the value of 0.1 Gauss/pulse. This indicate that the feedback suppresses the emittance growth effectively in the acceleration process.
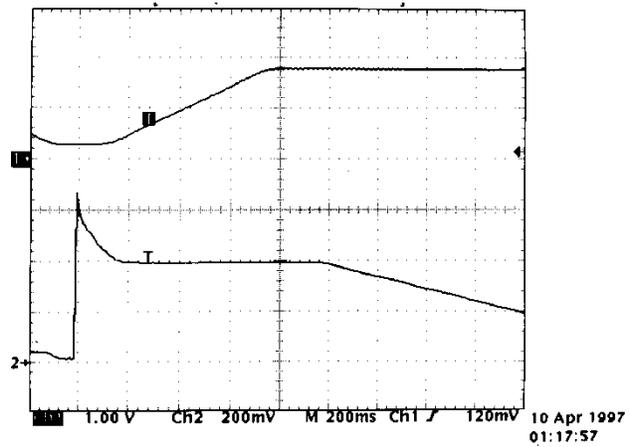

Figure 2-1   Beam intensity data (lower trace) from the injection to the flat top with B-clock step of 0.2 Gauss. Decrease of beam intensity at flat top is due to the slow beam extraction. Upper trace is current pattern of the dipole magnet. Horizontal scale is 200ms/div.
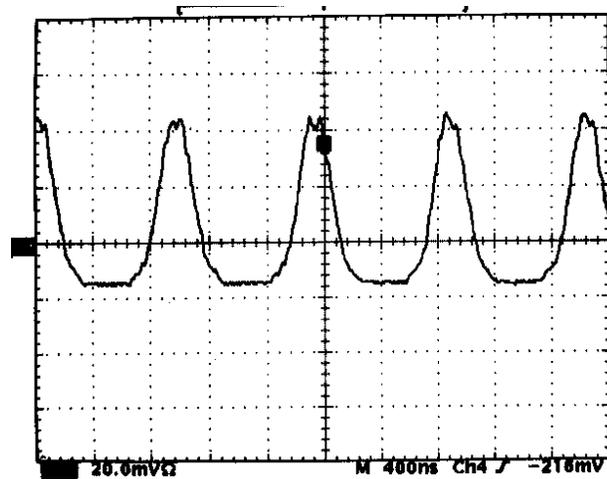

Figure 2-2   Beam bunch shape at flat base (15 msec after rf capture). Horizontal scale is 400 ns/div.
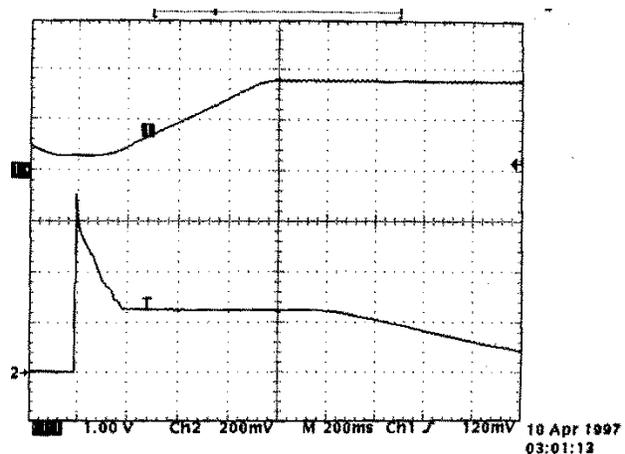

Figure 3 Beam acceleration with 0.4 Gauss/pulse instead of 0.2 Gauss/pulse in the B-clock. Traces are same as figure : 2-1.
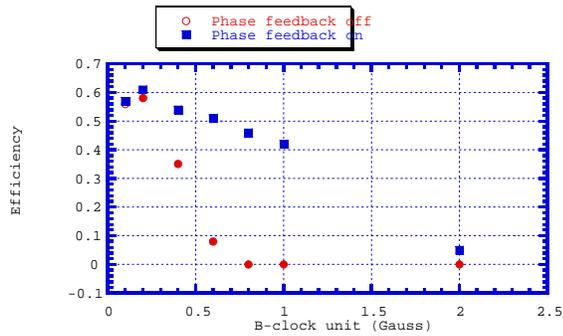
Figure 4   Dependence of acceleration efficiency on the step width of the B-clock.
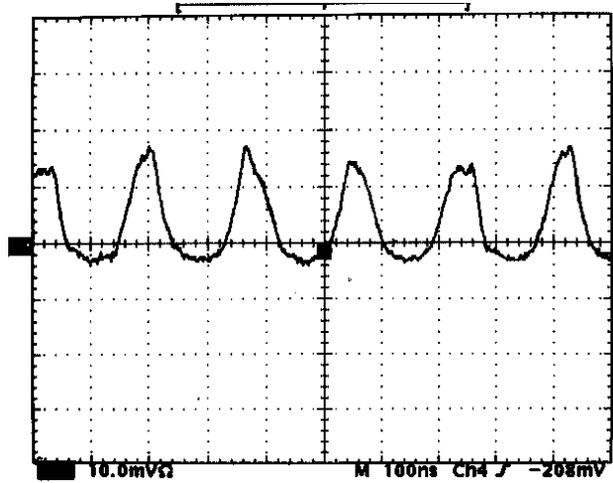

Figure 5-1   Beam bunch shape at flat top with B-clock step of 0.4 Gauss, where feedback was not used. Horizontal scale is 100 ns/div.
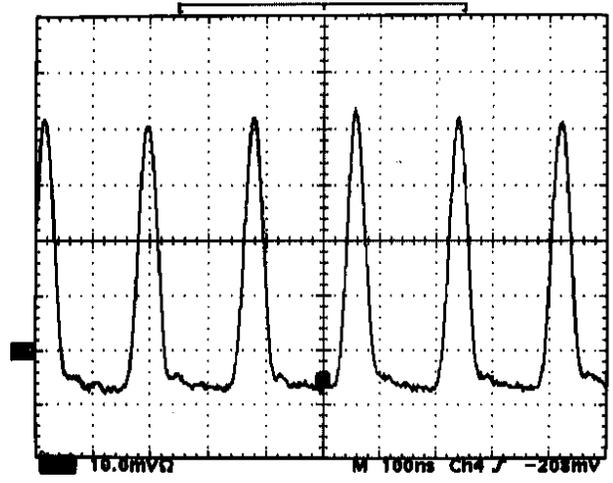

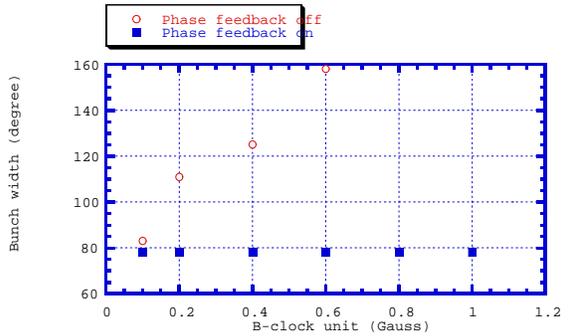Figure 5-2   Same figure as figure:5-1 with feedback.

Figure 6   Beam bunch width (FWHM) at flat top.

4 SUMMARY

The B-clock step of 0.2 Gauss/pulse seems to be precise enough to achieve good acceleration efficiency, though we can observe small longtudinal emittance growth in the case of no phase feedback. With the step of 0.1 Gauss, we can't observe any difference in the acceleration efficiency and in the beam bunch shape between the cases with and without the feedback.

5 ACKNOWLEDGEMENTS

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