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 motion 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 fast global orbit feedback system, which consists of 38 high-bandwidth air-coil correctors and 40 high-stable BPMs, is proposed to reduce the vertical orbit motion resulted from fast perturbations like mechanical vibrations and magnet power supply ripples. Numerical simulations show that this fast orbit feedback system can stabilise the vertical orbit motion in the frequency up to 100 Hz.

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 meter and 10 straight sections of 5.0 meter 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. Table 1 shows the beam orbit stability requirements at the beam position monitors (BPM) near photon source points.

Table 1: SSRF orbit stability specifications

	Horizontal stability	Vertical stability
BPMs	<30 μm	<5 μm

In this paper, we firstly present an analysis of beam orbit motion resulted from dominant sources, and then review the conceptual study of the dynamic orbit feedback in SSRF storage ring.

2 SOURCES OF ORBIT MOTION

In a realistic storage ring, many effects may cause beam orbit motion with time. Ground settlement, tunnel temperature variation and ground vibration can cause motion of the magnets and vacuum chamber, including the beam position monitor (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, the effects of the dominant sources, such as thermal drift, vibrations and magnet power supply variations, will be discussed.

2.1 Thermal drift

Magnet and BPM motion arises from variations in the temperature of cooling water for the magnet and vacuum chamber, variations in air temperature, and varying thermal loads associated with synchrotron radiation and ramping of magnets. Magnet motion causes beam orbit motion. Such orbit motion 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.

To minimise mechanical movement, the method of fixing the BPM with respect to the magnet center line is important. In SSRF storage ring, BPMs are fixed by two ways. Normal BPMs equipped with arc chamber are fixed to magnet girder. High-stable BPMs at both ends of DBA cell 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 2. Here, it is assumed that variation in tunnel air temperature is ±1°C, variation in magnet cooling water temperature is ±0.5°C and variation in vacuum chamber temperature is ±3°C.

Table 2: Thermal drifts of magnet, BPM and beam orbit

Element	Horizontal drift	Vertical drift
Magnet	~± 2μm	~± 7μm
Normal BPMs	~± 11μm	<± 15μm
High-stable BPMs	~± 2μm	~± 2μm
Beam orbit motion	~± 10μm	~±16μm

It can be seen from table 2 that the high-stable BPM’s thermal drift is smaller than the orbit stability requirement, but normal BPM’s thermal drift in vertical plane is much larger than the orbit stability requirement. Clearly, only with these high-stable BPMs, one can achieve the orbit stability goal by use of orbit correction.

It indicates that fixing the BPMs at both ends of the DBA cell to floor by low thermal expansion coefficients stands and being isolated from other vacuum chamber by bellows are crucial for realising the orbit stability goal in SSRF storage ring.

2.2 Vibration

The vibration sources can be considered as either external sources or internal sources. External sources are 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 3 shows the amplification factors and orbit motion due to internal vibrations and external vibrations in storage ring, where the maximum amplification in the frequency range of 0.01-100 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 500m/s, and the amplitude of the internal vibrations and external vibrations is assumed to be 300nm and 200 nm in the frequency range of 0.01-100Hz, respectively.

Table 3: Amplification factors (A_x, A_y) and beam orbit motion (σ_x, σ_y) at the photon source points due to vibration sources

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

Table 3 shows that the horizontal vibrations don't affect the beam orbit stability, but vertical vibrations may result in orbit motion with peak beyond the 5μm limit.

2.3 Magnet power supply variation

The effects of magnet power supply variations on beam orbit stability have been also studied. It was found that the beam orbit motion due to variations in the power supplies for dipole, quadrupole, and sextupole is much smaller than the beam orbit motion resulted 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 1.2mrad in horizontal plane and 0.8mrad in vertical plane. These correctors with power supply stability of 2×10^{-4} would cause dipole errors 0.24μrad in horizontal plane and 0.16μrad in vertical plane. Table 4 shows the amplification factors (A_x, A_y) and orbit motion (σ_x, σ_y) at photon source points caused by 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 motion around the 5μm limit.

Table 4 Amplification factors (A_x, A_y) and beam orbit motion (σ_x, σ_y) at photon source points due to corrector power supply variations

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

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

3 DYNAMIC ORBIT FEEDBACK

To achieve the goal of orbit stability, the SSRF storage ring will be equipped with a slow orbit correction system and a fast orbit feedback system. The static beam orbit distortions (COD) and slow beam orbit motion, which are resulted from the magnet alignment errors or other sources in slow time scales (e.g., thermal drifts), will be corrected every minute by the slow orbit correction system. And the fast orbit motion, which is caused by the sources in short time scales (e.g., 0.01~100Hz) like the mechanical vibrations and magnet power supply ripples, will be stabilized by the fast orbit feedback system.

In the following, we review the theoretical concepts of the fast orbit feedback in SSRF storage ring. There are two different ways to implement orbit feedback system [3]. The first is the so-called local orbit feedback, which could be tried to minimise orbit variation at each experiment individually involving only correctors around the insertion device. Another is the so-called global orbit feedback, which tries to minimise 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 feedback 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 minimising BPM errors and correcting only "physical" disturbances. *Therefore, a global orbit feedback will be adopted in the SSRF storage ring*.

Fig.1 shows the 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 that mentioned in sec.2.1, the BPMs at both ends of the DBA cell will be mechanically isolated by vacuum bellows located on the outside and mounted on mechanically stable stands with low thermal expansion coefficients and are much more stable than others. 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 hasn't AC correctors, there are totally 140 BPMs and 118 correctors around the storage ring, including 40 high stable BPMs and 38 high bandwidth air-coil correctors.

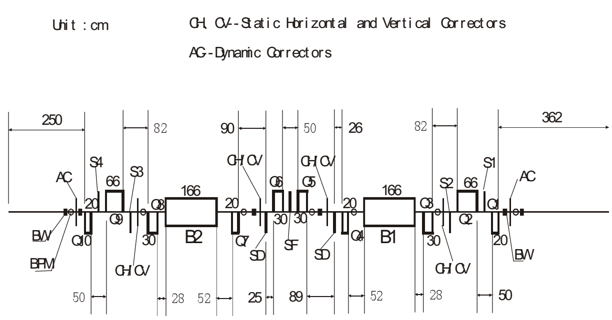

Figure 1. Layout of one DBA cell of the storage ring

In generally, all of these 140 BPMs and 118 correctors around the storage ring could be made available to the orbit feedback system. As that shown before, the BPMs at the ends of each cell are more stable than other BPMs, and the air-coil AC correctors at the ends of each cell has significantly higher effective bandwidth than the remained corrector magnets. *And then only the 40 high-stable BPMs and 40 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 also 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 [4] 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.

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 optimise the bandlimit digital filter and compensation filter. Figure 2 shows noise attenuation of the closed feedback loop with 2kHz data update rate and different loop delay. It indicates that the bandwidth of the closed feedback loop can be higher than 100 Hz with 1.0ms loop delay.

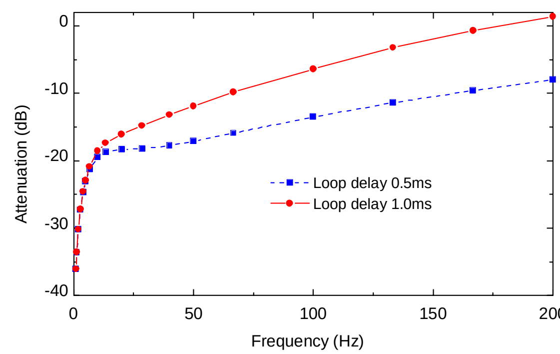

Figure 2. Noise attenuation of the closed feedback loop

4 CONCLUSIONS

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

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