# Observation of beam instability in the SSRF storage ring*

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**Abstract** During the SSRF(Shanghai Synchrotron Radiation Facility) storage ring phase-I commissioning, some instabilities have been observed, and the broadband impedance has also been measured. The primary instabilities at present stage are vertical beam blow up and resistive wall instability.

**Key words** SSRF, instability, impedance

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## 1 Introduction

SSRF is a 3rd generation synchrotron light source, which is composed of one 150 MeV linac, one full energy booster, one 432 m long storage ring and seven beam lines (phase-I). The phase-I commissioning of the storage ring started on Dec. 21st 2007, and a very successful progress was got[1]. In lack of superconducting RF cavities, tree normal conductive cavities were used, for which the beam energy was set to 3.0 GeV and the beam current was limited below 100 mA. The basic parameters of the storage ring were listed in Table 1.

Table 1. Main parameters of the SSRF storage ring.

| parameter | designed | measured |
|---|---|---|
| circumference | 432 m | |
| beam energy | 3.0 GeV(Phase-I) | |
| tune $\upsilon_x/\upsilon_y$ | 22.22/11.29 | 22.222/11.287 |
| emittance/(nm·rad) | 2.86@3.0 GeV | 2.83@3.0 GeV |
| natural chromaticity | −55.70/−17.94 | −50/−17 |
| coupling | < 1% | 0.52% |

## 2 Broadband impedance measurement

The broadband impedance is an important issue for the SSRF storage ring. The longitudinal broadband impedance may lengthen the bunch length while the transverse one may cause transverse single bunch instabilities. As a strip camera has not been installed yet, the transverse impedance was measured by observing the transverse tune changes with the single bunch current[2].

$$Z_{\perp \text{eff}} = \frac{4\sqrt{\pi}\,\sigma_1 \Delta \upsilon_{\perp} E/e}{\langle\beta\rangle\, R \Delta I_{\text{b}}} \ , \qquad (1)$$

where $\sigma_1$ is the bunch length, $E$ is the beam energy, $\langle\beta\rangle$ is the average of beta function, $R$ is the average ring radius and $\Delta\nu_{\perp}$, $\Delta I_{\text{b}}$ is the change of the betatron tune and single bunch current respectively.

The betatron motion was excited by a strip line using the sweeping signal. The tune was calculated by averaging five different BPM's fast-fourier transform (FFT) data. The tune is stable within $10^{-5}$ without any other disturbances, which is sufficient for the impedance measurement. As vertical impedance is dominant, vertical tune change with the single bunch current was measured only. The results are shown in Fig. 1.

From the measurement, we get the vertical tune change rate is $\Delta\nu_y/\Delta I_{\text{bunch}} = -0.00053\ \text{mA}^{-1}$ when the vertical chromaticity is near zero. The vertical effective broadband impedance is about 98 kΩ/m assuming that the bunch length is 5 mm (The

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bunch length could not be measured at present, the length is estimated by theory). According to the Panofsky-Wenzel theory, the longitudinal broadband impedance can be calculated[3]:

$$Z_{//\mathrm{eff}} = \frac{b^2}{2R} Z_{\perp\mathrm{eff}} \ , \tag{2}$$

where $b$ is the equivalence beam pipe radius, here we take for 17.5 mm. Using Eq. (2), the longitudinal impedance is about 0.22 Ω, which is close to the prediction value of 0.17 Ω.

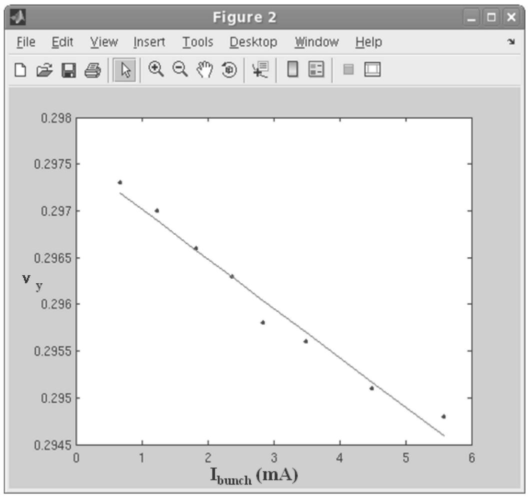


Fig. 1. Vertical tune changes with single bunch current.

## 3 Single bunch instability

Since at present streak camera has not been installed, the beam length information could not be got.

Fast beam blowup in vertical plane was observed in the SSRF storage ring. When chromaticity was near zero and the RF voltage was 1.2 MV, the threshold was 4.78 mA. The synchrotron radiation spot size from one of the bending magnets was recorded as shown in Fig. 2. The vertical beam size has step changes when the bunch current was injected above the threshold and decayed down below the threshold. (At the same time, the beam lifetime jumped form 0.5 hour to 20 hours and dropped down to 0.5 hour simultaneously.)

When the vertical chromaticity is above 2, the threshold rises to above 10 mA. The threshold also changes with the RF voltage as shown in Table 2. The phenomenon strongly denotes that the beam blowup is caused by the transverse mode coupling instability (TMCI). Further efforts should be done to confirm the conclusion by observing the synchrotron sidebands in the future. (At present, the cable from BPM to oscilloscope is too long, the signal is greatly attenuated, and small sidebands can not be observed).

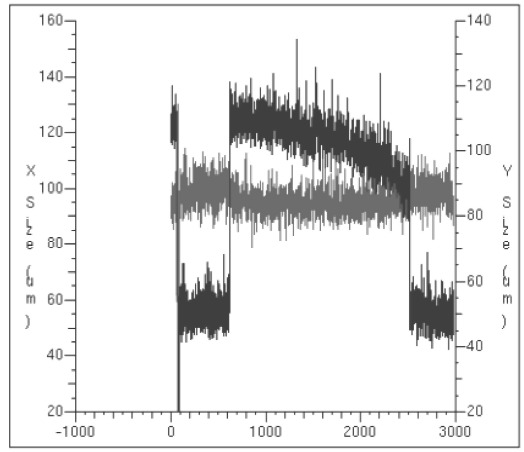


Fig. 2. Spot size of synchrotron radiation (the vertical axis is the beam RMS size μm, the horizontal axis is time $s$, the red one for the horizontal beam size, the blue one for the vertical beam size).

Table 2. Blowup threshold Vs. RF voltage.

| | | | |
|---|---|---|---|
| $V_{\mathrm{rf}}$ | 1 MV | 1.19 MV | 1.29 MV |
| $I_{\mathrm{th}}$ | 4.54 mA | 4.78 mA | 4.91 mA |

Above the fast beam blowup threshold or around, a sawtooth phenomenon has been observed. Fig. 3 shows the sawtooth like turn-by-turn beam position data. Although the fast change of beam size can not been measured at present, the sum value of BPM button voltage fluctuates at the same frequency as shown in Fig. 4, which indicate some information of the beam size change.

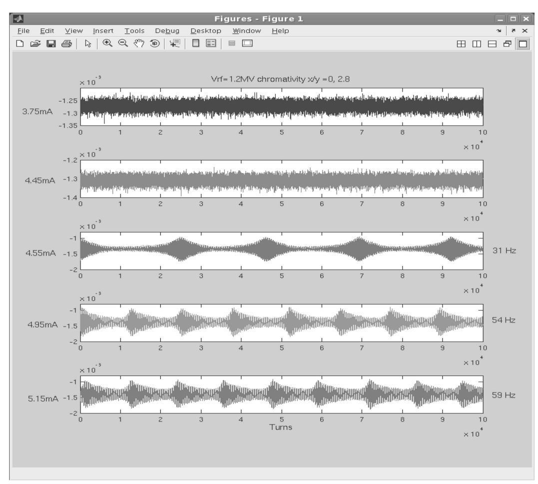


Fig. 3. Turn-by-turn BPM data for different bunch current.

Using a corrector to distort the vertical orbit can increase the threshold, but to distort the horizontal orbit has little effects. Neither does any effects of RF cavity tuner on the instability. So the sawtooth phenomenon is mainly caused by the vertical broadband impedance. Distorted vertical orbit leads to a stronger non-linear damping effect, which increases the threshold.

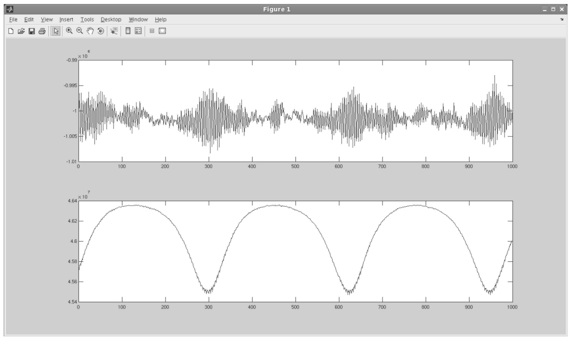

Fig. 4. Up: turn-by-turn BPM position data, below: BPM button sum data.

## 4 Multi bunch instability

In SSRF phase-I commissioning, tree normal conductive cavities were used. By careful tuning of the resonance frequency, longitudinal coupled bunch instability can be avoided.

At the very beginning of the commissioning, the average vacuum of the storage ring was about $3\times10^{-9}$ Torr, the transverse coupled bunch instability appeared when the beam current was above 60 mA. From the spectrum, it can be identified to be ion related instability. One month later, the storage vacuum was improved to $5\times10^{-10}$ Torr or less and the ion related instability never appeared again.

Resistive wall instability was observed. The threshold is about 64 mA which is very close to the prediction value 62 mA (at 3 GeV). Increasing the vertical chromaticity can raise the threshold as shown in Table 3. Uneven filling pattern could suppress the instability. However the effect is not obvious, the threshold only increases by a few milli-amperes.

Table 3. Resistive wall instability Vs. vertical chromaticity.

| $\xi_y$ | $I_{\mathrm{th}}$/mA |
|---|---|
| 1.7 | $>100$ |
| 1.3 | $>100$ |
| 0.9 | $>100$ |
| 0.5 | $>100$ |
| 0.4 | 90 |
| 0.3 | 70 |
| 0.1 | 64 |

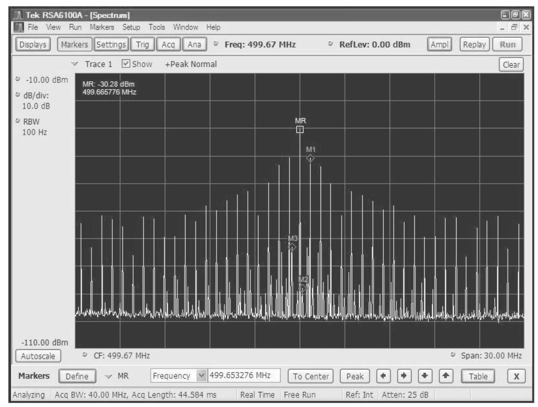


Fig. 5. Beam spectrum when resistive wall instability happens. The sideband is mainly concentrated at low frequency region which indicates resistive wall instability.

## 5 Summary

In SSRF phase-I commissioning a preliminary observation of beam instability has been done. The impedance is controlled at a low level. As expected, the resistive wall instability appears around 64 mA. The vertical beam size blows up at 4.78 mA/bunch which is about a half of the theory threshold of TMCI, so the mechanics of the blow-up and sawtooth phenomenon should be further confirmed.

### References

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