

EXPERIMENT OF RF VOLTAGE MODULATION AT SRRC

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Abstract

The effects of amplitude modulation of RF cavity voltage on the longitudinal beam dynamics were studied experimentally at SRRC by using a streak camera system. The characteristics of parametric resonance in single bunch beam was investigated both by simulation and measurement. The formation of beamlets in the bunch helps to damp the coherent bunch oscillation. This property is employed to provide stable beam in user's shift at SRRC.

1 INTRODUCTION

The modulation of RF system is one of the important beam dynamics topics in accelerator physics. More and more accelerator physicists use the nonlinear property of parametric resonance of RF field modulation intentionally as an advantage to improve the performance of the accelerator[1]. The parametric resonance of RF field modulation resulted in redistribution of particles in the longitudinal plane. The formation of islands within an RF bucket acceptance reducing the density in the bunch core. The beam dynamics property related to the bunch density such as beam life time, beam instability etc. can be improved. At SRRC the effect of the RF phase modulation and the effect of RF voltage modulation were studied. The study of RF phase modulation at SRRC was reported elsewhere[2]. In this paper we discuss the longitudinal beam dynamics with RF voltage modulation. A simulation program was written to track the particle distribution. The characteristics of single bunch under parametric resonance were measured by using streak camera. The application and effects on multibunch is also reported.

2 LONGITUDINAL BEAM DYNAMICS WITH RF VOLTAGE MODULATION

For a charge particle in a circular accelerator, when the amplitude of the RF cavity voltage is modulated by a sinusoidal wave with amplitude ϵ in unit of RF cavity operational voltage and frequency f_m Hz or modulation tune $\nu_m = \frac{2\pi f_m}{\omega_0}$, where ω_0 is the revolution angular frequency, the equation of motion are given by

$$\frac{d\phi}{d\theta} = \nu_s \delta \quad (1)$$

$$\frac{d\delta}{d\theta} = \frac{h\eta}{2\pi E_0 \nu_s} [eV_{RF}(1 + \epsilon \sin(\nu_m \theta + \xi)) \sin(\phi_s + \phi) - U] \quad (2)$$

Where $\theta = \omega_0 t$ is the revolution angle, ϕ_s the synchronous phase, δ defined by $\frac{h\eta}{\nu_s} \frac{\epsilon}{E_0}$ with η the slip factor, h the harmonic number, and U the radiation energy loss, which

depends on the energy of the particles. The synchrotron mapping equation are given by

$$\phi_{n+1} = \phi_n + 2\pi\nu_s \delta_n \quad (3)$$

$$\delta_{n+1} = \delta_n - 2\pi\nu_s [1 + \epsilon \sin(\nu_m \theta + \xi)] \cdot \sin(\phi_s + \phi_{n+1}) - \frac{4\pi\alpha}{\omega_0} \delta_n \quad (4)$$

Where α is the radiation damping factor, which is about $200 s^{-1}$ of storage ring at SRRC for 1.5 GeV. Comparing to the synchrotron angular frequency ω_s $1.6 \times 10^5 s^{-1}$, it is smaller. Neglecting damping term and the corresponding Hamiltonian is

$$H = \frac{1}{2}\nu_s \delta^2 + \nu_s [1 + \epsilon \sin(\nu_m \theta + \xi)] [1 - \cos \phi] \quad (5)$$

Analyzing the Hamiltonian we derive island structure in the phase space. The results of applying modulation frequency two times around the synchrotron frequency is summarized[3]. The stable fixed points(SFP's) are located at $J_{SFP} = 8(1 - \frac{f_m}{2f_s}) + 2\epsilon$ for $\theta = 0$ and $\theta = \pi$, the unstable fixed points(UFP's) located at $J_{UFP} = 8(1 - \frac{f_m}{2f_s}) - 2\epsilon$ for $f_m \leq 2f_s - \frac{1}{2}\epsilon f_s = f_2$, or $J_{UFP} = 0$ for $f_2 \leq f_m \leq 2f_s + \frac{1}{2}\epsilon f_s = f_1$ for $\theta = \frac{\pi}{2}, \frac{3\pi}{2}$. A tracking program by using Eq.(3) and Eq.(4) is written. Several cases represent the $f_m < f_2$, $f_m = f_2$, $f_2 < f_m < f_1$, $f_m = f_1$ and $f_m > f_1$ are investigated. The parameters of storage ring at SRRC are used for tracking. The synchrotron frequency of the ring is 25.45 kHz, the damping rate is $200 s^{-1}$, and the revolution frequency is 2.5 MHz. The modulation amplitude ϵ is 0.1 and the corresponding f_2 is 49.6275 kHz and f_1 is 52.1725 kHz. The initial particles are uniformly distributed 100×100 in a rectangular box of dimension $\phi \in [-\pi, \pi]$, $\delta \in [-2, 2]$. The results of tracking of 25000 turns are shown in Fig. 1. As the modulation frequency increases from low frequency to high frequency, the two outer islands move towards the center core, and the population in center core decreases and the two outer islands increases. As modulation frequency equals f_2 the center core disappears. As the modulation increases further the two outer islands come closer, at modulation frequency equals f_1 the two outer islands merge and there exists again single beamlet in a RF bucket. The two outer islands rotate around the center of the RF bucket with angular frequency equals to one half the modulation frequency in all the process.

3 EXPERIMENTAL RESULTS

The experiments of RF amplitude modulation is operated at single bunch mode with beam current about 2 mA. A sinusoidal wave from HP 33120A function generator was split into two to apply to the two gapvoltage feedback loop

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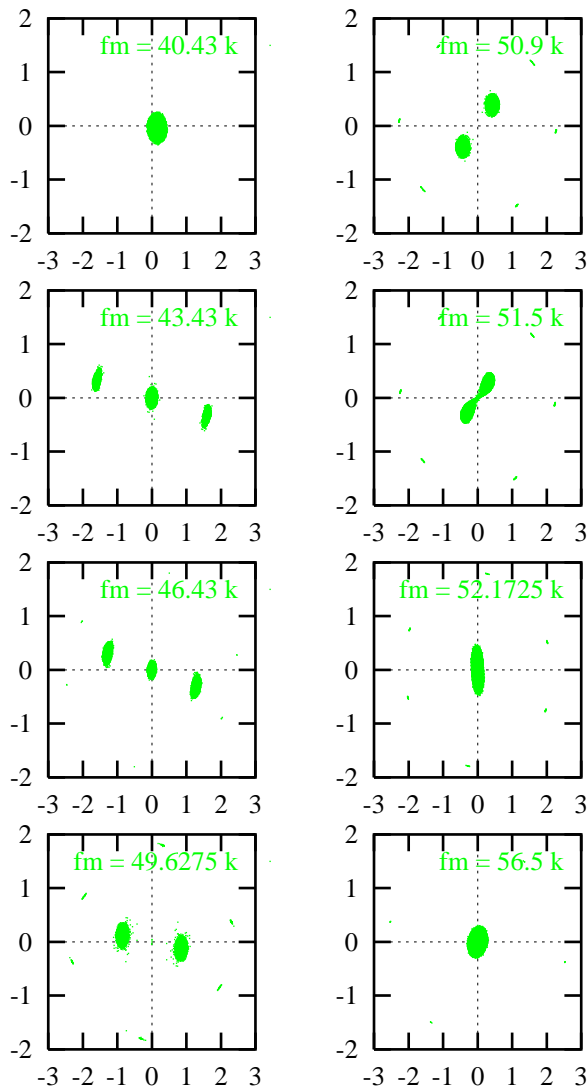


Figure 1: Simulation results of RF amplitude modulation. The modulation frequency is increased from top to down and left to right. The modulation amplitude is 10% of the cavity voltage.

of RF cavity low level system respectively. The operational gapvoltage of each cavity is 400 kV. The modulation frequency is increased step by step from low frequency below $2 f_s$ to high frequency above $2 f_s$. The modulation amplitude ratio is 0.083 and 0.066 respectively. The results were recored by the streak camera. The formation of three beamlets in a RF bucket is shown in Fig. 2. The modulation frequency was 51.08 K Hz with modulation amplitude ratio 0.083. From the upper part of the Fig. 2 it shows that two outer islands rotate with the bucket center at frequency one half the modulation frequency. The lower part of the Fig. 2 shows three beamlets in a single bunch. Which is predicted by the theoretical analysis at modulation frequency below f_2 . The theoretical value of f_2 in this case is 49.84 K Hz. However the observation revealed even at modulation frequency higher than 51.08 kHz there could exit three

beamlets in a single bunch. The reason for this discrepancy may be due to the non-coincidence when applied the modulation to the double RF system. The non zero single bunch beam current may affect the results too. It was also found the frequency response was different when modulation frequency was swept from low to high and from high to low. The phenomenon is like the hysteresis of magnetic field.

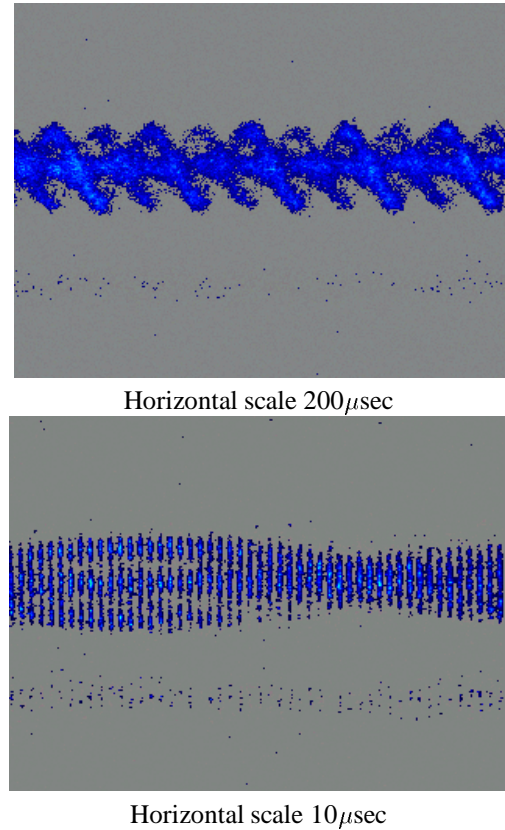


Figure 2: Formation of islands in single bunch beam under RF voltage modulation. The modulation frequency is 51.08 kHz and the amplitude is 8.3% of the RF cavity voltage. The upper plot shows the two outer islands rotate with the bucket center at frequency one half the modulation frequency. The lower part shows the structure in a bunch and the turn by turn motion. The full vertical scale is 1.4 ns.

4 SUPPRESSION OF BEAM INSTABILITY

Longitudinal coupled bunch beam instability is one of the beam instabilities, which deteriorate the beam property. A longitudinal bunch by bunch feed back system is implemented and under commissioning to suppress the instability [4]. Before the completion of the longitudinal feed back system the RF amplitude modulation is used as a temporary solution to suppress the longitudinal coupled bunch beam instability. A modulation frequency slightly below two times of synchrotron frequency with 10% amplitude modulation was applied to the RF system. A

beam spectrum measured from the BPM sum signal from HP4396A before and after the modulation is shown in Fig. 3. The intensity of the beam spectrum is largely reduced after applying the modulation. The suppression of synchrotron side band near revolution harmonics is also shown in Fig. 4. In Fig. 4 the two revolution harmonics is complementary to multiplier of harmonics numbers. The multibunch beam motion under RF amplitude modulation was also recorded by streak camera. The result is shown in Fig. 5. The picture is much like the single bunch event except the amplitude of motion is larger. This indicates that the rotations of beamlets within all the bunches are in phase.

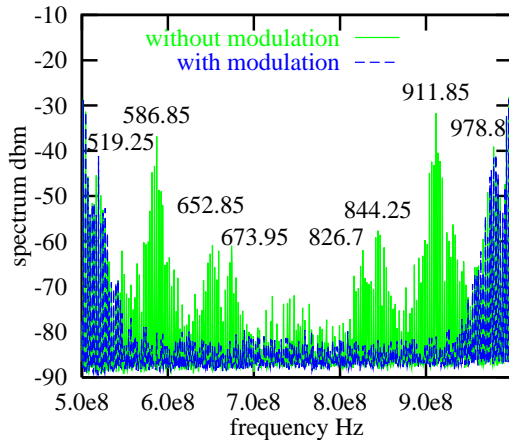


Figure 3: Beam spectrum from BPM sum signal before and after applying RF amplitude modulation. The modulation frequency was 50.155 kHz and the amplitude modulation is 10%. The frequency span of the spectrum is 500 MHz.

In order to further investigate the capability of suppression of beam instability by RF amplitude modulation, the sextupole strength of normal operation was reduced and the vertical betatron side had appeared. The synchrotron photon image pulsing on the screen monitor. When applying the modulation the vertical betatron side band was suppressed and the synchrotron photon image was stabilized again as shown on the screen monitor. From this study it shows the beam can be stabilized by the RF voltage modulation even at lower sextupole strength which is usually to be set to a higher value to provide the head-tail damping.

The application of the RF amplitude modulation close resonance will reduce line charge density, provide larger energy spread. Thus suppresses the coherent motion of beam and increase lifetime. However, because the increase of energy spread the horizontal beam size at dispersion region will increase.

5 REFERENCES

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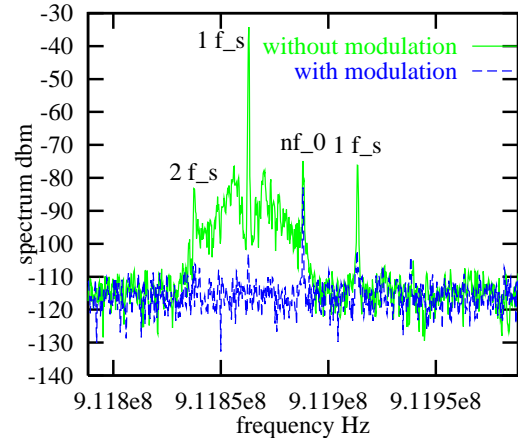
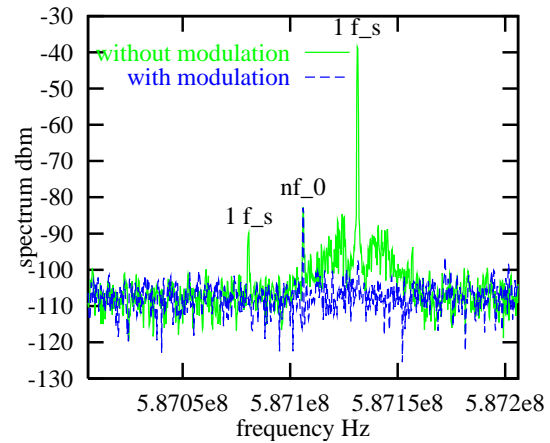
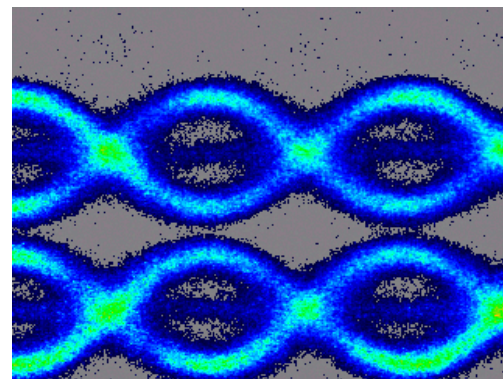


Figure 4: Beam spectrum zoom in from Fig. 3. The revolution harmonic frequency of the upper is 587.106 MHz, and the lower is 911.888 MHz. The frequency span of the spectrum is 200 kHz.



Horizontal scale 100 μ sec

Figure 5: Longitudinal motion of multibunch beam under RF amplitude modulation. The modulation frequency is 50.8 kHz and the amplitude is 8.3% of the RF voltage. The full vertical scale is 1.4 ns and 100 μ sec for horizontal.

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