ALIGNMENT RESULT FOR MAGNET UNITS OF THE SPRING-8 STORAGE RING

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1. INTRODUCTION

Magnet installation of the SPring-8 storage ring completed in March 1996. Commissioning of the ring started in March 1997. In this period, remaining parts of the vacuum chambers were installed and baked, positions of beam position monitors were measured in relation to the quadrupoles, and injection magnets as well as steering magnets were installed. The magnets were surveyed twice in horizontal and four times in vertical, because we want to observe seasonable position changes in elevation. In this presentation the survey results for the storage ring magnet units in horizontal are provided and followed by corresponding examination of the Leica's Smart 310 using for storage ring survey. Details of the elevation change will be presented by Dr. S. Matsui in another paper at this workshop.

2. RESULTS OF MAGNET INSTALLATION FOR THE STORAGE RING

The main magnet installation of the storage ring started from May 1995. Total 48 cells of the magnets were divided into four sections along the ring. Following each section's alignment, the vacuum chambers, pipes of cooling water, magnet power cables etc. were assembled. For the survey of the magnet units the Smart 310 is used to measure distance among reference points. The distances are then formed a survey network, which is composed of 1440 distances and more than 480 reference points [1]. The main magnet installation was ended by March 1996 and we got a satisfied alignment result.

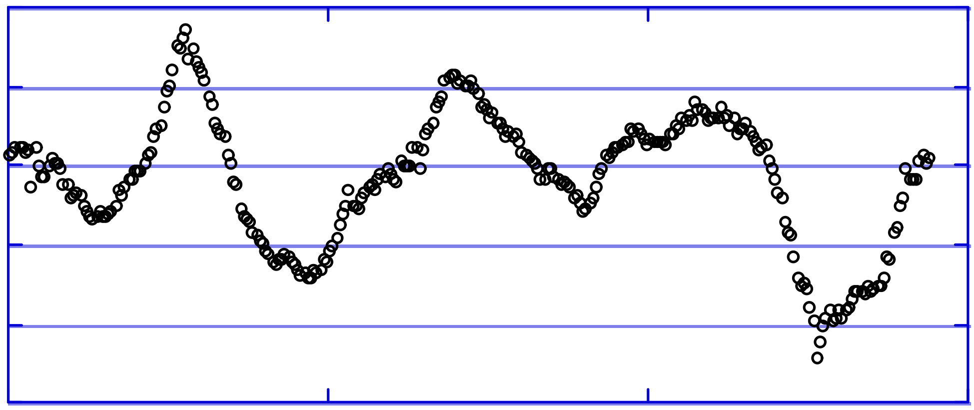

Fig.1 Magnet unit displacements in transverse, Dec.1995.

Figure 1 is the displacements of magnet units in horizontal transverse. It is the result for the third time survey after making two rounds of adjustments. For some reason certain points were adjusted after the third round survey.

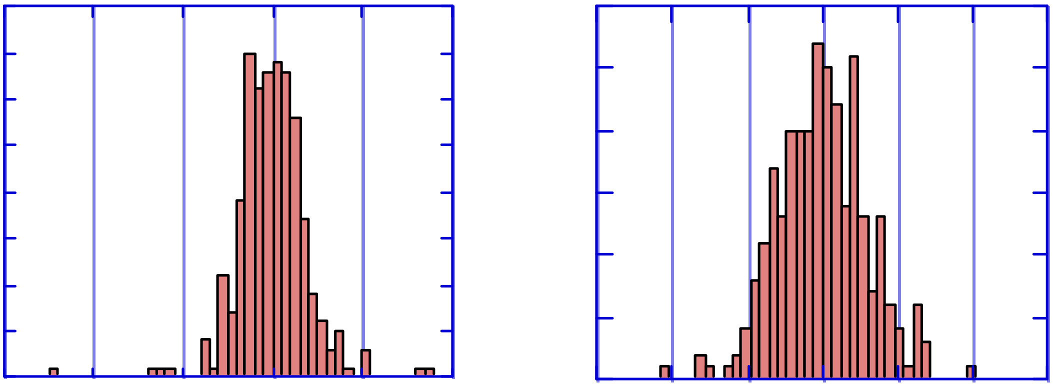

Fig.2(a) Relative displacement Δx (mm). Fig.2(b) Displacement Δz (mm).

Figure 2 shows relative displacements between units transversely (Δx), and the displacement in beam direction (Δz). They are ±0.04 mm and ±0.3 mm respectively. Both are well within the tolerance of ±0.2 mm and ±0.5 mm.

3. TWO ROUND SURVEYS FOR MAGNET UNITS

The magnet units were surveyed twice in October 1996 and Jan.1997 to take the last adjustment and to give final positions before the commissioning.

Each round of magnet survey is a little different from the previous. During the installation of 1995, survey started with the bending magnet setting. Angle measurements between monuments which are under the bending magnets were used to control the overall displacement of the ring. In the survey of October 1996, the monuments could not be used instead 14 reference points on the wall of the tunnel were used. These reference points are precisely measured from nearby monuments beforehand. But because of temperature these references are about 0.1-0.2 mm changeable and are not so stable as the monuments on the ground. To avoid local bias to the network when fixing these references for the calculations, we use the angles between these references but not the fixed datum. During the survey of January 1997 more angle measurements were used because the Smart 310 developed problems in the laser control program communication. The Network of distance measurements only was not satisfying for its large overall displacement. A total of 120 angles were measured between magnet cells.

Transverse deviation between adjacent magnet units was ±0.06 mm in the survey of October 1996. It was getting worse comparing to the results of Dec. 1995 that before vacuum chamber installation. But it was achieved with the vacuum system on, and after the multipoles being half-divided and restored to install the vacuum chambers. Small deterioration is owing to excellent design of the girders as well as the magnets. After this survey 27 out of 144 girders that displace over 0.1 mm transversely were adjusted. A number of bending magnets was also re-adjusted longitudinally to keep their deviations within tolerance. Position changes of the bending magnets are mainly caused by vacuum force coming from the bellows. Survey of January 1997 shows the magnet unit deviation is restored to ±0.05 mm.

Although many angles are measured between magnet cells, they are no effect on lessening relative deviations in our case. But they are effective on reduce the survey error for the overall displacement. Simulation shows that the overall bias of survey network will become the half if the angles are measured with 1" (5 μrad) between magnet cells.

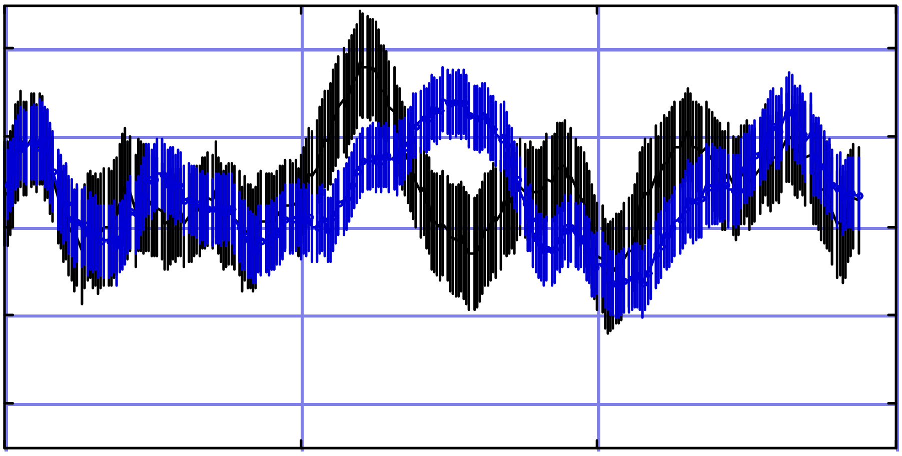

Fig.3 Magnet unit displacements in transverse, Oct.1996 and Jan.1997.

Figure 3 is the transverse displacements of the magnet units in Oct.1996 and Jan.1997. Estimated error bars for each survey are also shown in this figure. Survey error for Oct.1996 is 0.6 mm (1σ) and for Jan.1997 is 0.4 mm. Therefore, difference for the two round surveys is expected about 0.73 mm for a probability of 68%, and 1.5 mm for a probability of 95%. Surveys are coinciding with each other for this error range despite some big bumps seems to be in the path.

If we examine the relative displacement of each reference point with respect to the two adjacent points, Figure 4 gives the results of the two round surveys, except for the units that have been moved after Oct.1996's survey. One can see that the difference between them is quite small at 24 μm. That means the survey gives a precision better than this value.

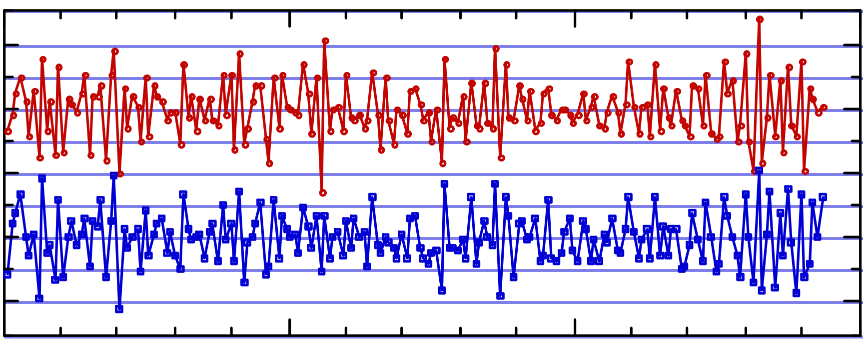

Fig.4 Displacement of each reference with respect to the two adjacent points.

The first closed orbit distortion (COD) is very small, about ±5 mm both in horizontal and vertical planes without any steering magnet correction. Because of the small COD, using only about 20 steering magnets the COD is reduced to 0.3 mm (r.m.s.) in both planes [2]. The amplitude of measured COD is coincident with that of calculated one using survey data.

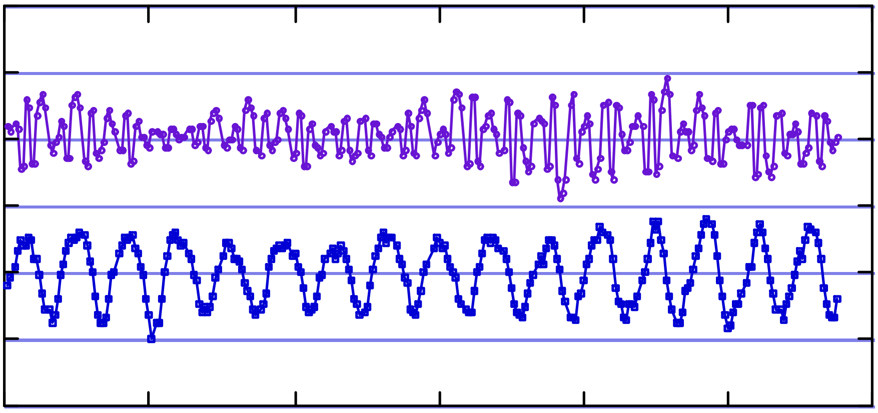

Fig. 5 COD in horizontal and vertical planes without any steering magnets.

4. CIRCUMFERENCE OF THE STORAGE RING

The storage ring has a circumference of 1436 meters with 48 magnet cells. In the procedures of monument survey and magnet survey & alignment, the magnets' global positions were well controlled by network measurements. But because we have no absolute reference datum in the tunnel the ring circumference can only be deduced from magnet displacement.

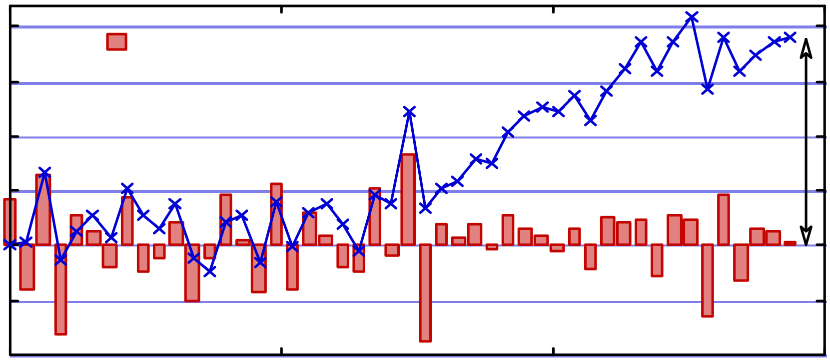

Fig.6 Circumference error and length deviation of each cell.

It is estimated to have a circumference error of 1.76±2 mm before direct circumference measurement. In this measurement the Smart 310 measures the chord of each cell. Because the Smart measures only one distance, it can be calibrated with a measurement error about 1 μm for 10 meters, and <4 μm for 20 meters. The sum of the 48 measured chords compared to the design length provides the circumference error of the ring.

Figure 6 gives the deviations of cell lengths and the circumference error. Temperature in the tunnel changes a little when measurement and on an average of 27.6 c. It coincides with that of machine operation. With an error about ±0.8 mm the circumference is measured 1.9 mm longer than designed one. The momentum compaction factor (α) of the storage ring is 1.5×10^{-4}, therefore momentum change (Δp/p) is about 1%. Actually we got first stored electron beam on the rf frequency shift about 660Hz/508.58MHz; corresponding circumference error is 1.8 mm.

5. COMPARING THE SMART COORDINATE MEASUREMENT WITH THE NETWORK SURVEY

The Smart is a 3-D measurement system. It measures the coordinates of reference points, which are usually on magnets, station by station along the ring. One station is in a range about ± 20 meters and the measuring points should be overlapped. Magnets' global coordinates can also be obtained if we combine each station together. When measurement using the Smart systematic error should be taken care. Statistics are made from our measurement of Oct.1996. It shows that there is about 0.2 mm (1σ) bias in 50 meters in horizontal if we use directly the combined coordinates. That is, the systematic error accumulation has a radius of curvature about 1.7×10^{9} mm. The bias is not very large in this plane. The curvature is more obvious in vertical and is two times of the horizontal, about 0.1mm/10m. Figure 7 gives an example of this bias where 3-D measurement is compared to network survey result. In horizontal it can be expected that in the Smart measurement range (± 20 meters) the peak to peak displacement is 0.1 mm, and in a length of 700 m (half ring in our case) the displacement is 15 mm. Figure 8 is the Oct.1996's survey with the global coordinates of magnet positions obtained from directly combining the Smart's 3-D measurement on each station.

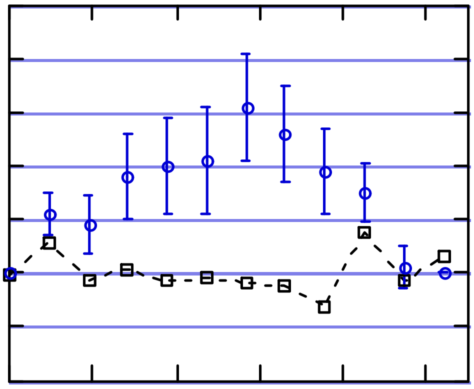

Fig.7(a) Smart 3-D measurement compared to Network survey in horizontal.

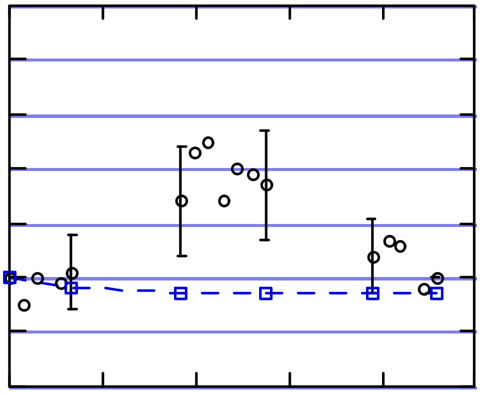

Fig.7(b) 3-D measurement compared to the N3 in vertical.

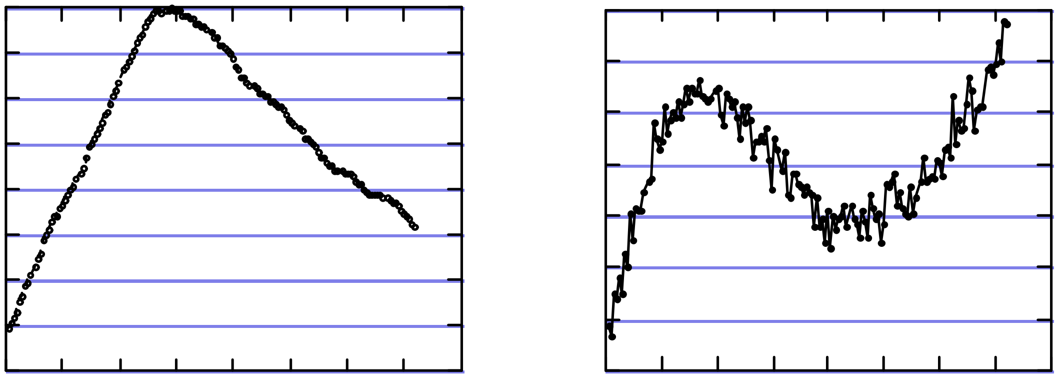

Fig.8 Magnets' global coordinates obtained by combining
the Smart's 3-D measurement for each station.

The solution to the large bias is that at any time measurement should be a closed survey, survey data are adjusted with closed condition. At least the measurement should have datum at its both ends. In these cases the systematic bias will be reduced remarkably.

As in Figure 4, for the relative deviation of each point with respect to the two adjacencies, comparison of the Smart coordinate measurement to the network survey is showed in Figure 9. Difference between them is 0.045 mm (1σ). From this as well as Figure 4 we can give approximately the Smart's accuracy when its 3-D coordinate measurement used directly for the ring survey. It is 0.04 mm in 8 meters horizontally for the relative position between measurement points.

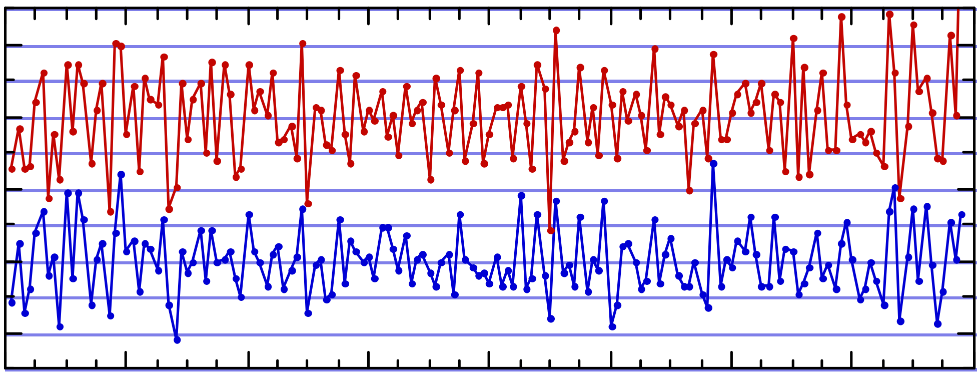

Fig.9 Relative deviation of each point with respect to the two adjacent points.

The same comparison was made in the vertical plan using 3D Smart measurement and N3 elevation measurements. The difference between them is 0.07 mm (1σ). Here the N3 measurement error is around 0.01 mm for adjacent units. It is obvious the Smart is less precise in vertical plan. It is now difficult to consider using the Smart for 3-D path smooth in the ring.

6. CONCLUSION

Alignment of the SPring-8 storage ring is successful. Both in horizontal and vertical planes the alignment results are confirmed by the ring commissioning.

The survey gives a precision about 0.02 mm for the relative position between magnet units. Displacement is kept in 0.05 mm after all system being ready. Circumference error of the ring is 1.9 mm/1.44 km. COD without any correction is very small.

If the Smart 310's 3D coordinate measurement is used directly in ring survey, it is still precise in horizontal plane, although it will have some systematic bias. Survey should be on the condition of closed measurement. Relative deviation is about 0.05 mm in 10 meters. In vertical the Smart is not satisfied. Therefore it is now difficult to consider using the Smart for 3-D path smooth in the ring.

REFERENCES

[1] C. Zhang, et al., 4th International Workshop on Accelerator Alignment at KEK, Tsukuba, Nov. 1995.

[2] N. Kumagai, SPring-8 Design Report, Vol.2 No.3, May 1997.