Effect of Temperature Variation to the Beam Stability of the SPring-8 Storage Ring

Koji TSUMAKI[1)], Junichi OHNISHI[2)], Kiyomitsu HASEGAWA[3)], and Sakuo MATSUI[1)]

1) SPring-8/JASRI, 2) RIKEN, 3) KUMAGAI GUMI CO., LTD.

1. Introduction

The third generation synchrotron radiation sources have high sensitivity against magnetic field errors and alignment errors. One of the sources that make the error field is the change of temperature: temperature variation of air, power cables, girders, cooling water and magnets. Temperature variation changes the length of equipment and shape of magnets and deteriorates the magnet alignment. Resultantly error fields are generated and the beam orbit varies according to these temperature variations.

Especially, the sensitivity of large third generation synchrotron radiation sources like SPring-8 storage ring is several times to several tens times higher than that of the first or the second generation radiation sources. Due to this high sensitivity there are possibilities to be problems even in the small temperature variation which is not problem in the usual synchrotron radiation sources. Therefore we studied the effect of temperature variation of girders, magnets and cooling water on beam stability.

2. Girder and Magnet Temperature Variation

2.1 Measurement of Girder and Magnet Temperature

After turning on power supplies of magnets, magnet coils and power cables are heated. Though coils are cooled by water maintained at a temperature of 30 ˚C, the heat are conducted to the magnet yoke and temperature of magnet increases. Girder is also heated by the heat transfer from the magnets and the power cables that are passing through under the girder. With these temperature changes, alignment of magnetic center also changes. Therefore we measured the temperature of magnets and girders and alignment change of the magnets. Temperature distributions were measured for one girder and magnets on that girder in detail.

Temperatures at 57 points were measured by the thermocouples: 19 points for magnets, 25 points for a girder, 12 points for surrounding atmosphere and 1 point for a cable. Tilt angle of magnets and girders were also monitored. Change of alignment was measured for eight girders by a laser system that is composed of He-Ne laser and CCD camera.

2.2 Measurement Results

After turning on the power supplies, magnet and girder temperature increases and reaches to the equilibrium after about 48 hours as shown in Fig. 1.

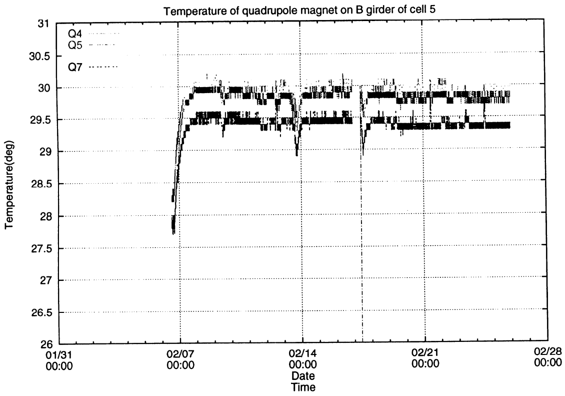

Fig.1. Temperature variation of quadrupole magnet.

Figure 2 shows the temperature distribution after reaching the equilibrium condition. In the figure only the differences of temperature between before and after turning on the power supplies are shown.

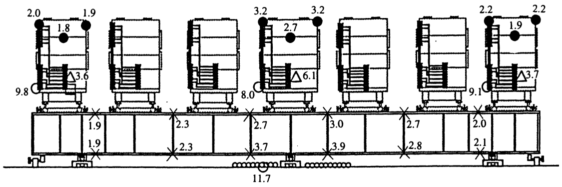

Fig. 2. Temperature distribution of magnets and girder. (• : magnet yoke, x : girder, o : cable, Δ : cooling water)

Temperature rise of magnet yoke is two or three degrees and in the middle of the girder, it is higher than that of magnets on both ends of a girder. This tendency is the same for the girder temperature and the atmospheric temperature. This means that the expansion rates of magnets and central part of girder are higher than that of both ends of the girder and the magnetic center of magnets in the middle of the girders is higher than that of both ends of the girder.

In Fig. 3 the alignment change before and after turning on the power supplies are shown. Fiducial points are magnets on both ends of a girder. Figure shows that the position of magnets in the center of a girder is 12 μm higher in average than that of magnets on both ends of a girder. For horizontal direction there were no apparent change. Taking the temperature rise of magnets and girders into account, the fiducial points of the magnets mounted on the center of a girder should be 17 μm higher than that at each of its end. This is consistent with the measured alignment change.

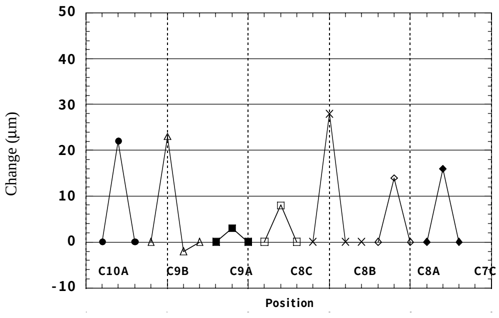

Fig. 3. Relative alignment change before and after applying the electric current to the magnets.

2.3 Relation between Electron Orbit and Temperature Variation

After turning on the magnet power supplies vertical electron orbit was observed to move downwards for a few days. Total amount of movement is about 60 μm. This phenomenon is similar to that of temperature dependence of magnets and girder. According to the temperature measurement results, the fiducial point of magnet on a center of a girder is 17 μm higher than that of magnets on both ends of a girder, which corresponds to 12 μm at the magnet center. The quadrupole magnets on the middle of a girder are defocusing magnet. This means that if the magnet center moves to upwards the electron beam is kicked downwards systematically and as a results the closed orbit moves downwards. Measured alignment change at the fiducial point is 12 μm in average and it corresponds to 9 μm at the magnet center.

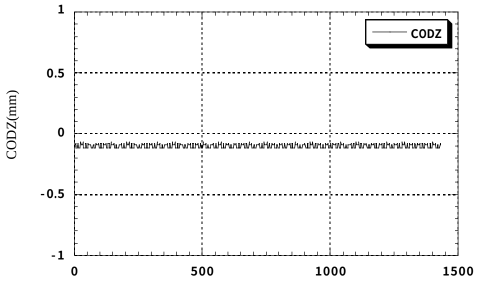

Fig. 4. Calculated vertical closed orbit distortion.

Figure 4 shows the calculated closed orbit distortion assuming that the quadrupole magnet on the middle of a girder is 10 μm higher than the magnets on both ends of a girder. The calculated closed orbit is slightly larger than the observed one but taking into accounts the measurement accuracy and small number of measurement points, calculation agrees with the measured value substantially.

3. Cooling Water Temperature Variation

Periodic variation of closed orbit distortion was observed. Since one of the causes of orbit deviation was considered to be due to temperature variation of cooling water of magnets, we studied the effect of cooling water temperature.

3.1 Cooling Water System

SPring-8 storage ring facility was divided to four zones named A, B, C, and D respectively. In each zone there is a cooling water system for magnet cooling: Magnets of each zone are cooled by independent cooling water system. Primary cooling water was maintained at 30 ± 1°C by changing the secondary cooling water temperature and the amount of flowing rate.

3.2 Relation between Cooling Water Temperature and Beam Orbit

We measured the relation between beam orbit and temperature of cooling water of zone A. Beam orbit was measured by the beam position monitor at a cell of No. 3. Since the primary cooling water temperature was always monitored every 5 minutes, we used that data. Measurement results are shown in Figs. 5 and 6. Periods of orbit and temperature variation are both about twenty minutes and there is close relation between cooling water temperature and beam orbit. Vertical orbit variation is small compared to the horizontal one. It is vertical dipole field variation that affects the horizontal beam orbit.

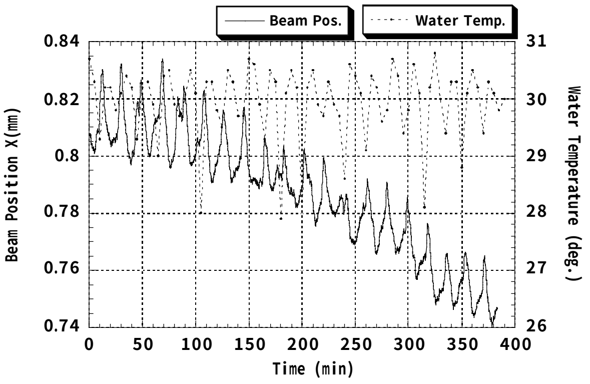

Fig. 5. Relation of horizontal beam orbit and cooling water temperature.

Even if there are cooling water variations, it is difficult for quadrupole and sextupole magnets to produce vertical dipole fields due to their symmetric structure.

Contrary to this, bending magnets of SPring-8 storage ring are C shaped structure and are easy to be affected by temperature variation.

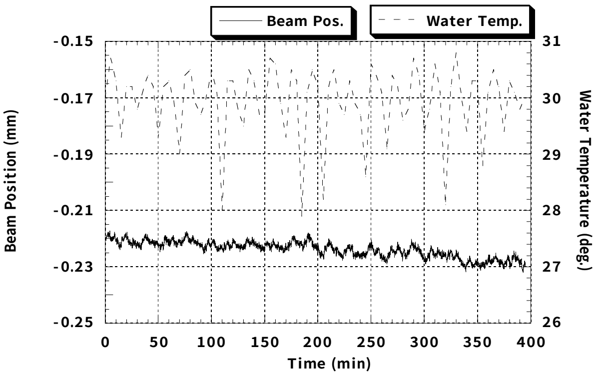

Fig. 6. Relation of vertical beam orbit and cooling water temperature.

We measured the variation of tilt angle of bending magnet setting the tilt meter on the bending magnets. Results are shown in Fig. 7. Variation period of magnet tilt angle coincides with the temperature variation period of cooling water. This indicates that the orbit variation originates from the cooling water temperature variation. When the temperature changes, only the temperature of iron yoke surface, where the magnet coil was contacted, changes and the most of the iron yoke keeps their temperature constant and resultantly iron yoke behaves like a bimetal. When the cooling water temperature decreases, temperature of the surface of the inner part of yoke decreases and pole gap distance becomes shorter and the field strength increases and vice versa. If the cooling water temperature variation is same in all zones and field change of dipole magnet is same, no variation of orbit change will appear. However this water temperature variation usually occurs one or two zone. In this case orbit varies with the temperature.

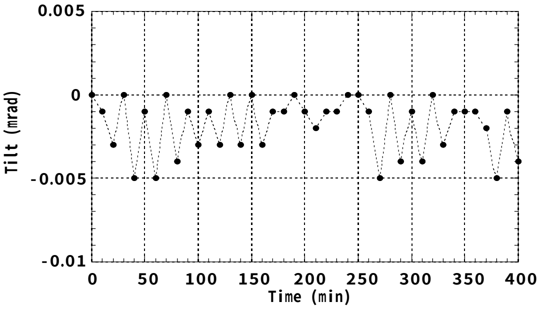

Fig. 7. Bending magnet tilt angle variation.

4. Conclusion

We measured the temperature variation of magnets and girder before and after turning on the power supplies of magnets. Temperature rise of magnets and girder in the middle of a girder is about 1 ˚C higher than that of the both ends of a girder. This means that the magnet height in the middle of a girder should be about 17 μm higher than that of the both ends of a girder. According to the alignment measurement, magnets in the middle of a girder is 12 μm higher than the magnets on the both ends of a girder. We concluded that the observed vertical closed orbit movement to the downward for a few days was due to this temperature variation.

We also measured the cooling water temperature variation of magnets and found that the orbit variation is caused by the cooling water temperature variation via C shaped bending magnet deformation.