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BEAM ORBIT STABILIZATION AT THE SPring-8 STORAGE RING

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1. INTRODUCTION

The SPring-8 storage ring is a third generation X-ray source providing brilliant photon beams. Continuous performance improvement realizes small horizontal and vertical beam sizes reaching to respectively 280μm and 4μm in rms at the source point of each standard insertion device (ID) [1]. Especially in a vertical plane, small orbit variation enlarges the vertical beam size and an orbit drift also changes intensity of monochromatized X-ray beam at an experimental hutch. Beam orbit stability is thus one of the most important subjects for the best use of an advantage of a small source size. However, the sufficient orbit stability is not easily achieved, because the beam orbit variation is generated by a complicated system that the various kinds of perturbation sources are interrelated and widely distributed over the ring. This complex environment prevents us from finding out the main perturbation sources easily and also limits the effectiveness of countermeasures.

To overcome this, it is critically important that equipment, utility systems, beam controls, and a building structure, such all machine subsystems are re-investigated, improved and re-integrated from the unified viewpoint of orbit stability. In this context, a project on beam orbit stabilization in the SPring-8 storage ring started aiming at sub-micron stability at the beginning of year 2001. Experts of all machine subsystems were gathered to form the project team for systematic and unilateral investigation of the problem.

During the last two years, we have successfully reduced the orbit variations in a frequency range from DC to a hundred Hz and reached to a point where the stability of sub-micron level comes into our landscape. In this paper, we review our activities and show present results on the orbit stabilization focusing on the latest topics.

2. APPROACH TO ORBIT STABILIZATION

Our goal of the orbit stabilization is a sub-micron level. This requirement mainly comes from the small vertical beam size. We also expect that such ultimate beam stability might be a key to future accelerators including forth generation light sources.

It is doubtful that such high stability can be achieved only by a feedback-like system covering broad frequency-band from DC to a few hundred Hz. The gain of such a system is generally limited at most to 20dB or so. This means that the orbit stability should be at least a micron level

Toc

before introducing a feedback system. At SPring-8, we are trying to achieve the stability of a micron or less not by the feedback systems but by the thorough source suppression as a first step. After this step, some proper feedback correction should be installed to push the stability up to sub-micron level as the second step. This is our strategy to realize the orbit stability of sub-micron [2]. We stress here that the conditioning, in other words exhaustive source suppression before installing the feedback system is the key to the ultimate stability.

3. ACTIVITIES IN THE SPRING-8 BEAM ORBIT STABILIZATION PROJECT

Before starting the project of beam orbit stabilization, our efforts were mainly focused on the source suppression of slow orbit variations. In the period from autumn 1997 to winter 2000, the following countermeasures were carried out to suppress the perturbation sources: (1) preservation of thermal equilibrium in the machine tunnel, (2) temperature control improvement of the cooling water for magnets and vacuum chambers and (3) precision improvement of correction table for an insertion device error field. And also, to reduce the orbit drift during the user operation, a periodic correction of closed orbit distortion (COD) was introduced since autumn 1998 [3]. A periodic correction of beam energy by changing the RF frequency successively started in the user operation since winter 2000.

The project of beam orbit stabilization started in January 2001. At the beginning of the project, we reviewed the previous activities and understood the achieved level for each subject to clarify remaining critical issues. Through elaborate discussion, three main subjects were selected out to push the project forward. The first is to understand a dominant source on the fast orbit variation and its suppression. Figs. 1 and 2 are respectively horizontal and vertical beam spectra measured from January 2000 to November 2002. The blue lines represent the spectra of horizontal and vertical beam variations before the project starts, which were measured on Jan. 29th, 2000. We see several broad peaks in the horizontal spectrum and one broad and huge peak from 20Hz to 70Hz in the vertical spectrum. These broad peaks mainly contribute to the fast orbit variation. The second subject is to make clear the design concept of a fast orbit feedback system. This is a critical item at the second step of the orbit stabilization as described in Section 2. The third subject is to prepare measurement infrastructure to realize real time measurement for correlation study. This enables us to understand the quantitative relation between the magnitudes of orbit and source variations.

As a result of extensive research and study, we successfully found out the cause of the horizontal orbit variation in the range from 0.1Hz to 10Hz. The current ripple of power supplies for quadrupole magnets (QPSs) caused this variation. The current ripple changes fields of quadrupole magnets. This field change induces eddy current in vacuum chamber and results in a vertical dipole field at around the center of vacuum chamber when the chamber cross section is asymmetric horizontally [4]. In order to suppress the current ripple, we improved a current stabilizing circuit of each QPS and achieved the current stability which is lower than 1×10^{-5} [5, 6]. The red lines in Figs. 1 and 2 represent the beam spectra measured after this improvement. We see significant reduction of the horizontal variation amplitude in the range from 0.1Hz to 10Hz and from 30Hz to 40Hz. However, we see no significant change in the vertical beam spectrum as shown in Fig. 2. This is due to the symmetry of the vacuum chamber cross section.

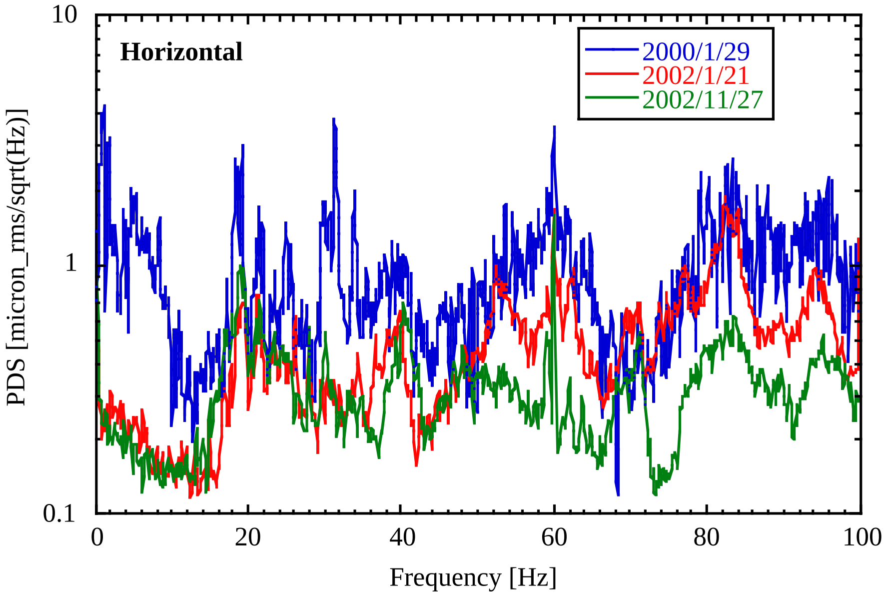

Fig.1 Change in horizontal beam spectrum by suppression of current ripple of power supply
2000/1/29: before the beam orbit stabilization starts
2002/1/21: after suppressing the current ripple of the power supplies
2002/11/27: after suppressing the vacuum chamber vibration

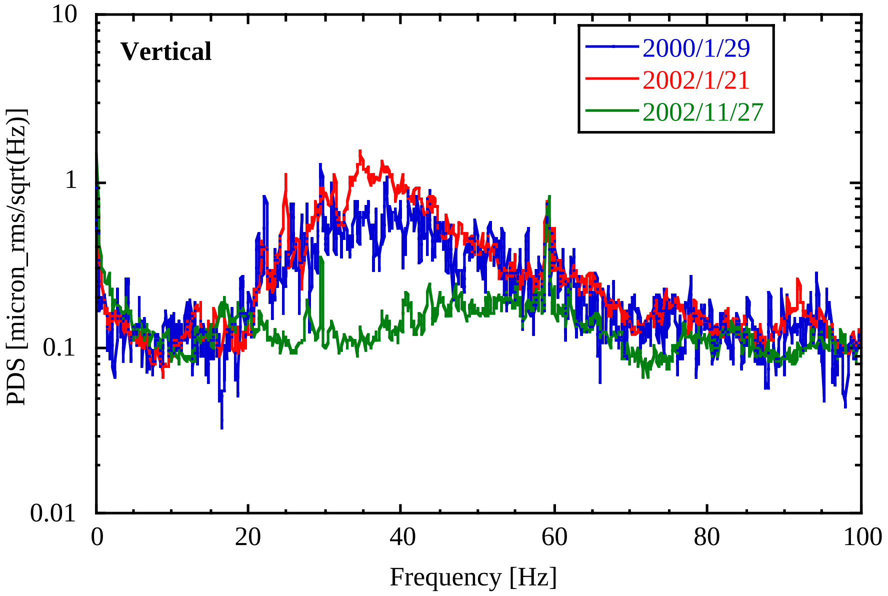

Fig.2 Change in vertical beam spectrum by suppression of current ripple of power supply

Toc

The current ripple mainly induces the vertical dipole field, i.e., the horizontal kick under the SPring-8 boundary condition.

On close investigation of the perturbation sources, we also found out a broad peak around 30Hz in the vertical vibration spectrum of a part of vacuum chambers, which is similar to that observed in the vertical beam spectrum. Owing to a non-rigid mechanical structure the chamber was easily vibrated by disturbance of the cooling water supplied to the absorber [7]. Through detailed investigation of the chamber vibration [8], we saw plural parts of the chambers excite the vertical orbit variation from 20Hz to 70Hz and horizontal one from 50Hz to 100Hz. A vibration of conductive chamber in a quadrupole field also induces eddy current, which generates horizontal and vertical dipole fields according to the direction of the chamber vibration. In order to suppress the chamber vibration, following three countermeasures were taken: (1) addition of supports to fix the vacuum chambers, (2) exchange of grove type valves for needle type ones and (3) reduction of cooling water flow-rate [7, 9]. After this improvement, the vertical peak was drastically reduced as shown by the green line in Fig. 2. The horizontal beam variation in the range from 70Hz to 100Hz was reduced as shown in Fig. 1. Figs. 3 and 4 show respectively the horizontal and vertical beam variations in time domain measured by the same system as used for the beam spectrum. We see that the countermeasures reduce the horizontal and vertical fast orbit variations respectively to about half and one forth.

In parallel to the above source suppression, specification of a fast orbit feedback system was discussed from the viewpoint of achieving sub-micron orbit stability. It was concluded that the sub-micron stability is achievable by the proposed system with the button pick-ups used in the present beam position monitor (BPM) system. In the proposed design the thorough noise reduction is pursued especially in the analog part of a BPM electric circuit [10] to achieve the target S/N of 90dB at around the stored current of 100mA. Response analysis of the feedback loop is also being performed by both numerical and experimental ways.

In stabilization of the slow orbit drift, the periodic COD correction system was upgraded in the summer of 2002. The number of both horizontal and vertical steering magnets was increased from twelve to twenty-four to reduce the slow drift at each beam line [11]. Aiming at almost perfect transparency of IDs without any perturbation on the orbit, a new scheme has been completed [12] for a precise ID feed-forward correction by using real time measurement system of electron and photon beam positions. Here, we adopted a wavelet transformation to extract the orbit variation originating from the change in ID parameters [13].

4. PRESENT BEAM ORBIT STABILITY

The present beam orbit stability is summarized in Table 1. Since the vertical beam size (4μm) is much smaller than the horizontal one (280μm) at each standard ID source point, further improvement of the orbit stability is necessary in the vertical plane for efficient use of the sharp photon beam. As seen in the table, the slow orbit drift is presently lager than the fast orbit variation. This slow drift is not limited by resolution of the BPM system, but by the number of steering magnets used in the periodic correction and also by the correction algorithm.

Fig. 5 shows the typical orbit drift for one day with the periodic correction turned on. In the present operation, beam refilling is scheduled once a day for multi-bunch filling and twice a day

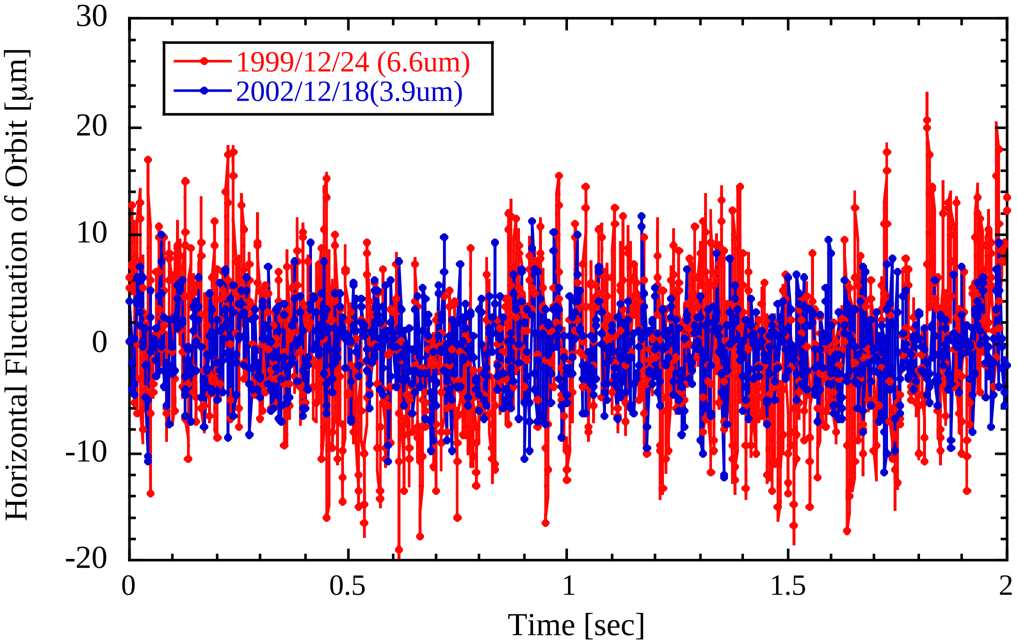

Fig.3 Horizontal beam orbit variation measured at the center of the unit cell

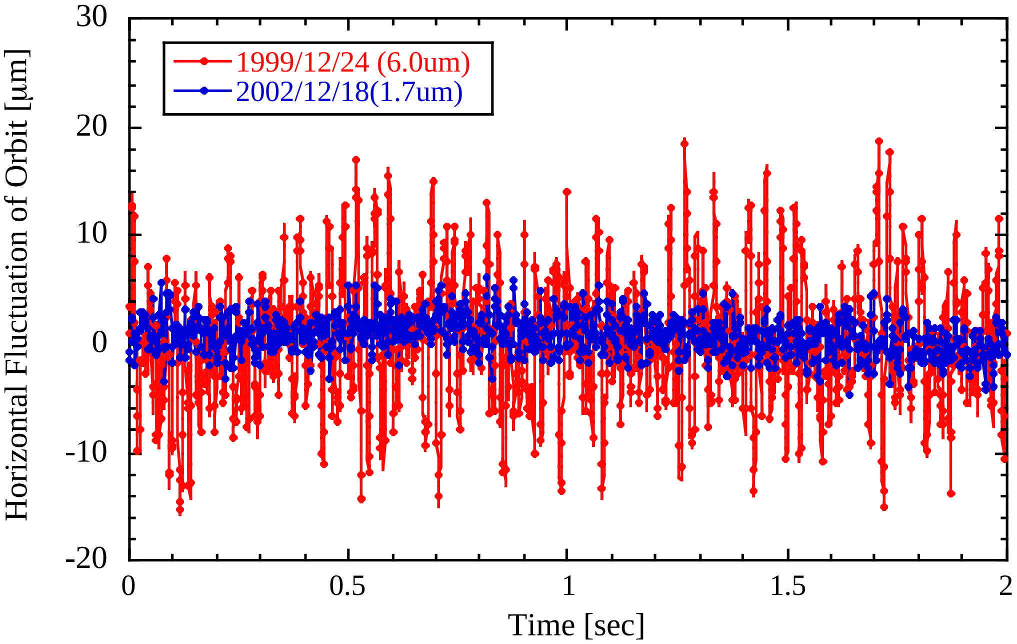

Fig.4 Vertical beam orbit variation measured at the center of the unit cell

TOC

for several bunch or hybrid (multi-bunch beam train + several single bunches) filling. The manual orbit correction is performed at the every scheduled beam refilling and the orbit drift is reset there. The significant and rapid increment of orbit drift is seen just after the beam refilling. We think that the changes in heat load, beam energy loss, and ID gap condition cause the large drift and so called top-up operation will suppress this drift by keeping the ring condition constant.

By adjusting RF frequency the stability of the stored beam energy has been controlled under 2×10^{-5} in full width. Fig. 6 shows the typical energy stability for 10 days user operation. The horizontal DC component of 1μm corresponds to the relative energy deviation, $\delta p/p$ of 10^{-5}. We see the RF frequency change, the red line in the figure reflects the tidal movement of which period is about half a day [14].

Table 1 Present beam orbit stability at ID source point

	Horizontal (rms.)	Vertical (rms.)
Fast (0.1~ 200Hz)	~4μm	~1μm
Slow (<0.1Hz)	5~6μm	5~6μm

5. CONCLUSION

The systematic source suppression in the SPring-8 storage ring successfully improves the slow and fast orbit stability. The vertical fast orbit stability reaches to 1μm level and we are now ready for proceeding to the second step toward sub-micron orbit stability. Regarding to the slow orbit drift there remains some room for the improvement to reduce the drift down to the reproducibility of BPMs, which is about 1μm. The fast and precise orbit feedback system is now under development and the orbit feedback correction will start in three years.

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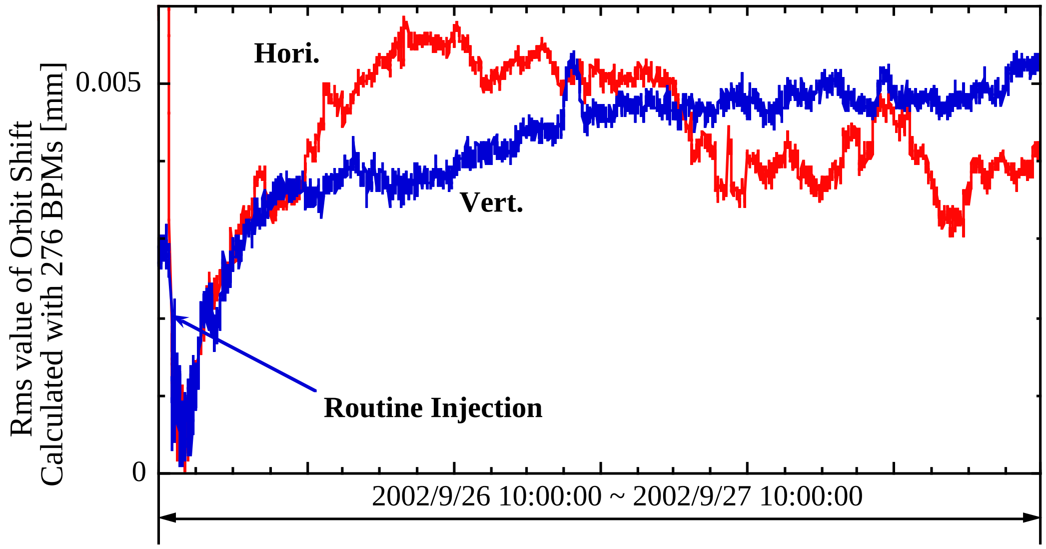

Fig.5 One day slow orbit drift in user operation

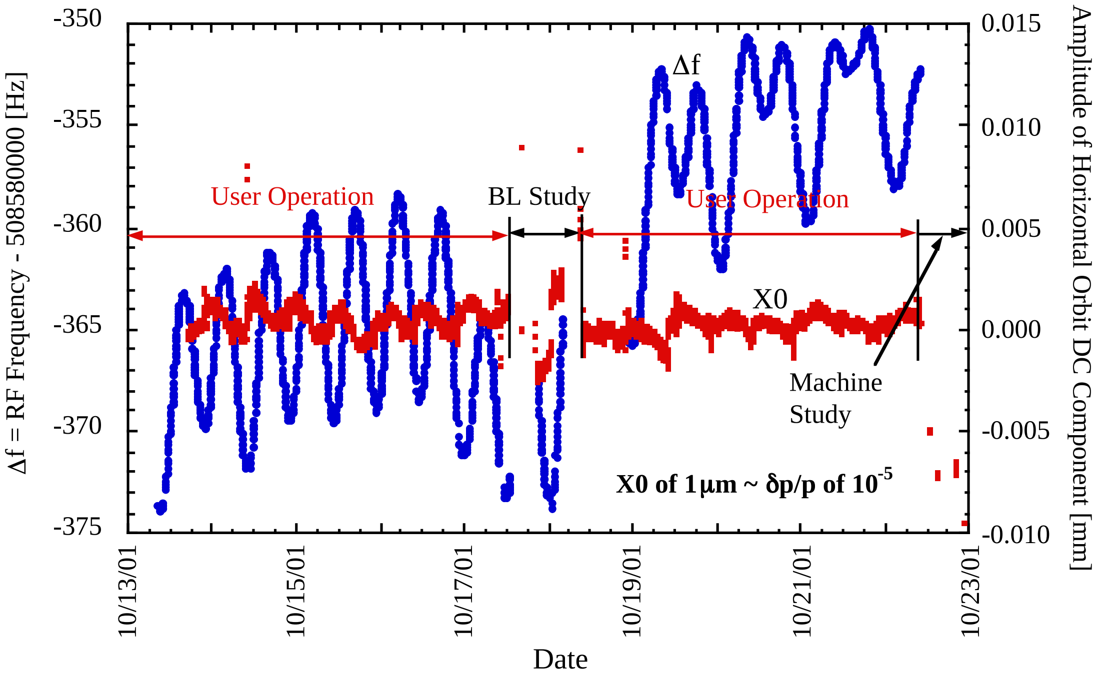

Fig.6 Energy stability in user operation