Beam Orbit Distortion caused by Temperature Fluctuation of Cooling Water at SPring-8 Storage Ring

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Abstract

We investigated the influence of temperature change of cooling water of magnets and vacuum chambers to the closed orbit distortion of the SPring-8 storage ring. We changed the temperature of cooling water intentionally and measured the change of the closed orbit distortion. We then found some mechanisms of the orbit distortion in both horizontal and vertical directions due to the temperature change of the cooling water.

1 Introduction

Stability of the electron beam orbit is important for the utilization of a low emittance storage ring as a high brilliance radiation source. Temperature stabilization of cooling water of the storage ring magnets is one of critical conditions to keep the beam orbit stable. At a phase of beam commissioning, cooling water temperature was controlled in 30±1.0℃. As the temperature control sequence was improved at September 1998, temperature fluctuation was reduced to ±0.3℃. In the present condition after the improvement, the magnitude of the beam orbit fluctuation is ±10 μm and ±5 μm in horizontal and vertical directions at a representative dispersion free section [1]. In order to stabilize the beam orbit more, we studied the influence of the cooling water temperature on the beam orbit.

2 Experiment

The SPring-8 storage ring has 48 Chasman-Green cells, and the temperature of cooling water of magnets and vacuum chambers is controlled by four cooling circuits individually. The magnets and vacuum chambers placed in 1-12 cells are cooled by a cooling circuit (A zone). Cooling circuits of B, C and D zone work for 13-24, 25-36, and 37-48 cells, respectively. The vacuum chambers, crotches, absorbers and front-end components in the storage ring are also cooled by the same systems.

Procedure of out experiment is as follows. After storing a beam in the ring, the set value of the cooling water temperature in B-zone was changed from 30 ℃ to 32 ℃ and kept for about 90 minutes. Then it was fallen to usual temperature (30 ℃). We performed the same sequence for each cooling circuit in turn. A typical time dependence of the temperature rise of cooling water is shown in Fig. 1. The cooling water temperature was measured at both the inlet of the water to each zone and the return circuit from that. The cooling water at the return circuit reached equilibrium of temperature in about fifteen minutes. The closed orbit distortion (COD) was measured every 30 seconds using 288 BPMs during experiment.

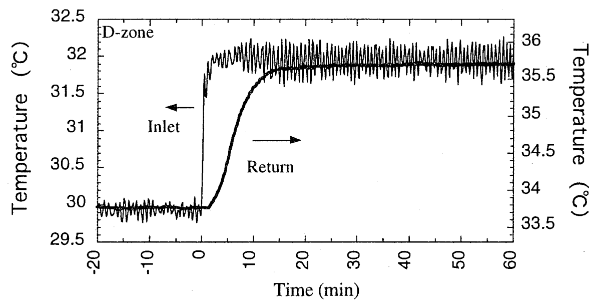

Fig. 1 A typical time dependence of the temperature rise of cooling water. The water temperature was measured at the inlet to each zone and the return from that in the circuit.

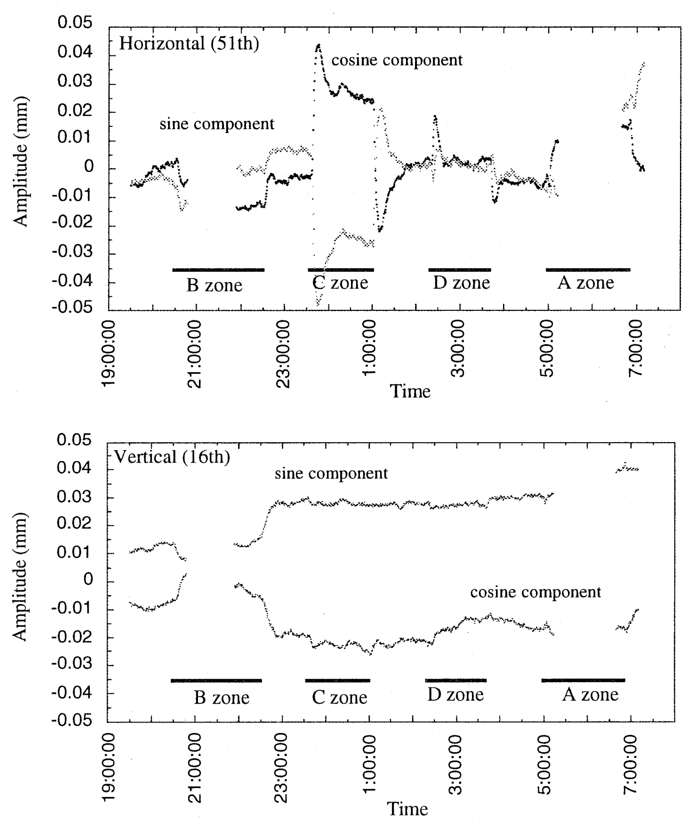

Fig. 2 Amplitude of Fourier components of COD whose harmonic number is betatron tunes in horizontal (above) and vertical (below) directions. Thick solid lines indicate periods when the temperature of the cooling water at each zone was raised to 32 ℃.

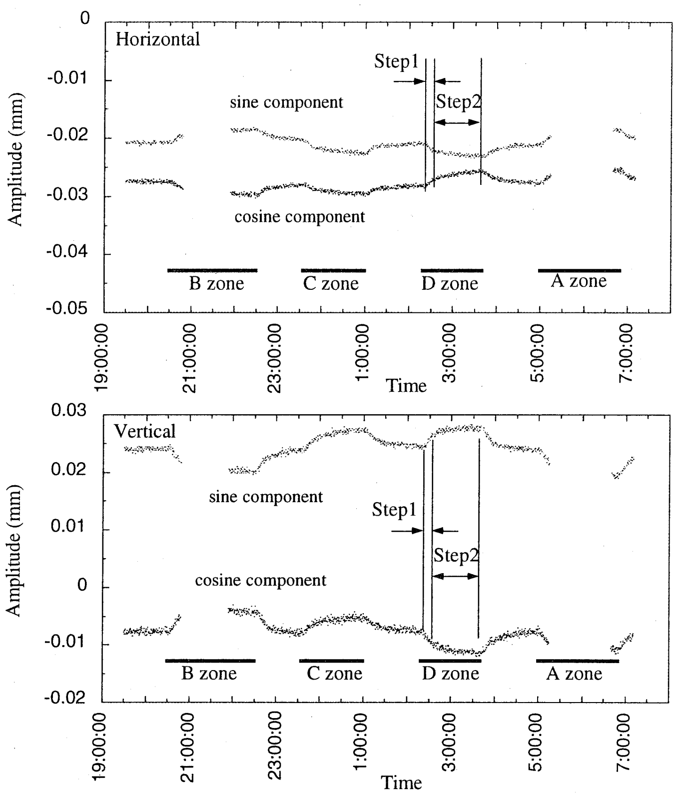

Fig. 3 Amplitude of Fourier components of COD whose harmonic number is 1 in horizontal (above) and vertical (below) directions.

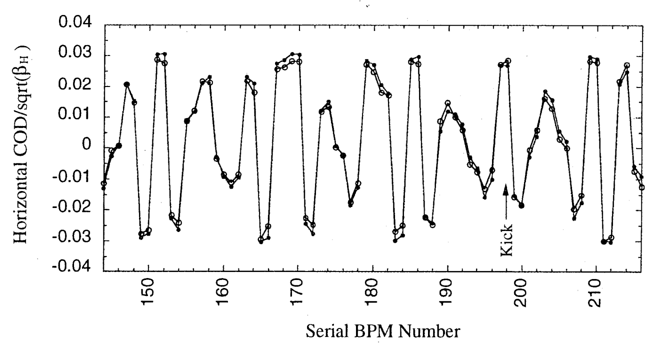

Fig. 4 Measured (open circle) and simulated (solid circle) orbit distortion in horizontal direction in a quarter of the ring. Simulated orbit was calculated with +5.6 μrad single kick between BPM No. 197 and 198.

3 Results

Amplitudes of Fourier components of COD whose harmonic number is an integer part of betatron tunes (ν_H, ν_V) = (51.16, 16.31) are shown in Fig 2. Figure 3 shows the amplitude of the first harmonic Fourier component which means a distortion of the ring. From these figures we can see several distinctive features. Horizontal amplitude of 51th Fourier components changes with short time constant after the water temperature was raised. On the other hand, horizontal and vertical amplitudes of first Fourier components change slowly as shown in Fig. 3

3.1 Unexpectedkick at C-zone

We analyzed a remarkable growth of horizontal 51th amplitude in Fig. 2 after the temperature of the cooling water at C-zone was raised. The source of the closed orbit distortion was found to be a single kick produced by one of several magnets on a common girder placed in cell 33. Measured closed orbit distortion is good agreement with the simulated one which is calculated with a single kick as shown in Fig. 4.

From the prediction of the simulation, we found that an edge of a vacuum chamber in cell 33 was contacted with a quadrupole magnet. It was expected that the vacuum chamber deforms and leans on the quadrupole magnet when the temperature of the cooling water flowing in the chamber is raised. The movement of position of a quadrupole magnet in horizontal direction was evaluated to be about 8 μm. After the edge of the vacuum chamber was scraped at January 1999, the large distortion of the beam orbit due to the water temperature change disappeared.

3.2 Rapid change of the COD

As shown in Fig. 2, horizontal amplitude of 51th Fourier component at D-zone increased immediately along with the temperature rise. The amplitude returned to previous value in about fifteen minutes. The increase of the amplitude of the 51th harmonic component is regarded as an effect of a few random error sources. We can understand the random error sources are distributed on several dipole magnets placed near the inlet of the cooling circuit. These dipole magnets increase their gaps and reduce their fields faster than the other dipole magnets due to the temperature rise, because their plumbing route of cooling circuit are shorter than the others. Calculating from the velocity of water and the diameter of the pipe, the magnets near the inlet are changed in temperature about five minutes faster than the magnet at an end of the route.

After the transitional state of temperature as described above, the field error sources are distributed to all dipole magnets in D-zone systematically. Therefore the amplitude of 51th Fourier component is reduced and the amplitude of the Fourier component caused by the systematic error sources grow. (See *3.3*)

3.3 Slow change of CODs

Horizontal and vertical amplitudes of the first harmonic component increase slowly and slightly after the temperature of cooling water was raised as shown in Fig. 3. In about twenty minutes after the temperature was raised, the amplitude changes relatively fast (Step 1) and changes very slowly afterward (Step 2). The two steps are caused by different processes as explained below.

Step 1: Figure 5 shows the change of the COD in horizontal and vertical directions at 95 minutes past after the temperature of cooling water at D-zone was raised to 32 ℃. As shown in this figure, the horizontal beam orbit at dispersive sections came inside of the ring at A - C zones and left outside at D-zone. The movement of the beam orbit can be simulated as the decrease of the momentum of the beam which is caused by the field reduction of all dipole magnets at D-zone as described in *3.2* . Fig. 6 (a) shows a simulated horizontal COD in case that the reduction of the magnetic field of each dipole magnet in D-zone is about 0.01%. The value of 0.01% can be explained as a deformation of the magnet core by the temperature change. At the same time COD in vertical direction is also changed because of the deformation of the dipole magnets.

Step 2: Although the deformation of the dipole magnets is almost finished in the period of step 1, the slight change of amplitude of the first Fourier component continued especially in vertical direction. The shape of vertical COD whose beam orbit came down at the region of D-zone shown in Fig. 5 can be simulated as the sum of vertical kicks caused by dipole magnets as mentioned previously and QF magnets placed in D-zone. In the SPring-8 storage ring, QD magnets are placed at both ends of every common girder and QF magnets are placed around the center. When magnets and chambers rise in temperature, height of the magnets placed in the center of the girder tends to get taller than those placed at both ends of the girder [2]. The reason is that air temperature around the center of girders becomes higher than end parts since air temperature in the ring tunnel is controlled lower (27℃) than the temperature of magnets and chambers. As the temperature rise of the QF magnets is very slow, the amplitude of first Fourier component changes slowly. Simulated vertical COD shown in Fig. 6 (b) was calculated with kicks of 0.77 μrad distributed to every QF magnet in D-zone. The strength of the kick means that QF magnet becomes 1 - 2 μm taller than QD magnet relatively. We could not distinguish clearly the strength of the kicks due to QF magnets from the kicks due to dipole magnets.

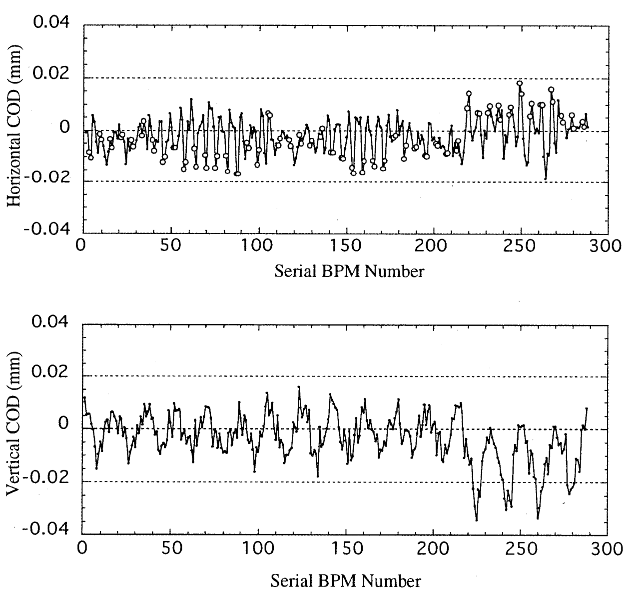

Fig. 5 Change of COD in horizontal (above) and vertical (below) directions at 95 minutes past after the temperature of cooling water at D-zone was raised to +32℃. Large open circles show the orbit at BPMs located in dispersive sections.

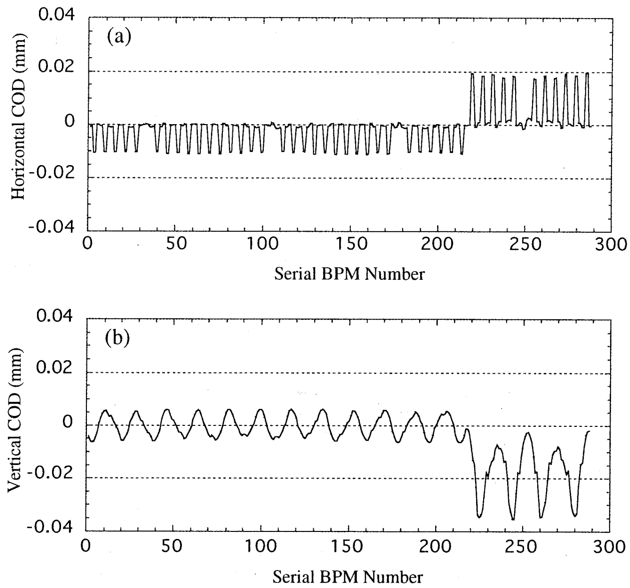

Fig. 6 Simulated horizontal (a) and vertical (b) COD. (a) The momentum change caused by 0.01 % reduction of field strength of dipole magnets in D-zone was found. (b) 0.77 μrad kicks are assumed to be distributed to every QF magnet in D-zone.

4 Conclusion

We found rapid and slow change of horizontal beam orbit caused by reduction of magnetic field of dipole magnets. Slow change of vertical beam orbit caused by the dipole magnets and the quadrupole magnet heights was also found. We could find out a unexpected kick source by changing the water temperature intentionally. Change of vertical 16th Fourier component at B-zone was relatively large as shown in Fig. 2, but this case could not be explained by the mechanisms described in this paper.

We will improve our cooling system so that the temperature can be controlled within about ±0.1℃. The movement of the beam orbit is expected to be less than ±2 μm for horizontal direction and ±1 μm for vertical direction when the cooling water temperature is controlled to be 30±0.1℃.

5 Acknowledgments

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References

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[2] S. Matsui et al., "Magnet Alignment Results of the SPring-8 Storage Ring", The 11th Sympo. on Accel. Sci. and Tech., Harima, Japan (1997) 44.