LONGITUDINAL BEAM INSTABILITY OBSERVATION WITH STREAK CAMERA AT SRRC

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Abstract

The longitudinal beam instability of the 1.3 GeV TLS storage ring at SRRC was investigated by using a HAMAMATSU C5680 streak camera. The single bunch length as a function of beam current was measured and a longitudinal broad band impedance was deduced. The longitudinal beam motions in the case of single bunch, two bunches and a few bunches were studied. A HAMAMATSU PLP-02 pico second pulse laser had been used to calibrate the streak camera and the results are presented.

1 INTRODUCTION

The SRRC is a 1.3 GeV electron light source built at Taiwan. The design of SRRC had been presented in the previous IEEE PAC conference[1,2]. A HAMAMATSU C5680 streak camera had been set up at SRRC[3] for the machine study. Two kinds of plug-in: fast single sweep unit and synchroscan unit had been used to study the beam instability at SRRC. By using the fast single sweep unit the single shot bunch length can be measured. The single bunch length as a function of beam current was measured. From the theory of bunch lengthening an effective longitudinal broad band impedance was derived. By using the synchroscan unit the beam motion in the longitudinal direction could be observed. Several cases of a few bunches longitudinal beam instability had been observed. The multi bunch filling pattern for users could also be visualized.

2 BUNCH LENGTH MEASUREMENT

When beam circulates in the ring it will interact with the environment. The beam environment interaction will then influence the beam in return. This beam environment interaction is called the collective effect[4]. The longitudinal Hamiltonian under the influence of this effect will become:

$$H = \frac{p^2}{2} + \frac{\omega_s^2 \tau^2}{2} + \frac{\eta e}{E_0 T_0} \int^{\tau} V_W(\tau') d\tau' \qquad (1)$$

Where $V_W(\tau)$ is the wake potential. This potential at low beam current will distort the accelerating potential provided by the RF cavity and when beam arrived the RF it will see different slope of accelerating voltage and shows different bunch length. The bunch length will lengthen above transition if the vacuum component is inductive and shorten if the component is capacitive[5]. This is the potential well distortion of the single bunch beam. When beam intensity increased and exceeds a threshold current another beam instability microwave instability will occur. In this instability the bunch lengthening is accompanied with an energy spread. The lengthening of the bunch will decrease the beam intensity and decrease the interaction and stabilize the beam. The stabilized bunch length can be measured and an effective broad band impedance could be deduced[6]. The microwave bunch lengthening for long bunch is:

$$\sigma_l \propto (\xi Z_0 R^3)^{1/3} \qquad (2)$$

and for short bunch is:

$$\sigma_l \propto (\xi Z_0 R^3)^{1/(2+a)} \qquad (3)$$

where $\xi = \frac{I\alpha}{\nu_s^2 E}$ is the scaling parameter. I is the beam intensity, α the momentum compaction factor, ν_s the synchrotron tune and E the energy. A threshold current could be obtained by using coasting beam assumption, assuming the bunch length is much longer than the wave length of the impedance. In this model the threshold current is given by:

$$I_{th} = \frac{\sqrt{2\pi}\alpha^2(\frac{E}{e})}{\nu_s \mid Z/n \mid}(\frac{\sigma_E}{E})^3 \qquad (4)$$

The single bunch length measurements had been performed at SRRC by using the streak camera. The single shot bunch image could be captured and the image profile data could be obtained. By fitting the profile data of the streak image the bunch length of the beam could be obtained. In figure 1 we shows the bunch length measurement versus beam current at several different operating RF gapvoltage. Because the bunch length was short compare to the beam pipe a short bunch scaling law eq.(3) was applied to fit the curve. The fitting result shows the broad band impedance of SRRC is about 0.904 Ω and the exponent a in the eq(3) is about 1.11. It shows the exponential dependence on current of bunch lengthening is near the long bunch behavior. The threshold current of the bunch is about 5.8, 5.2 and 4 mA for RF gapvoltage 400kV, 500 kV and 700 kV respectively. Which implies the effective impedance is around 0.86 Ω to 1.05 Ω. It is consistent with the fitting result.

3 LONGITUDINAL BEAM INSTABILITY

The longitudinal coupled bunch motion can be observed by using the streak camera with the synchroscan unit. A 500 MHz signal (corresponding to the RF frequency) from the master clock through a 1/4 frequency divider is used

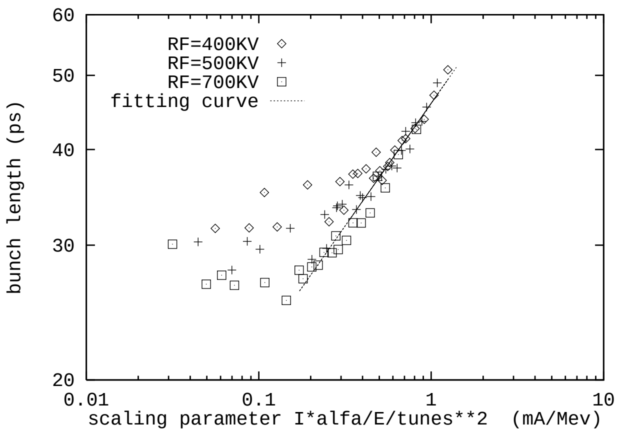

Figure 1: The single bunch length measurement at different RF gap voltage

to trig the vertical sinusoidal sweep voltage of the synchroscan unit. The period of each sweep is 8 ns and the time difference of two next bunches is 2 ns. Thus in each sweep it includes four bunches. But because it will show only the range of approximately linear sweeping voltage on the screen, there are only two bunches with 4 ns delay shown on the screen in each sweep. Applying 2 ns delay to the trigger signal the other two bunches can be brought to the screen.

The modes of a few bunches had been studied. As described in the previous paper[3] the single bunch and two bunches with different spacing had been studied. No obvious beam oscillation were observed that time. We proceeded the study for four symmetric bunches, again if the single bunch purity was fine then there would be no obvious beam oscillation observed on the streak camera. But when the single bunch purity was not good. A small bunch next to the main bunch appeared then it would induce the couple bunch oscillation. The coupled bunch oscillation in such situation is shown on the figure 2. Where the upper figure shows the motion of four symmetric main bunches and the lower figure for the side bunches. The full horizontal time scale is 100 μs. The vertical scale is 1.4 ns. The oscillation amplitude of the main bunch is 150 ps and for side bunch is 200 ps. The oscillation frequency of the bunches is around 20.3 kHz which is the frequency of the first synchrotron side band. The simulation of four symmetric coupled bunch modes on the streak camera is shown in figure 3. Those figures represent the coupled bunch modes of zeroth , $\pi/2$, π and $3\pi/2$ mode respectively. Comparing with the simulation we can see the oscillation mode shows in figure 2 is of the coupled bunch mode $\pi/2$ mode or $3\pi/2$ mode. At meantime a HP 4396A spectrum analyzer was used to measure the spectrum of the first synchrotron sideband up to 200 revolution frequency. The result is shown on figure 4. In figure 4 a repetition of four revolution is shown which is the characteristics of the four symmetric bunch pattern. The maximum amplitude occurred at every fourth revolution which corresponded to the coupled bunch mode of $3\pi/2$ mode. A thing worthy noting was the coupled bunch mode was not fixed as the experiment continued. The phase relation of the side bunches had changed to none of the above four modes. A possible explanation was the filling pattern was not exactly the case of four symmetric bunches. There were other mode occurred. The beam motion observed on the streak camera was the supposition of all modes. It was consistent with the spectrum measurement in figure 4, where the spectrum was not exactly repeating at four.

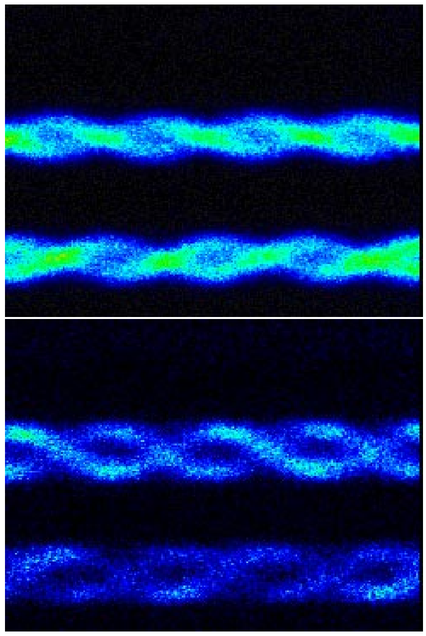

Figure 2: The longitudinal coupled bunch motion of four symmetric bunches (upper) with side bunches(lower).

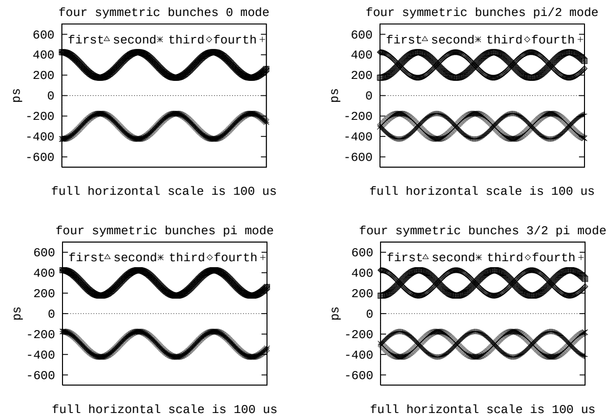

Figure 3: The simulated coupled bunch motion of four symmetric bunch on streak camera

The filling pattern of storage ring could also be visualized by using the synchroscan unit of the streak camera. One of the user-run filling pattern is shown in figure 5. In the figure the two bunch in the same vertical streak is four ns depart and in the horizontal the two neighboring bunches is 8 ns apart. The full horizontal scale of the figure is 500 ns and the full filling pattern of SRRC is 400 ns. The two

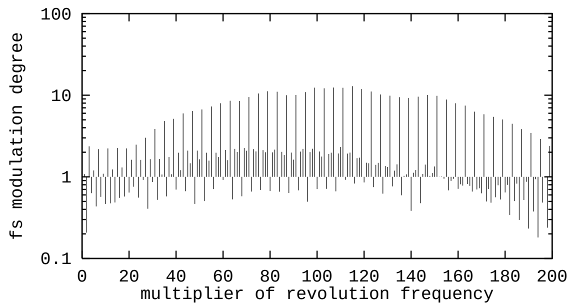

Figure 4: The spectrum of first synchrotron sideband of four symmetric bunches with small side bunch

figures shoes all the bunches exists in the ring and their coupled bunch instability. The maximum oscillation amplitude of the bunches is around 200 ps. The individual bunch also shows the effect of bunch lengthening or bunch contraction. It will be a good observation tool for the injection pattern and the longitudinal feedback system under construction at SRRC.

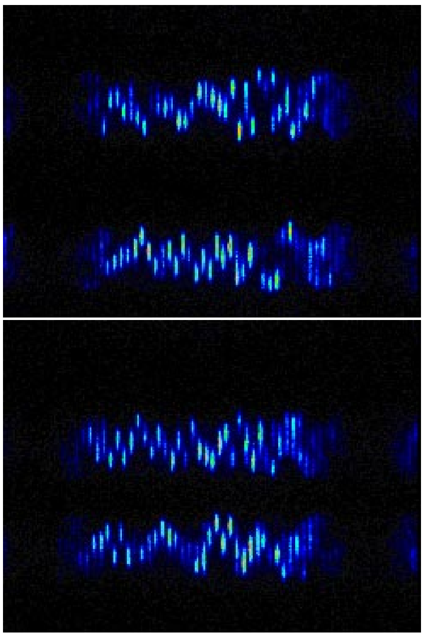

Figure 5: One of the filling pattern of SRRC at user time.

4 CALIBRATION OF STREAK CAMERA

A HAMAMATSU PLP-02 pico second pulse laser had been used to calibrate the streak camera. The pulse of PLP-02 with fixed pulse width and power was directed into C5680. The pulse width and the output photon count were measured as the MCP gain number increased. The MCP gain number represented the multiplication of the Micro Channel Plate in the streak camera. The MCP gain number from 0 to 63 represents the multiplication from 2 to 8000. But the multiplication is not linear. The bunch length measured was quite stable while the MCP gain number changed as shown in figure 6. From this we are sure the intensity of the beam will not effect the bunch length measurement unless the beam intensity is so high that it saturates the 16 bit data storage. When saturation happens the bunch length measured will longer than real bunch length. The rate of measured intensity increased as the MCP gain number increased is quite consistence with the data of the characteristics of MCP gain provided by the HAMAMATSU company except there is an offest. The possible reason of this offest is consulting with the company. The pulse intensity versus the MCP gain number was shown in figure 7.

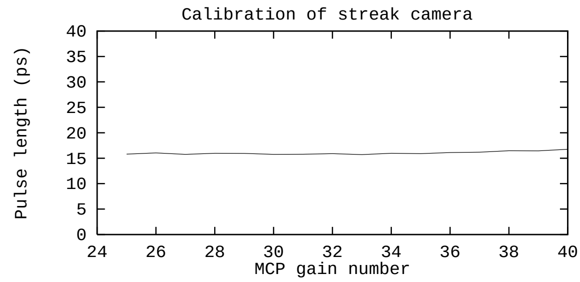

Figure 6: The pulse length of PLP-02 measured at different MCP gain number of streak camera.

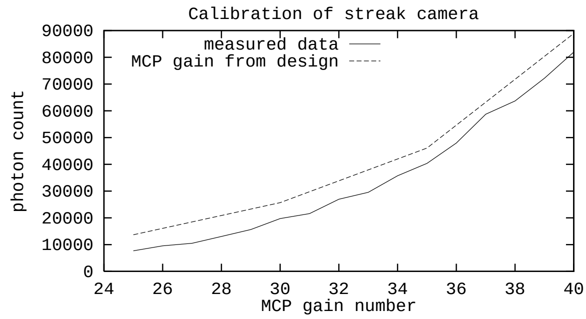

Figure 7: The intensity of PLP-02 measured at different MCP gain number of streak camera.

5 REFERENCES

[1] C.C. Kuo, et al., "Beam Dynamics of the SRRC 1.3 GeV Storage Ring", 1991 PAC Conference Proceedings, p.2667, C.S. Hsue, et al., "Lattice Design of the SRRC 1.3 GeV Storage Ring", ibid, p.2670.

[2] Y.C. Liu, et al., "Construction and Commissioning of the SRRC Storage Ring", 1993 PAC Conference Proceedings, p.1635.

[3] M.H. Wang, et al., "The Observation of Longitudinal Coupled Bunch Motion on Streak Camera at SRRC", 1993 PAC Conference Proceedings, p.2971.

[4] R.D. Ruth, "An Overview of Collective Effects in Circular and Linear Accelerators", Frontier of Particles Beams, Springer-Verlag, Lecture Notes in Physics 343, p. 247.

[5] Alex.W. Chao, "Physics of Collective Beam Instabilities in High Energy Accelerators", Wiley Series in Beam Physics and Accelerator Technology, chap. 6.

[6] P.B. Wilson, et al., "Bunch Lengthening and Related Effects in Spear II", IEEE, NS-24, No.3, p.1211, M.S. Zisman, et al., " ZAP User's Manual".