PHENOMENON OF CHROMATICITY EFFECTS ON THE TRANSVERSE INSTABILITIES IN THE SRRC STORAGE RING

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Abstract

The Chromaticity is an important parameter in the electron storage ring. It provides the chromatic correction on the beam. At the same time a damping mechanism happened on the beam accompanies the chromatic effects through the beam environment interaction. For electron storage ring the transverse instability is a crucial issue. Transverse instability could deteriorate the beam quality. In SRRC storage ring different transverse instabilities could show up in different operation modes. The chromaticity can be used to suppress these instabilities. In this paper we report the results of the suppression of transverse beam instability by chromaticity at different operation conditions.

1 INTRODUCTION

The chromaticity is defined as

$$\xi_{x,y} = \frac{\Delta \nu_{x,y}}{\frac{\Delta p}{p}} \qquad (1)$$

That means the variations of tune $\Delta\nu$ versus energy • •/• in transverse planes. In electron storage ring, the electrons within bunches do not have the same energy. As an electron passing through quadrupoles, chromatic effects due to the slightly different energy of electrons within bunches will show. This is the natural chromaticity. At least two families of sextupole magnets in the dispersion region are introduced to compensate the natural chromaticities at both transverse planes. In the electron storage ring the quadrupoles are used to determine the lattice parameters. The natural chromaticities are determined when the lattice has been designed. Chromaticity adjustment is usually achieved by sextupoles. Compensation of the natural chromaticities from sextupoles is the so-called geometric correction. The second kind chromatic correction is achieved from the sextupoles in the dispersion free regions. This scheme was used to cancel the high order chromatic terms from sextupoles used for natural chromaticity compensation in dispersion region.

The chromaticity has also effect on beam instability, the head tail instability. By including the betatron frequency information versus momentum of two macro particles within bunches, the instability growth rate is inversely proportional to the chromaticity[1,2]. For most cases the chromaticities were chosen slightly positive above transition to avoid the head tail instability.

2 TRANSVERSE INSTABILITY IN SRRC

The transverse instabilities have been found since commissioning. In the commissioning stage the source of transverse instability is mainly gas related. Figure 1 shows the transverse beam spectrum due to beam instability around the n=201 multiplier of revolution frequency for all RF buckets filled pattern at 1.5 Gev. The harmonic number of SRRC storage ring is 200. The fundamental frequency of RF system is 500 MHz. From Fig. 1, it shows the slow sideband is stronger than the fast sideband. This kind of instability was easy to be found as the empty gap in the bunch train becomes smaller. This showed the correlation between the instability and trapped ions. The study of the effect of trapped ion was then started. From the series studies it was proved that ions really contributed to the transverse beam instability[3,4,5]. Another possible sources of transverse beam instability were the transverse impedance from the vacuum chamber and RF cavities. The instability from cavities was found mainly on longitudinal but not on transverse. The broad band impedance was also not so big[6,7]. Hence the contribution of the transverse wake force to the transverse beam instability become less important as compared with the gas-related issues.

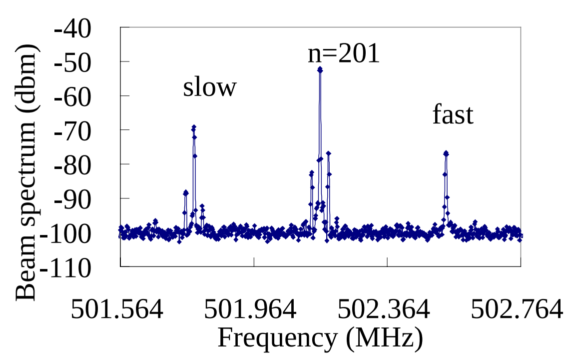

Figure 1: Vertical beam spectrum around frequency of n=201 revolution harmonic at 1.5 GeV.

There are many features of the transverse beam instability in SRRC. The first is that it can show up or dismiss by changing the number of gaps in the bunch train. The second is the occurrence in the high vacuum. The third is the tune shift with and without the electric field of clearing electrode. Many methods have been tried to cure this kind of beam instability[4]. Among them there are RF knock out, beam modulation and beam size dilution. They can be applied to reduce or even suppress the transverse beam instability. Adjusting chromaticity is also one of the effective method. In this paper we will concentrate on the chromaticity effects on the transverse beam instability.

3 CHROMATICITY EFFECTS

The betatron oscillation frequency of a particle in a circular accelerator depends on the energy error $\delta = \Delta E / E$ of the particle. The betatron frequency for an off-momentum particle can be written as

$$\omega_\beta(\delta) = \omega_\beta(1 + \xi\delta) \qquad (2)$$

Where ω_β is the betatron frequency of on momentum particle, ξ is the chromaticity parameter introduced in Eq.(1). The energy offset coupled the synchrotron and betatron motion introduced a so-called head-tailed phase $\xi\omega_\beta \hat{z} / c\eta$ in the betatron motion. Where $\hat{z}$ is the bunch length, c is speed of light and η is the slip factor. It is the physical origin of head-tail instability. In a two macro particles model the growth rate of the transverse oscillations is given by[2]

$$\tau_{\pm}^{-1} = \mp \frac{N r_0 W_0 c \hat{z} \xi}{2\pi\gamma C \eta} \qquad (3)$$

Where N is the number of particles, r_0 is the classical radius of electron, W_0 is impedance and γ is the ratio of electron energy to the rest mass of electron. There are two modes of the oscillation, the + mode means the two macro particles oscillate in phase and the – mode means the two macro particles oscillate out of phase. The instability of the + mode implies the oscillation amplitude of bunch center grows exponentially while the instability of the – mode is the transverse beam size grows exponentially. When one mode is stable the other is unstable.

In SRRC, the chromaticity was set slightly positive to prevent beam instabilities in the routine operation. But the transverse instability did not dismiss at small positive chromaticity. It is found the amplitude of the transverse spectrum, which is used to estimate the instability, varied not only by the chromaticity but also by the numbers of the empty gaps in the bunch train. In most cases, especially after the energy of the storage ring has been upgraded to 1.5Gev, the vertical instability was severer than the horizontal in the user shifts. Hence the vertical beam spectrum was chosen for the studies. The vertical spectrum at the multiplier of revolution harmonic of n=200 was investigated first at different chromaticity settings in an uniform filling pattern. It is found the peak amplitude and width varying with the chromaticity setting. Larger chromaticity gives the smaller peak amplitude and width. This shows the instability was clearly affected by the chromaticity. For more information the spectrum of the vertical slow sideband was picked up along different revolution harmonics from 1 to 250 in different chromaticities. In this studies the measurements were obtained after the beam injection such that the filling pattern was keeping the same while the beam current was a little bit different. The beam energy is 1.5 GeV and almost all of buckets were filled but the population in each bunch is a little different. The results were given in Fig. 2. It is found the pattern of the vertical spectrum was changed by the chromaticity. The pattern shown in Fig. 2 indicates the strength of the beam instability was affected by the chromaticity. In Fig. 2, it is obtained that there are several peaks along the harmonics as the chromaticity setting equals 0.45 which is too small to suppress the beam instability. But most of the peaks will be damped out as the chromaticity setting goes up to 1.25 except the spectrum near the revolution harmonics of n=200. As the chromaticity goes up further the spectrum near harmonics n=200 will disappear finally.

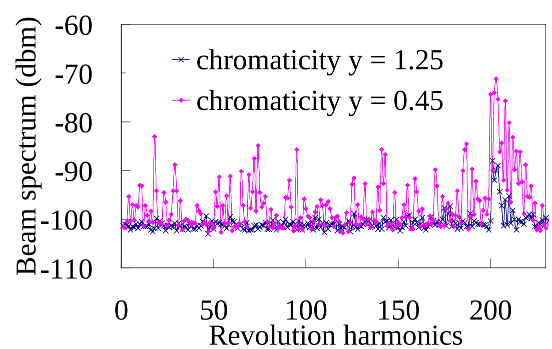

Figure 2: Vertical beam spectrum versus different chromaticity at 1.5GeV.

From the experiments it is found the vertical transverse beam instability depends not only on the chromaticity, as shown in figure 2, but also on the filling pattern of the bunch train. The same features also obtained as the vacuum pressure was getting higher[5]. These facts imply the instability has correlation among these three phenomena. Two of the phenomena, different vacuum pressure and different gap in the bunch train, were to change the strength of the beam instability. Different settings of chromaticity were used to suppress the beam instability to some extent. From these understandings, the possible source of the instability, shown in figure 2, is gas or ion related.

Since the gaps in the bunch train has effects on the instability and the chromaticity can effectively suppress the instability, it is worthy to study the relationship between them. These studies were performed at 1.3 GeV for the easy occurrence of the beam instability with almost the same beam current but different gaps. The positive chromaticity was engaged in the suppression of the instability. Fig. 3 shows the settings of chromaticity to suppress the transverse beam instability versus different empty gaps of filling patterns. As expected, the case of large gap needs small chromaticity. As there is no gap in the bunch train, the chromaticity is increased up to around +6.5 for both transverse planes to suppress the beam instability. From Fig. 3 it is also shown that the chromaticity needed to suppress the instability for vertical is larger than the horizontal one. This indicates the vertical instability was severer than horizontal as the instability was built up.

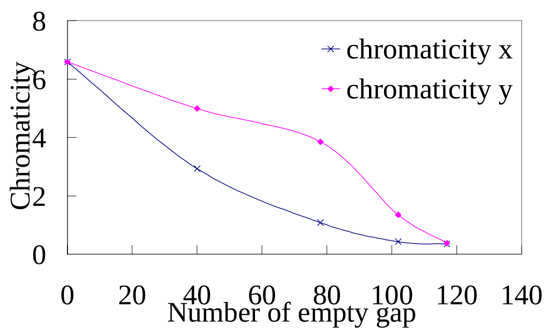

Figure 3: The settings of chromaticity to suppress the beam instability in different empty gaps at the same beam current at 1.3 GeV.

4 CONCLUSION

From the above experiments, it indicates the transverse beam instability shown in SRRC storage ring has strong correlation with the gas or ion trapping phenomenon. The chromaticity can provide a damping mechanism for the instability. The head-tail damping described in section 3 is a single bunch result. But from the experiment it shows the positive chromaticity can provide damping to suppress the instability in multibunch. It implies the damping effect of chromaticity can be extended from two macro particle within one bunch to multi bunches. It is worthy to point out that the damping mechanism provided by the chromaticity is an overall effect and it doesn't concern which kind of instability to deal with.

From the studies the vertical beam spectrum, which is used to indicate the beam instability, can be suppressed fully by the setting of chromaticity. For the severe cases strong positive chromaticities will be needed. If the instability was strong, there were lots of peaks of beam spectrum along the revolution harmonics. As the setting of chromaticity getting higher, the vertical beam spectrum at the low revolution harmonics, roughly from n=20 to 150, will be suppress first. The last beam spectrum suppressed is the peaks near n=200. In case of all the peaks were suppressed by strong chromaticity the beam is basically stable.

The disadvantage of the chromaticity damping is the shortage of the lifetime. Changing the chromaticity was achieved by tuning the sextupole settings. Strong chromaticity means the big sextupole field, which introduce large nonlinear driven force to the beam. The dynamic aperture and the lifetime will be reduced from the strong sextupole field. Moreover the blow up of beam size due to the beam instability was also reduced by the effect of chromaticity damping. The Touschek lifetime is reduced as the beam size become smaller. In the experiments of Fig. 2 the horizontal beam size didn't change much while the vertical beam size shrunk from 149 μm to 136 μm as the vertical chromaticity increased from 0.45 to 1.25. The lifetime reduced 5 hours in this experiment. To compromise the beam lifetime and the beam instability a small positive chromaticity and RF gap voltage modulation were applied to suppress the beam instability and obtained long enough beam lifetime in routine operation. The lifetime can be larger than 10 hours at 200mA in 1.5GeV for this comprised method.

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