THE OBSERVATION OF THE LONGITUDINAL COUPLED BUNCH MOTION ON STREAK CAMERA AT SRRC

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Abstract

A Hamamatsu C5680 streak camera was set up to observe the beam motion at one of the synchrotron light ports at SRRC. The single bunch, two bunches and a few bunches longitudinal beam motion were observed by the streak camera. The longitudinal dipole mode motion was seen in some cases. The oscillation amplitude was measured and compared with the signal from stripline on spectrum analyzer. The experimental observation was also compared with theoretical predictions.

I. EXPERIMENTAL SETUP

The experimental setup is shown in fig.1. Synchrotron light from one of the bending magnet is guided by optical elements into the streak camera through the pin hole or slit at the head of streak camera. The main body of the Hamamatsu C5680 streak camera is mainly composed of one photocathod, 2 pairs of sweeping electrodes, one in vertical and another one in horizontal, MCP(micro channel plate) streak tube, phosphor screen and a high sensitive camera. The synchrotron light is first converted into electron by the photocathod. The electron is deflected when passing through the electrodes and then is multiplied by the MCP streak tube. The MCP gain can be controlled according to the experimental needs. Finally the electrons hit on the phosphor screen after streak tube and are converted into light again. By using the CCD, the image, usually called the streak image, can be displayed on a TV monitor. By measuring the time structure of the synchrotron light the longitudinal information of the beam can be derived.

There are optional plug-ins for the sweeping voltage of the vertical electrode. At SRRC we use two kind of plug-ins for the vertical electrode sweeping voltage. One is M5676 fast single sweep unit with maximum sweep repetition rate 10 kHz and vertical range from 200 ps to 50 ns. The sweeping voltage used for this unit is linear. Another plug-in used is M5675 synchroscan unit with 125 MHz sinusoidal sweeping voltage. Considering the linearity of the sweeping voltage of M5675 only a limited vertical time scale up to 1.4 ns is used. By applying a M5679 Dual Time Base Extender unit to the horizontal sweep electrode the display of the image can be extended in the horizontal direction to make a two dimensional time display of streak image. This makes the single shot measurement of the beam possible. The maximum repetition rate of the unit is 10 Hz and the horizontal sweep range is from 100 ns to 100 ms. Because of the different time scale of the two dimensional display the vertical axis is called fast axis and the horizontal slow axis, respectively.

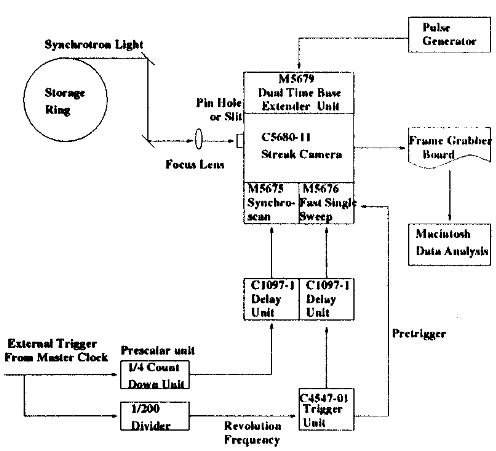

Figure 1. The set up of streak camera system

The signal from the master clock (500 MHz) is used as the source of the trigger signal to the streak camera. For synchroscan operation mode the signal from the master clock is put into a prescalar unit to divide the frequency down to 125 MHz. At every sweep of the sinusoidal wave there will be 4 bunches. But as mentioned above considering the linearity of the sweeping only the bunches located at the approximately linear region will be displayed. Hence in the synchroscan operation mode only the streak image of two bunches displayed on the monitor and the two bunches are not successive bunches but first and third or second and fourth bunches. A 2 ns delay is used to select which pair of bunches to observe. For fast single sweep the signal from the master clock need to be divided by two hundred to match the revolution frequency of 2.5 MHz. The revolution frequency is put into a C4547-01 trigger unit to generate a trigger and a pretrigger signal. These two signals are then put into fast single sweep unit for streak trigger and gate mode trigger. The gate mode operation will filter out unwanted noise and enhance the measurements. In single bunch experiment a delay unit is needed to delay the trigger signal to coincide with the single bunch event.

The streak image can be displayed on a TV monitor. A frame grabber board is used to acquire the image data and an image data processing software is implemented on a power Macintosh to analyze the data. Through the GPIP the power MAC can also be used to control the operation of the streak camera instead of using a local controller.

II. THE EXPERIMENTAL RESULTS

A. Synchroscan Operation

Because of the high repetition rate of the sweeping voltage, the synchroscan operation mode can be used to observe the bunch motion in successive turn. By choosing the horizontal sweeping time longer than the period of synchrotron motion, one can observe the longitudinal coupled bunch motion on the streak camera. At SRRC the period of synchrotron motion is 37 μs at RF gap voltage of 700 kV. Different bunch patterns such as single bunch, two symmetric bunches, two equal bunches with different spacing, three equal successive bunches and three unequal successive bunches were observed. The bunch pattern was shown on a Tektronic 602 digitizing signal analyzer by puting the signal of stripline electrodes to the analyzer. The spectrum of synchrotron sideband was measured by spectrum analyzer and was compared with the results on streak camera. The time domain longitudinal bunch motion was observed on the streak camera. The results are shown in fig.2, 3 and 4. The full scale of the slow (horizontal) axis is 500 μs except in fig.4 which is 50 μs. The full scale of the fast axis is 1.4 ns. In fig.2 we see no obvious longitudinal beam oscillation for single bunch at current of 12 mA. For two successive bunch each with current of 3 mA, again no obvious longitudinal oscillation was observed. The same results were obtained for two equal bunch with different spacing, 4 ns, 6 ns, 8 ns, 10 ns, 100 ns and 200 ns (symmetric bunches). The longitudinal bunch motion of three equal successive bunches are shown in fig.3. Here a very small fourth bunch is shown. The bunches performed longitudinal periodic motion as is shown in the figure. The period of the motion is around 37 μs which is consistent with the frequency of the first synchrotron sideband as measured from the spectrum analyzer. The longitudinal dipole mode motion was observed on the streak camera. The oscillation amplitudes of the bunches were first $<$second $<$third $\leq$fourth. The total current of the bunches was 8mA. Fig.4 shows the motion of three unequal successive bunches. It shows clear sign of dipole mode oscillation of the beam. One can even observe the periodic changing of bunch length in twice the frequency of dipole mode motion. This is believed to be the quadrupole mode motion. The observation on streak camera was consistent with the results showed on the spectrum analyzer where the second synchrotron sideband showed. The oscillation amplitude went smaller when beam current was smaller. This tendency showed both on streak camera and spectrum analyzer.

B. Fast Single Sweep

The fast single sweep unit can be used to measure the single shot bunch population and bunch length. Due to the repetition rate of this unit, it can't be used to observe the turn by turn motion. Further works on the investigation of the longitudinal beam instability by using this unit are in progressing. Here we show in fig.5 the results of single bunch length versus RF gap voltage with current around 2 mA. It is compared with the natural bunch length at the same gap voltage. The measured bunch length is consistent with the calculation except at gap voltage 150 kV. The streak image get at this mode is shown in fig.6. The vertical axis of the figure is 1 ns, the horizontal is 1 ms and the rate of the vertical sweeping is 10 kHz.

III. DISCUSSION

The longitudinal beam instability was also investigated at SRRC[1] by using the spectrum analyzer. The frequency for the longitudinal symmetric coupled bunch motion is[2]:

$$f^{\pm}_{s,\mu} = nBf_{rev} \pm Sf_{rev} \pm \mu f_s \quad (1)$$

Where S=0,1,...,B-1, B is the number of bunches, $(2\pi/B)S$ is the phase difference of adjacent bunches and μ is the coupled bunch mode number. For longitudinal dipole mode μ equals to 1. From the observation the beam mode with frequency close to the resonant frequency of TM_{011} —–higher order cavity mode was found. The resonant frequency of this mode is around 743 MHz, which close to mode of n=1, B=200, S=97 for 200 bunches, or n=148, B=2, S=1 for two symmetric bunches. The longitudinal beam instability of symmetrical coupled bunch of SRRC had been calculated[2]. The contribution of the growth time of the TM_{011} mode in the worst case with 0.2 mA per bunch is 0.4 ms. Comparing with the synchrotron damping time 8.7 ms, it can cause beam instability. So an attempt was made to characterize on streak camera the effect of TM_{011} and other high Q mode by using a single bunch and two symmetric bunches operation. As showing in fig.2 there is no obvious oscillation for single bunch. The same result is shown for two symmetric bunches. We had tried to change the spectrum of the bunch population by changing the spacing of the two bunches. But still no obvious beam oscillation was seen at that time. An interesting phenomena is shown in fig.3. The oscillation amplitudes of the bunches are different and increasing one by one. The possible reason is that the motion is caused by a short wake field. The leading bunch can't see the wake field due to the latter bunch since the field already decays when leading bunch arrives. The wake field will effect only several near bunches and will add up. So the latter bunch sees the larger wake field thus operates bigger oscillation.

References

[1] W. K. Lau, M. H. Wang, K. T. Hsu, L. H. Chang, C. H. Wang, and C. C. Kuo, "Study of the Longitudinal Coupled Bunch Instabilities in the SRRC Storage Ring", these proceedings.

[2] Jiunn Ming Wang, "Symmetrical Coupled Bunch Modes in SRRC Storage Ring", SRRC/BD/92-01.

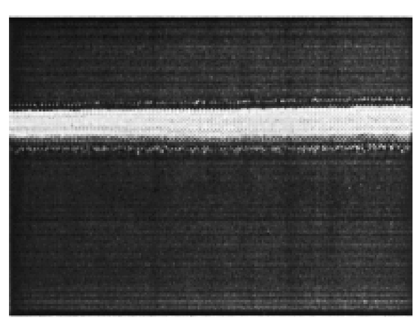

Figure 2. The streak image of single bunch. The full vertical scale is 1.4 ns and is 500 μs for the horizontal.

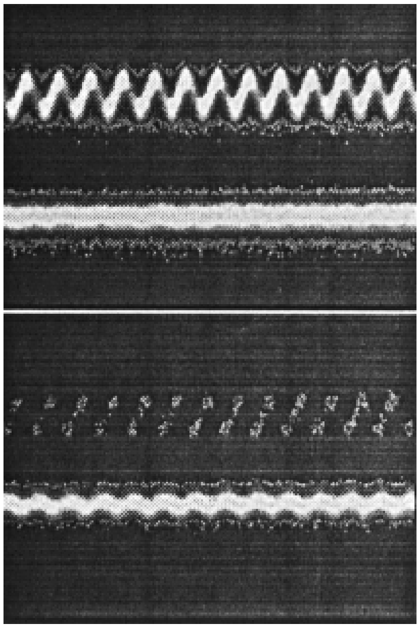

Figure 3. The streak image of four successive bunches. The bunch sequence from top to bottom is third, first, fourth and second. The vertical scale is 1.4 ns and is 500 μs for the horizontal.

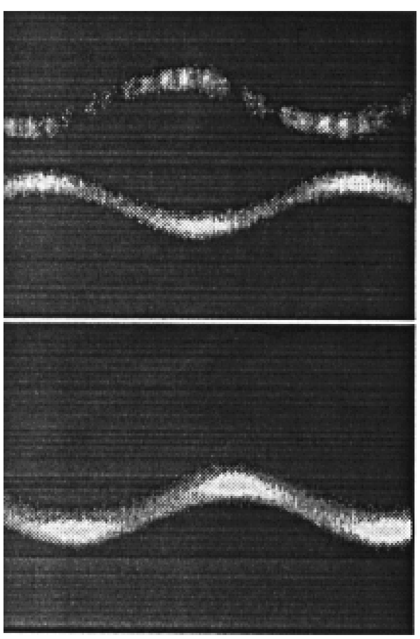

Figure 4. The streak image of three successive unequal bunches. The bunch sequence from top to bottom is third, first and second. The vertical scale is 1.4 ns and is 50 μs for the horizontal.

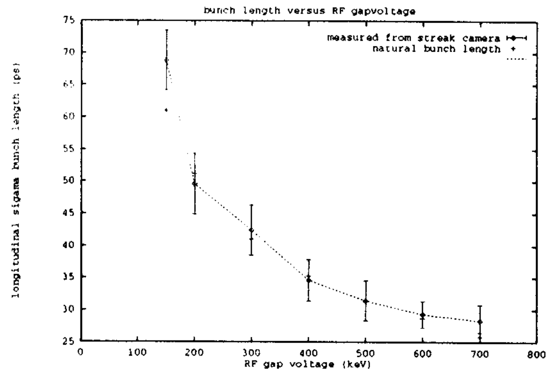

Figure 5. The single bunch length versus RF gapvoltage.

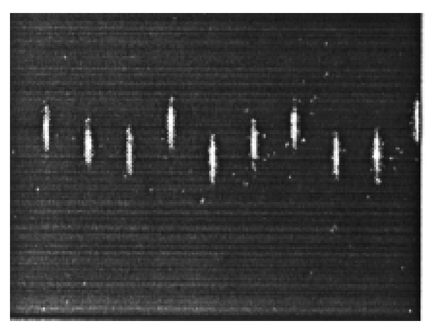

Figure 6. The streak image of single bunch on fast single sweep mode. The vertical scale is 1 ns and the is 1 ms for the horizontal.