Study of orbit stability in the SSRF storage ring

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Abstract In this paper, analysis of the beam orbit stability and conceptual study of the dynamic orbit feedback in the SSRF storage ring are presented. It is shown that beam orbit position movement at the photon source points is smaller than the orbit stability requirements in horizontal plane, but exceeds the orbit stability requirements in vertical plane. A dynamic global orbit feedback system, which consists of 38 high-bandwidth air-coil correctors and 40 high-precise BPMs, is proposed to suppress the vertical beam orbit position movement. Numerical simulations show that this dynamic orbit feedback system can stabilize the vertical beam orbit position movement in the frequency range up to 100 Hz.

Keywords Synchrotron radiation light source, Electron storage ring, Beam orbit control

CLC numbers TL503, TL594

1 Introduction

The Shanghai Synchrotron Radiation Facility (SSRF) is a low-emittance (e.g., ε_x~10 nm·rad) third-generation light source under design and R&D.[1,2] It is composed of 20 DBA cells and provides 10 straight sections of 7.24 m and 10 straight sections of 5.0 m for the inclusion of insertion devices, injection components and RF cavities. It is well-known that electron beam orbit stability is critical for successful operation of a third generation synchrotron radiation source.[3] According to stability requirements of photon beam position and intensity at experimental stations, electron beam orbit stability with 10% or better of the photon beam size and divergence at photon source points is required for the SSRF storage ring. Horizontal and vertical stability of the beam orbit at the beam position monitors near photon source points, is <30 μm and <5 μm, respectively.

In this paper, we firstly present an analysis of beam orbit position movement resulting from dominant sources, and then review the study of dynamic orbit feedback in SSRF storage ring.[4]

2 Sources of beam orbit position movement

In a realistic storage ring, many effects may cause beam orbit position movement with time. Ground settlement, tunnel temperature variation and ground vibration can cause motion of some installations including magnets, vacuum chamber and beam position monitors (BPM) which are used as reference points for the orbit correction system. The beam orbit is also affected by variations in magnet power supplies. Effects of ground settlement of a few hundred microns may be compensated by slow orbit correction. But larger motion must be corrected by realigning the magnet girder. In the following, effects of the dominant sources, such as thermal drift, vibrations and magnet power supply variations, will be discussed.

2.1 Thermal drift

Motion of magnets and BPMs arises from variations in temperature of cooling water for magnets and vacuum chamber, variations in air temperature, and varying thermal loads associated with synchrotron radiation and ramping of magnets. Magnet motion causes beam orbit position movement. Such beam orbit position movement may be stabilized by slow orbit correction with steering magnets. However, the correction is again only effective if the BPM themselves are immune to thermal variation. So BPM's thermal drift is one of the most challenges for orbit stability.

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To minimize mechanical movement, the method of fixing the BPM with respect to the magnet center line is important. In SSRF storage ring, there are two type BPMs. One is the normal BPMs equipped with arc chamber, which are fixed to magnet girder. The other is the high-precise BPMs at both ends of DBA cell, which have larger button and smaller vertical gap and are mechanically isolated by vacuum bellows located on the outside and mounted on mechanically stable stands to floor with low thermal expansion coefficients. The analysed horizontal and vertical thermal drifts of magnet, BPM and beam orbit are summarized in Table 1. Here, it is assumed that variations in tunnel air temperature, magnet cooling water temperature and vacuum chamber temperature are ±1°C, ±0.5°C and ±3°C, respectively.

It can be seen from Table 1 that the thermal drift of high-precise BPMs is smaller than the orbit stability requirement, but that of normal BPMs in vertical plane is much larger than this requirement. Clearly, only with these high-precise BPMs, one can achieve the orbit stability goal by using orbit correction. It indicates that fixation of the BPMs at both ends of the DBA cell to floor by low thermal expansion coefficients stands and isolation from other vacuum chambers by bellows are crucial for realizing the orbit stability goal in SSRF storage ring.

Table 1 Thermal drifts of magnet, BPMs and beam orbit position movement

Element	Horizontal drift (μm)	Vertical drift (μm)
Magnet	~± 2	~± 7
Normal BPMs	~± 11	<± 15
High-precise BPMs	~± 2	~± 2
Beam orbit position movement	~± 10	~± 16

2.2 Vibration

The vibration sources can be classified to external sources and internal sources. External sources cover seismic ground motion, traffic and equipment such as pumps and compressors in the site at large distances from the storage ring. Internal vibration sources are those close to the storage ring in experimental area or the inner area of the machine, which include linac and booster and associated equipment. One may treat the external sources as plane wave vibrations, and the internal sources as random vibrations.

Table 2 shows the amplification factors and beam orbit position movement due to internal vibrations and external vibrations in storage ring, where the maximum amplification in the frequency range smaller than 100 Hz for the external sources has been used. For simplicity, it is assumed that the ground vibrations are transferred without amplification or attenuation onto the magnets and the external vibration waves with no damping along the machine diameter. The speed of vibrations is set to be 500 m/s, and the amplitude of the internal vibrations and external vibrations is assumed to be 300 nm and 200 nm in the frequency range 0.01 to 100 Hz, respectively.

Table 2 shows that horizontal vibrations do not affect the beam orbit stability, while vertical vibrations may result in beam orbit position movement with a peak beyond the 5μm limit.

Table 2 Amplification factors (A_x, A_y) and beam orbit position movement (σ_x, σ_y) at the photon source points due to vibration sources

Vibrations	A_x	A_y	σ_x (μm)	σ_y (μm)
Random	51	17	15	5
Plane-wave	100	55	20	11

2.3 Magnet power supply variation

The effects of magnet power supply variations on beam orbit stability have also been studied. It was found that the beam orbit position movement due to variations in the power supplies for dipole, quadrupole, and sextupole is much smaller than that resulting from variations in the power supplies for COD correctors in the SSRF storage ring.

The maximum values of COD correctors in storage ring are respectively 1.2 mrad in horizontal plane and 0.8 mrad in vertical plane. These correctors with power supply stability of 2×10^{-4} would cause dipole errors of 0.24 μrad in horizontal plane and of 0.16 μrad in vertical plane. Table 3 shows the amplification factors (A_x, A_y) and beam orbit position movement (σ_x, σ_y) at insertion device (ID) photon source points caused by the corrector power supply variations. It indicates that the power supply variations would not cause a problem for horizontal beam orbit stability, but result in vertical beam orbit position movement around the 5 μm limit.

Based on the above studies, it can be seen that beam orbit position movement at the photon source points is smaller than the requirement of orbit stability (e.g., 30 μm) in horizontal plane, but exceeds the requirement of orbit stability (e.g., 5 μm) in vertical plane.

Table 3 Amplification factors (A_x, A_y) and beam orbit position movement (σ_x, σ_y) at photon source points due to the corrector power supply variations

SR source point	A_x	A_y	σ_x (μm)	σ_y (μm)
ID	56	26	13	4

3 Dynamic orbit feedback

To achieve the goal of orbit stability, the SSRF storage ring will be equipped with a dynamic orbit feedback system. In the following, we review the theoretical concepts of the dynamic orbit feedback in the storage ring. There are two different ways to implement the orbit feedback system.[3] The first is called local orbit feedback, which function is to minimize the orbit variation at each experiment individually involving only correctors around the insertion device. The other, named global orbit feedback, tries to minimize the orbit variations at all experiments at the same time. The local feedback system has some disadvantages. For example, the non-locality of the correction would lead to a crosstalk between the local feedbacks which would be extremely difficult to control. Moreover, the BPM movement, induced by variation in vacuum chamber temperature, is particularly harmful if these are used in local correction schemes. Global correction of the orbit using many BPMs has then the advantage of minimizing BPM errors and correcting only "physical" disturbances. Therefore, a global orbit feedback will be adopted in the SSRF storage ring.

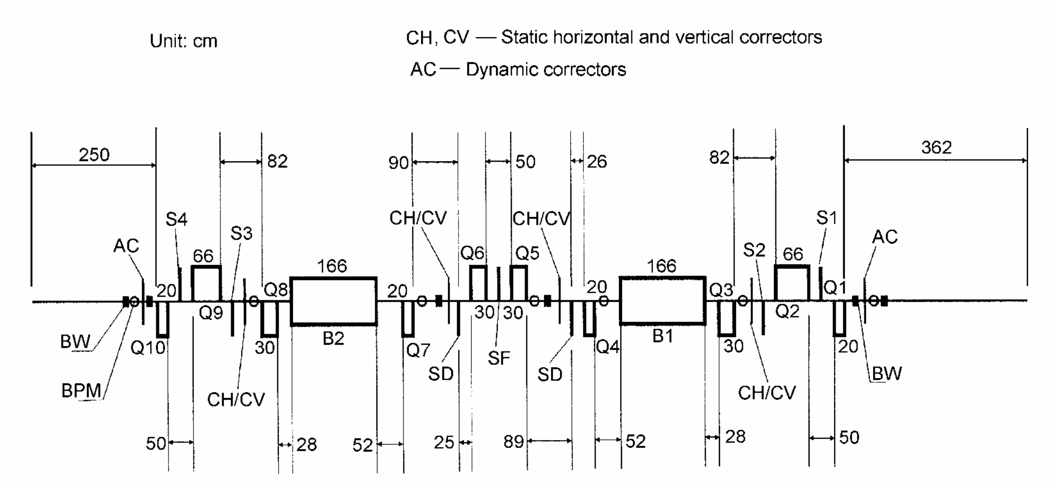

Fig.1 Layout of one DBA cell of the storage ring.

Fig.1 shows a layout of the DBA cell including the locations of the BPMs and correctors. The storage ring will be equipped with 7 BPMs per DBA cell. One BPM will be located at each end of the cell, one in each quadrupole triplet and near the harmonic sextupole S2 or S3, and other three in the achromat straight section. As mentioned in Sec.2.1, the BPMs at both ends of the DBA cell will have larger button, smaller vertical gap and be mounted on mechanically stable stands with low thermal expansion coefficients, so that they will be much more precise and stable than other normal BPMs. From Fig.1, one can also see that each DBA cell has a total of 6 corrector magnets. The two AC correctors at both ends of straight section are air-coil type, which surround stainless vacuum chambers. The remaining correctors (CH/CV) in each cell are iron-core type and surround a thick aluminum vacuum chamber. The air-coil correctors have significantly higher effective bandwidth than other correctors, and its magnetic field penetration roll-off frequency is >1kHz. Since one long straight section will be equipped with RF cavities and not have AC correctors, there are totally 140 BPMs and 118 correctors around the storage ring, including 40 high-precise BPMs and 38 high bandwidth air-coil correctors.

In general, all of these 140 BPMs and 118 correctors around the storage ring could be made available to the orbit feedback system. In view of the above-mentioned facts, only 40 high-precise BPMs and 38 high bandwidth air-coil correctors will be used in the global feedback system.

The correlation between correctors and monitors for the linear optics is established by superimposing the monitor reading pattern for every single corrector. The coefficients of the two resulting correlation matrices, or called response matrices, can be derived analytically from the machine model or from orbit measurements in the real machine. To turn this into a correction algorithm, it is necessary to invert the matrix in order to get the corrector pattern as a function of a given BPM pattern. The SVD algorithm[5] will be used to select the BPMs and correctors and invert the matrix. This numerically very robust method minimizes the rms orbit and the rms orbit steer at the same time.

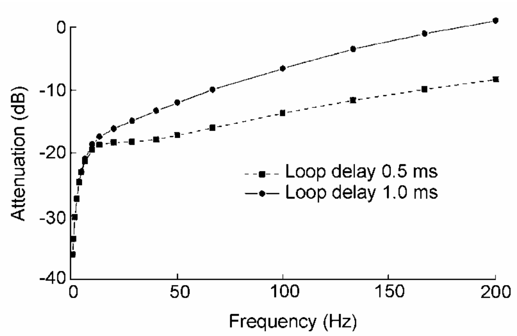

Fig.2 Noise attenuation of the closed feedback loop.

By use of the MATLAB based code SIMULINK, we develop a feedback model to study the effects of loop delay, PS parameters, air-coil correctors, and vacuum chamber, BPM errors on the closed loop bandwidth, and optimize the bandlimit digital filter and compensation filter. Fig.2 shows noise attenuation of the closed feedback loop with 2 kHz data update rate and different loop delay. It indicates that the bandwidth of the closed feedback loop can be higher than 100 Hz with 1.0 ms loop delay.

4 Conclusions

Our studies show that beam orbit position movement resulting from the thermal drift, vibrations and variations in magnet power supplies is smaller than the horizontal orbit stability requirement, but the vertical beam orbit position movement due to these sources exceeds the vertical orbit stability requirement. And therefore a dynamic vertical orbit feedback is required. The proposed dynamic global vertical orbit feedback system includes 38 high bandwidth air-coil AC correctors and 40 high-precise BPMs. Numerical simulations show that this dynamic orbit feedback system can stabilize beam orbit position movement in the frequency range up to 100 Hz.

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