TIME TREND OBSERVATION OF CERTAIN REMARKED BUNCHES USING A STREAK CAMERA

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Abstract

A streak camera with two-dimensional sweep function enables the trend of the longitudinal beam profile in the ring. In the case of the multi-bunch measurement, the different bunch profile sit on same vertical position, thus, we could not distinguish the behavior of each bunch. We have been developed a trigger circuit to measure the bunch-by-bunch longitudinal beam profile using a sweep frequency, which is not the acceleration RF frequency divided by integer. The bunch profile of each bunch sit on different position in this measurement. We observed the increase of the synchrotron oscillation amplitude from the first bunch to the 20th bunch in the KEK-ATF Damping Ring by using this system. This paper describes the measurement system and the measurement results.

INTRODUCTION

The KEK-ATF is a test facility to develop the accelerator technologies for the future Linear Collider. [1][2] The damping ring (DR) produces extremely low emittance beam and supplies the low emittance beam to the ATF2 beam line to test the final focus system. The DR operates not only in single bunch mode, but also multi-bunch and multi-train mode. To understand the instability in the multi-bunch and the multi-train operation is one of important issue in the KEK-ATF. Some fundamental parameters of DR are listed in Table 1. The design fill pattern of the multi-bunch and multi-train operation in the DR is indicated in Fig. 1. The beam from the linac is not injected equally filled in the RF buckets. The linac accelerates one bunch train consist of up to 20 bunches in one pulse. We have two types of beam train, one has 1 to 10 bunches with the bunch spacing of 5.6ns and the other has 1 to 20 bunches with the bunch spacing of 2.8ns in single train. The bunch spacing can choose by controlling the laser timing of the photo-cathode RF gun. Each train has 154ns spacing, when the linac injects 3 trains to the DR.

To diagnostic the longitudinal beam characteristics, a streak camera with synchro-scan and dual-axis sweep units, is used for measuring visible light of synchrotron radiation in the DR. We studied the damping time measurement [3] and the impedance measurement [4] using this streak camera for the single bunch operation. The theoretical work has been done for the case of multi-bunch operation [5]. From this work, some of the different longitudinal behavior from the first bunch to the following bunches are reported. So, it is important to observe the bunch-by-bunch longitudinal behavior of the instabilities in multi-bunch operation. We had used a steak camera with a sweep frequency of 1/8 of the acceleration RF frequency. Due to the slow horizontal sweep, the different bunches coming in later timing would be recorded in very close to the first one in the horizontal axis. Then different bunches would overlap each other in the horizontal direction. So, some other idea was necessary to observe the behavior of individual bunch.

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Table 1. Parameters of the DR

Beam energy	1.3 GeV
RF frequency	714MHz
Harmonic number	330
Revolution period	462ns
Synchrotron frequency	10.4kHz at Vc=300kV

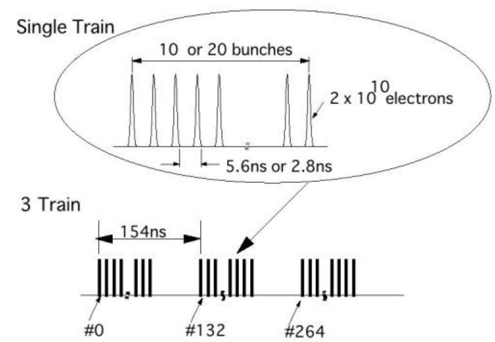

Figure 1: Beam filling pattern in DR.

SINGLE BUNCH BEAM OBSERVATION

In this section, some results of the streak camera measurement in single bunch operation in the DR is described. The important parameters of the streak camera, Hamamtsu C5680, are listed in Table 2. The dual-axis sweep function enables us the observation of the slow time-trend record of the longitudinal profile. Figure 2 shows results of observation for behavior of the beam after the injection, 2a: injection to 100μs, 2b: 0.6msec after the injection to 0.7msec, 2c: 6msec after the injection to 6.1msec, and 2d: 60msec after the injection to 60.1msec, respectively. The vertical scale is 800ps in full range and the horizontal scale is 100μs in full range. Because the turn-by-turn streak images are horizontally overlapped each other the change of the bunch length and the position were recorded continuously. Due to the large off-energy

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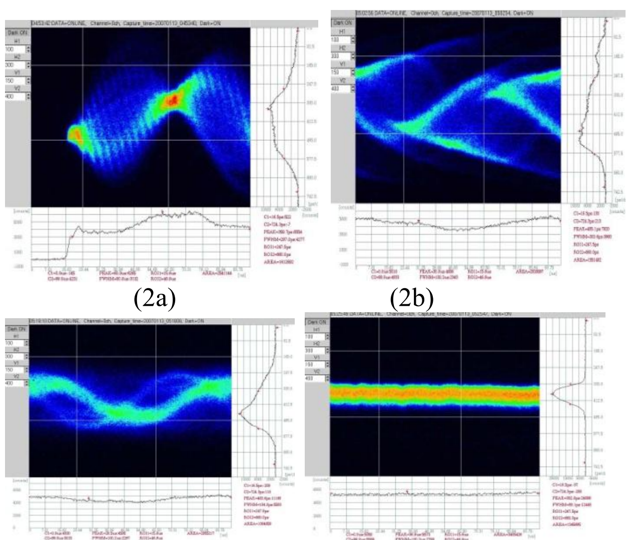
injection, and the large energy spread at the injection, the particles in the beam made the synchrotron oscillations with different phases. The amplitudes of the synchrotron oscillations are gradually damped and the phases are converged into the same phase. The measured dumping time of the bunch length is 24.5+/-4.5ms. This result is agrees well with the theoretical damping time 20.5ms. From the Fig. 2(d), no synchrotron oscillation is observed at the timing of 60ms after the injection.

Table 2. Main Parameters of C5680 Streak Camera

Vertical sweep (synchroscan)	
Streak time	280ps to 1/6fs
Sweep frequency(fs)	75MHz to 165MHz
Resolution	< 2ps
Horizontal sweep	
Sweep range	100ns to 100ms
Rep. frequency	10kHz(max.)
MCP Gate time	50ns to DC



(2a) (2b)

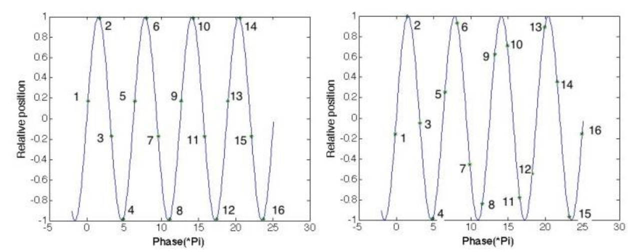
(2c) (2d)

Figure 2: Results of observation for behavior of the beam after the injection - 2a: injection to 0.1ms, 2b: 0.6m after the injection to 0.7msec, 2c: 6ms after the injection to 6.1ms, and 2d: 60msec after the injection to 60.1ms. The vertical scale is 800ps in full range.

IDEA FOR MULTI-BUNCH BEAM OBSERVATION

The sweep frequency of the streak camera was 89.25MHz, which is 1/8 of the accelerating RF frequency. In the case for the multi-bunch beam having a 2.8 ns spacing with this sweep frequency, the position of bunches on the sinusoidal sweep of the streak camera is shown in Fig. 3(a). Every 4th bunch, e.g., first, 5th, 9th, 13th, ….., sit on the same position on the sinusoidal sweep. The synchrotron oscillation frequency of the ATF DR is 10.4kHz at the acceleration voltage Vc=300kV. To observe the synchrotron oscillation, the horizontal sweep range has to be set 100μs or more. In this measurement range, the streak image of the different bunches overlaps each other. As a result, we cannot observe behaviour of the individual bunch.

Then we developed a new idea, changing the different the sweep frequency from 89.25MHz to 95.2MHz. This frequency is 1/7.5 of the acceleration RF frequency, then streak images of different bunches sit different vertical positions on the sinusoidal sweep as shown in Fig. 3(b). This frequency is selected to make appropriate phase difference for each bunch. The synchro-scan sweep unit needs to adjust the frequency after changing the frequency, because the sweep unit has a narrow bandwidth. When using the Hamamatsu C5680, the streak images are displayed only in the narrow area around the centre of the sinusoidal wave. By this reason, for the observation of the all bunch, we need to change the delay timing of the sweep frequency to bring the interested bunch in the display window. Then we can observe any bunch of interest one by one.



(a) (b)

Figure 3: Longitudinal bunch profile position on the sinusoidal sweep - (a) Longitudinal bunch profile position for the 89.25MHz (b): Longitudinal bunch profile position for the 95.2MHz, Horizontal scale is in radian.

The every 16th bunch will overlap again in the 95.2MHz sweep frequency. In the case for the measurement more than 16 bunches of the multi-bunch, we applied a gate for the MCP. When the gate timing is adjusted to the interested bunches, the other bunches are disappeared on the steak display. The minimum gate width is 50ns and the maximum repetition rate is 10kHz. Figure 4 shows the timing of the gate signal. By scanning the gate timing, we can select arbitrary bunches.

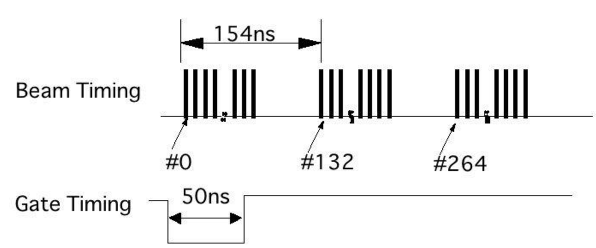


Figure 4: Timing of the gate signal.

When applied the gate to the streak camera, the streak image is appeared with 100μs interval, which is limited by the maximum repetition rate of the gate. We cannot observe the turn-by-turn longitudinal image in this case.

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But the time trend of the selected bunch in the multi-bunch can be observed. Combining this gating and the 95.2MHz sweep frequency, the oscillation amplitude of the arbitrary bunch can be measured, even if the large number of bunches are circulate in the ring.

OBSERVATION OF TIME TREND BEHAVIOR IN MULTI-BUNCH

Observation of Multi-Bunch with 2.8ns Spacing

The observation result for the time trend behavior of the longitudinal bunch profiles using the idea described in the previous section is shown in Fig. 5. The bunch train has 20 bunches with 2.8ns spacing in the DR. The vertical scale is 1200ps in full range and the horizontal scale is 500μs in full range. The time trend is measured from 180ms after the injection. 180ms is about 9 times of the damping time. For the convenience to keep enough temporal resolution, 6 set of time trend for 1st, 3rd, 5th, 7th, 12th and 14th bunches are indicated simultaneously in the display. The other bunches are sit on the out of view of the display. We can set the interested bunch to the center by changing the delay of the sweep frequency. The different amplitudes of synchrotron oscillation were observed in the different bunches. The results for amplitude of the synchrotron oscillation in 4 different beam currents (2, 7, 13, 20 mA), as a function of bunch number is shown in Fig. 6.

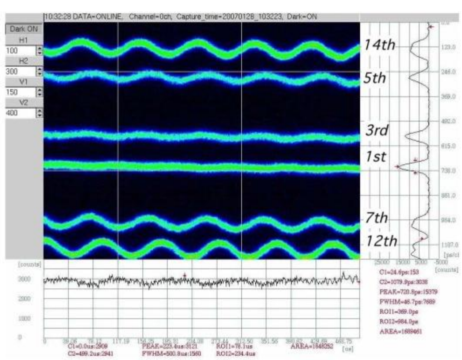

Figure 5: time trend of the longitudinal bunch profile (2.8ns spacing multi-bunch) - The vertical scale is 1200ps in full scale and the horizontal scale is 500μs in full scale.

From this figure, we can see an increase of the amplitude of the synchrotron oscillation as the bunch number increase. We can also see a saturation of this increase around bunch number 7 at 28mA. The small amplitude of the synchrotron oscillation remains at the first bunch for each intensity. Since the bunch currents for 18th, 19th and 20th bunches were too small at the moment for the measurement, we could not observe the time trend behavior of them.

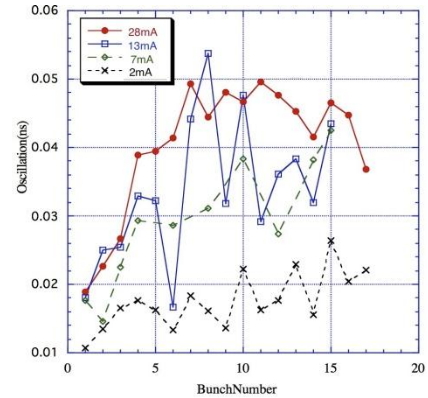

Figure 6: the amplitude of the synchrotron oscillation for each bunch. Each line shows the different intensity of 2mA, 7mA, 13mA and 28mA, respectively.

We assumed that some wake sources induced the longitudinal wake fields, which enhance the synchrotron oscillation of the following bunches [6]. Longitudinal wakefield of a bunch, whose synchrotron oscillation is induced by some noise, excite an oscillation to the following bunches. A calculation of the enhancement of the synchrotron-oscillation amplitude in following bunches and the oscillation phases are shown in Fig. 7. In this calculation, the shunt impedance R/Q=100ohm, the quality factor Q=50, the resonance frequency f_{res}=2GHz are assumed for the source and 20bunches, 2.8ns spacing and 20mA are assumed for the beam. From Fig. 7, we can see an exponential increase of the synchrotron oscillation amplitude and the phase fluctuates. From this result, we could explain a simple increase of the amplitude of synchrotron oscillation, however, this result could not explain the observed saturation in the synchrotron oscillation at the high current, 28mA.

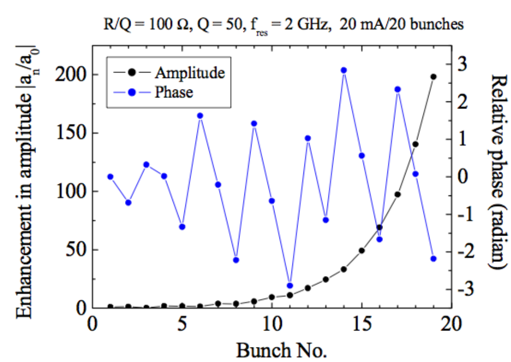

Figure 7: A calculation result for the amplitudes and the phase fluctuation for the synchrotron oscillation [6].

Observation of Multi-Bunch with 5.6ns Spacing

We measured beam of 8 bunches with 5.6ns spacing in the DR. The time trend behaviors of the longitudinal bunch profiles are shown in Fig. 8. The intensity was 6mA. Since the bunch spacing was twice of the bunch spacing the

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previous measurement, the 1st, 2nd, 3rd, 4th and 5th bunch of 5.6ns spacing correspond to the 1st, 3rd, 5th, 7th, 9th bunch of 2.8ns spacing. There was no visible synchrotron oscillation at this condition. We have not yet observed the other conditions.

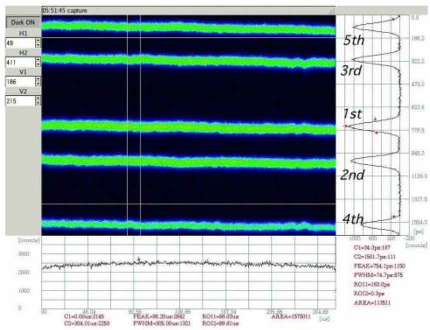

Figure 8: Time trend of the longitudinal bunch profile (5.6ns spacing multi-bunch) - The vertical scale is 1600ps in full scale and the horizontal scale is 300μs in full scale.

SUMMARY

A new method to observe the time trend behavior of the longitudinal beam profile in multi-bunch operation using a streak camera has been developed. At first, the damping phenomena of the single bunch were observed using a streak camera with dual time scanning when the injection beam had large energy offset and large energy spread. For the individual beam profile observation in the multi-bunch operation, we developed a new method in which we used a combination of a sweep frequency of 95.2MHz (1/7.5 of the RF frequency) and MCP gate. We succeeded to measure synchrotron oscillations of the individual bunches in the multi-bunch operation with this method. A simple increase in the amplitude of synchrotron oscillation was observed at lower beam current (2-13mA), and the saturation in the amplitude was observed in high current 28mA. We performed a simulation for the coupled bunch wakefield effects to the synchrotron oscillation. Result of simulation shows a simple increase of the oscillation amplitude along bunch train, but not the saturation at high beam current.

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