STUDY OF LONGITUDINAL COUPLED-BUNCH INSTABILITIES IN THE SRRC STORAGE RING

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Longitudinal coupled-bunch instabilities in the SRRC 1.3 GeV storage ring have been studied by analyzing the signals picked up from the stripline electrodes and rf power reflected from the cavities. The current dependence of the instability strengths was measured. As a cross check, the bunch phase jitters as a function of beam current has also been measured by using sampling optical oscilloscope. Threshold currents of a few milliamperes have been determined from both measurements. They agree with each other very well. It is also found that the strength of the instabilities can be reduced significantly by randomly distributing electron bunches around the ring.

I. INTRODUCTION

In a storage ring, longitudinal coupled-bunch instabilities of an electron beam are driven by the interaction of the beam with its environment, especially with the high Q components in the ring. They are the main obstacles in achieving high beam intensity with low emittance. In a synchrotron radiation facility, the poor emittance due to the instabilities will deteriorate the quality of light emission from undulators. In this study, we report the observations of the instabilities in the SRRC 1.3 GeV storage ring. A list of relevant parameters in this study is in Table 1.

Table 1. Parameters of the SRRC 1.3 GeV storage ring.

E	Beam Energy	1.3 GeV
I_b	Nominal Beam Current	200 mA
α	Momentum Compaction Factor	0.00678
f_{rf}	RF Frequency	499.668 MHz
f_o	Revolution Frequency	2.49834 MHz
h	Harmonic Number	200
R_s	Shunt Impedance (two cavities)	6 MΩ
V_c	Cavity Gap Voltage	800 kV
σ_τ	FWHM Bunch Length	58 psec
f_s	Synchrotron Freq.@800 kV	28.73 kHz
τ	Longitudinal Damping Time	8.708 msec

Observation was done in the frequency domain by analyzing beam signals picked up from the stripline electrodes. The stripline was installed in one of the straight sections where the beam dispersion is low. The instabilities are characterized by the synchrotron sidebands near the harmonics of revolution frequency (unequal bunch lines). Some modes were found significantly stronger than the others. Current dependence of these modes was measured. From such measurement, threshold beam current and the saturated amplitude of the instability can be determined. Excitation of high order modes can be monitored from the cavity reverse powers. For a coherent longitudinal beam motion, electron bunches jitter about synchronous phase. By using a sampling optical oscilloscope triggered at revolution frequency, bunch phase jitters can be measured from the synchrotron light emitted by the electron bunches. The bunch phase jitters as a function of beam current was also measured. There exists a threshold above which the bunch phase jitters increase with beam current. The threshold currents obtained from both measurements agree with each other.

A simple method has been tried to reduce the strengths of the longitudinal coupled-bunch instabilities by distributing electron bunches randomly around the ring such that the bunch spacings are not fixed. In such scheme, the symmetry of bunch spacing does not hold and thereby reduce the strength of the beam coherent motions that are excited by cavities high order modes. In a preliminary experiment, the strengths of the instabilities were reduced significantly.

II. LINE SPECTRUM OF LONGITUDINAL COUPLED-BUNCH INSTABILITIES

A. Identification of The Beam Modes

Each line in the spectrum represents a specific mode of coherent beam motions. The signal spectrum consists of lines with frequencies

$$f^{\pm}_{\mu,m} = nf_{rf} \pm (\mu f_o + mf_s)$$

that represent longitudinal coupled-bunch modes. Where f_{rf} is the rf frequency, f_o the revolution frequency and f_s the synchrotron oscillation frequency; n=0,1,2,...,∞; μ and m are the coupled-bunch mode and the within bunch mode numbers respectively.

A 740 MHz signal was observed from the reverse power of one cavity. This frequency coincides with the resonant frequency of TM_{011} -like cavity mode. Beam modes close to this frequency were ~20 dB larger than the others. It is believed that these modes have been excited by the TM_{011} -like mode. At 700 kV gap voltage, a typical spectrum picked up from the stripline is shown in Fig.1

In the figure, the measured central peak frequency

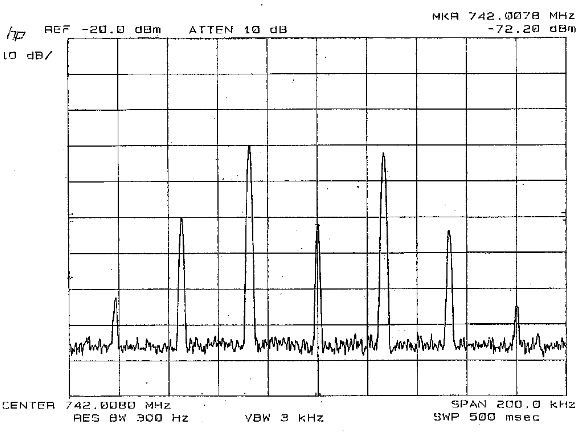

Figure 1: Synchrotron sidebands near the 97th harmonics of the revolution frequency.

is exactly the 97th harmonics of revolution frequency. It has sidebands at 27.5 kHz separations. The first synchrotron sidebands of the central peak correspond to the coupled-bunch dipole mode with mode number μ=97 (right hand side) and μ=103 (left hand side). The second harmonics of synchrotron frequency correspond to the quadruple modes. And the third harmonics of synchrotron sidebands correspond to the sextuple modes. Since the dipole modes are ~20 dB larger than the quadruple modes, we expect the bunches will mainly execute coherent rigid bunch synchrotron oscillations as observed by streak camera in an independent study [1].

B. Instability strengths and Threshold Current

Current dependence of the μ=97 dipole mode was measured at 700 kV gap voltage. The amplitudes of the mode with respect to the strengths of the rf carrier at the same current, I_s/I_{rf} , are plotted in Figure 2.

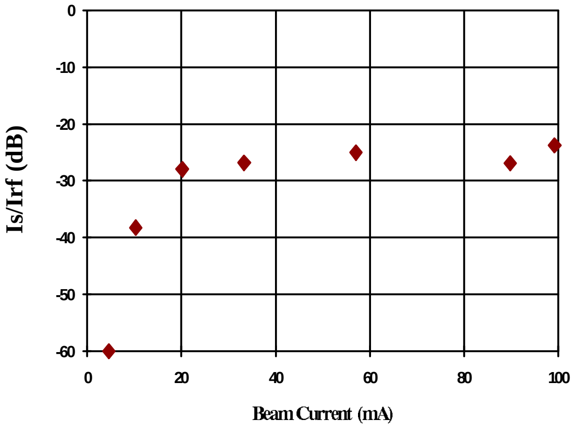

Fig.2 Relative amplitude of the μ=97 longitudinal coupled-bunch mode versus beam current.

At beam current lower than the 4 mA threshold, no oscillations are observed. Above 4 mA, the instability built up rapidly and saturated beyond 30 mA. The saturated amplitude was 25 dB lower than the rf carrier. It is equivalent to a phase modulation to the rf carrier of about 6°. It is believed that the instability was stabilized by the Landau damping. However, the overall effect of all longitudinal coupled-bunch modes is equivalent to ~12° phase modulation to the rf carrier.

C. Random Bunch Distribution

A simple method has been proposed to reduce the longitudinal coupled-bunch instabilities by filling the bunches into buckets and leaving the gap between bunches arbitrarily. In a first test, sixty out of two hundred buckets were chosen by a random number generator and each of these buckets was filled at ~0.3 mA by single bunch injection. At 18 mA, the measured amplitude of the μ=97 dipole mode was ~15 dB lower than the previous observation at the same current. Unfortunately, further studies are limited by the slow injection process. In further studies, multibunch injection will be employed and individual bunches can be knock out randomly by using an impulse kicker. Since the randomness of the bunch distributions depends on the harmonic number and the maximum current depends on number of bunches in the ring and the threshold current of single bunch instabilities.

III. AMPLITUDES OF BUNCH PHASE OSCILLATIONS

Bunch phase jitters can be measured from a synchrotron light monitor which is installed for the measurement of beam size in the middle of a long straight section. In such setup, a HAMAMATSU OOS-01/VIS sampling optical oscilloscope triggered at revolution frequency has been used. Time structure the of the electron beam can also be studied.

A. Current Dependence of Bunch Phase Oscillations

The experiment were performed under following conditions. A beam current of 200 mA was accumulated with ~20% gap. The bunch current was kept below the microwave instabilities threshold such that bunch length would not be affected. During the measurements, beam current was varied by inserting the scraper into the chamber gradually and pulled it all the way out during data collections. The current dependence of the bunch phase jitters are depicted in Figure 3. At high beam current of about 180 mA, the averaged FWHM bunch phase jitters was about 240 picosecond. Amplitude of the jitters decreases as the beam current decreases until the beam current drops to about 6 mA. As the current went below 6 mA, the jitters stayed constant at ~80 picoseconds.

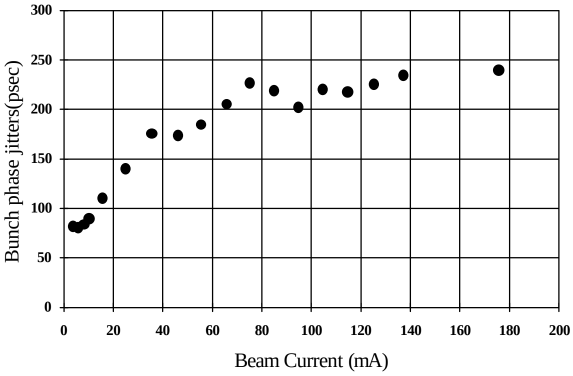

Figure3: Measured bunch phase jitters versus beam current.

B. Systematic Error

Since the measured value (we called it bunch phase jitters for simplicity) is the square root sum of "real" bunch phase jitters, natural bunch length and the systematic error. In order to determine the threshold current for the phase jitters, systematic error of the setup should be calibrated. Calibration can be done by measuring the bunch length as a function of synchrotron frequency at low beam current. Synchrotron frequency can be controlled by changing the cavity gap voltage (Figure 4). An offset of about 50 picoseconds were found by comparing the measured values with the theoretical values at 1 mA.

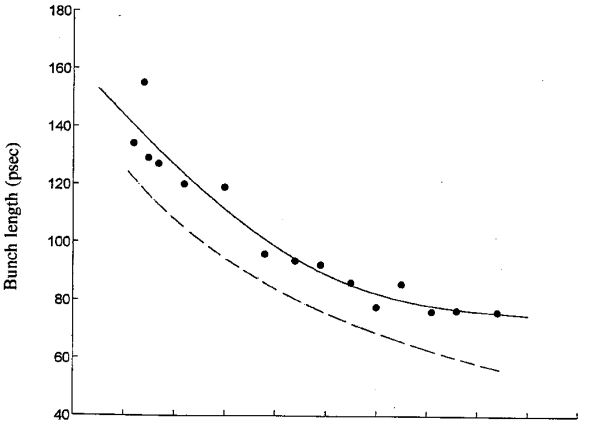

Figure 4: Measured bunch length (dots) versus synchrotron oscillation frequency at 1 mA beam current. Solid line represents the fitted curve from the measured data. Theoretical curve (dashed line) is drawn to compare with the measurements.

It shows that the system has an error of 50 picoseconds contribute to the measured values. Therefore, by subtracting systematic error and assuming no bunch phase jitters, the values at very low current in the bunch phase measurements are ~60 picoseconds. They are consistent with the theoretical bunch length. This result justified the assumption of no bunch phase jitters at beam currents lower than 6 mA. We concluded that the threshold determined in this measurement is 6 mA. It agrees very well with the previous frequency domain measurement.

IV. SUMMARY AND DISCUSSIONS

In summary, observations on longitudinal coupled-bunch instabilities have been performed. The current dependent characteristics of certain modes were measured. The threshold currents of the instabilities are rather low. The instabilities can be excited by electron beam of a few milliamperes and saturated at about few tens of milliamperes. The sole effect of these instabilities is equivalent to ~12° phase modulation to the rf carrier at 200 mA. As observed in the spectrum, dipole modes dominate over quadruple modes by ~20 dB. Excitations of dipole modes in the SRRC storage ring have been predicted by Juinn-Ming Wang [2]. The bunch phase jitters was measured by sampling optical oscilloscope. At 200 mA beam current, bunch phase jitters can be as high as 240 picoseconds. Threshold current measured in such experiment was 6 mA. It agrees with the frequency domain measurement.

A simple way to reduce the amplitudes of the instabilities by random bunch distribution was tested. A reduction of ~15 dB have been observed at 18 mA in compare with the ordinary bunch distribution. The effectiveness and the usefulness of this approach have to be justified in further studies. The feasibilities of implementing longitudinal feedback to damp the bunch phase oscillations[3] and frequency control of high order modes by changing cavity temperature to avoid the excitations of the instabilities [4] are under study also.

V. REFERENCES

[1] M.H. Wang et al., "The Observation of Longitudinal Coupled Bunch Motion on Streak Camera at SRRC" (these proceedings).

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[4] E. Karantzoulis et al.," Observation of Instabilities in the ELETTRA Storage Ring", Proceedings of the Fourth European Particle Accelerator Conference, June 1994.