Measurement of Storage Ring Deformation and Smoothing Method for Pohang Light Source*

Seung-Chan Lee, Ae-Hee Maeng, and Kwang-Won Seo
Pohang Accelerator Laboratory, Postech, Pohang 790-784, Korea

ABSTRACT

Since the Pohang Light Source(PLS), a 2 GeV synchrotron radiation source, started its operation from August 1994, the storage ring tunnel has moved by 1.0mm and 3.0mm per year in the horizontal and vertical direction, respectively. Deformations of the storage ring tunnel by the ground motion give rise to the offsets of storage ring magnets from the ideal beam path. We introduced a smoothing analysis using a low-pass filter method in order to determine the relative positional errors close to the actual beam path of the storage ring. Based on deformation measurements and operation status, we come up with an idea that the maximum deviation of 2.0mm from the ideal beam path is allowable. The results of the case study on the relation between boundary conditions of the smoothing analysis and relative positional errors are described in this presentation.

1. INTRODUCTION

The Pohang Light Source(PLS), a third generation synchrotron radiation source, consists of a 2 GeV full energy injector linear accelerator(Linac) of 150m long, a beam transport line(BTL), and a storage ring(SR) with a circumference of 280m. The storage ring has 36 bending magnets, 144 quadrupole magnets, 48 sextupole magnets, and other components. The allowable relative positional errors(rms) for the quadrupole magnets and sextupole magnets are 0.15mm in the horizontal and vertical direction, respectively[1]. The storage ring which consists of 12 super-periods with a triple bend achromat(TBA) structure will provide 32 beamports, 22 from bending magnets and 10 from insertion devices. At present, the storage ring provides a stable beam of 100-130mA with a lifetime of more than 10 hours. Six beamlines are installed and operational. It is planned to build over 20 beamlines including five insertion devices by 2002[2].

When the storage ring was aligned in 1994, its magnets were precisely positioned to the ideal beam path. Since then, we monitored tunnel deformations which resulted in storage ring deformations. Because the machine operation was normal in spite of the deformations, it was necessary to develop a method for estimating the positional errors based on the actual beam path. In order to determine the actual beam path of the storage ring in the form of a smoothed curve, the smoothing analysis by the low-pass filter method was employed. The results of some case

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studies in August 1995, which were presented at the 4th IWAA at KEK, Japan in November 1995, confirmed that the smoothing method reduced only the systematic errors by a gradual slope such as ground settlement and lateral deformation of the tunnel, while it did not reduce random errors[3]. Applying the smoothing method to the storage ring magnets alignment in 1995, we estimated the cutoff frequency of 3MHz and the outlier criteria of 0.3mm. The cutoff frequency coincides with the number of waves in the smoothed curve fitting. The outlier criterion is the range of magnet deviations from the smoothed curve. As the number increases, the range of magnet deviations decreases. We believed some case studies should be performed thereafter to verify smoothing parameters such as the filtered frequency and the range of the deviations which illustrate the relation between the positional errors and storage ring operation status. Since then, we have studied the smoothing technique using the data of storage ring deformation measurements.

The surveys of the tunnel settlement from August 1993 show the storage ring has been deformed unequally in the vertical direction about 3mm(peak to valley) a year and the trend is expected to keep going on. The settlement of 3mm results in the storage ring vertical deformation of ±1.5mm. The results of the case studies for the smoothing analyses by the low-pass filter method from 1995 to 1997 are as follows; the number of cutoff frequencies is enlarged to 6MHz, 2σ(±0.3mm) of the deviation criteria from the smoothed curve is achieved, and the absolute positional tolerance, the range of maximum deviations from the ideal beam path, which is required by beam physicists in the PLS is ±3mm. Therefore it is expected the PLS storage ring is to be realigned in every two years.

2. TUNNEL DEFORMATION

Measurements for the determination of tunnel deformation in lateral and vertical directions have been repeated at intervals of every six months since the first survey of the PLS control networks in the tunnel was performed in June 1993. The control networks consist of a surface net and tunnel nets. These are linked with one another to establish a global coordinate system. The tunnel nets consist of TNET and ENET. The TNET of which the monuments are installed on both sides of the inner wall controls horizontal locations, and the ENET embedded in the tunnel floor controls elevations.

For the determination of the TENT conventional survey instruments such as theodolites(E2, T3000) and the mekometer(ME5000) were employed. The design of the forced centering mechanism used for the TNET was based on the precise fit of a Taylor Hobson sphere and conical cup mounts which are assembled on the wall brackets. Glass target and prism which are fitted in the Taylor Hobson sphere were also used for the direction and distance survey, respectively. For the elevation survey of the ENET N3 Level and NEDO invar staff were used. The 1 σ absolute error ellipses obtained for the TNET survey are in the range of 0.2mm. It is estimated with the GEONET program developed at SLAC. The accuracy of ENET survey is within 0.07mm in the 1 σ value[4].

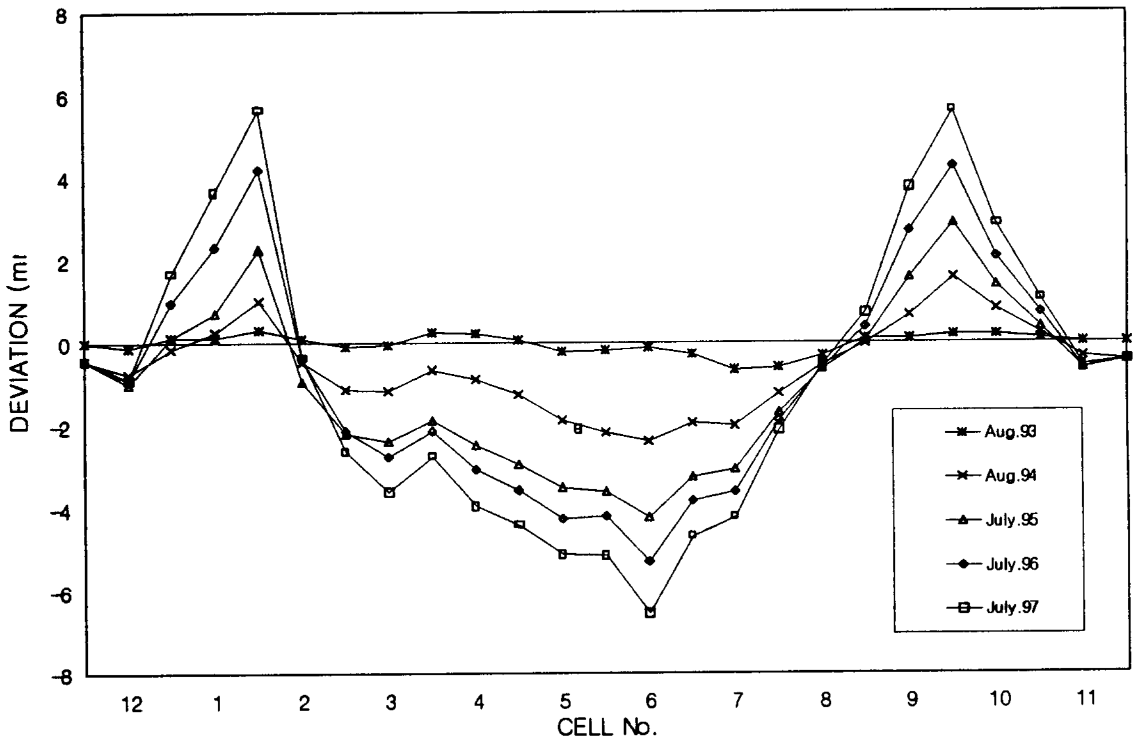

Fig.1 PLS storage ring settlement surveys

As shown in Figure 1, the comparisons of each ENET survey epoch to the reference elevation which was established in June 1993, the settlement of the storage ring tunnel keeps going on in-equally about 3.0mm(peak to valley) per year. But the lateral deformations are within the range of ±1.0mm.

The settlement of the storage ring tunnel is believed due to the properties of mudstone. The PLS site which was prepared by removing a few hills of 100m high is made of mudstones. While the mudstones of the PLS foundation had been wet before the building construction was completed in 1993, the mud particles containing water seemed to have swelled up like a ball. But when the weights of the building structures, which are uneven along the tunnel, were reloaded after building construction, the mud particles started being flattened by losing water slowly. The areas of Cell numbers 12 and 5 where the foundation concrete is thick and heavy are relatively settled more. The area of Cell 12 coincides with the joint area of the beam transport line(BTL) tunnel and the storage ring tunnel, and under the Cell 5 there is a vehicle tunnel underpass. It is expected the deformations last over years.

For the continuous monitoring of long-term settlement of the storage ring tunnel floor, a hydrostatic level system(HLS) with 12 sensors from Fogal Nanotech is planned to be installed in the near future.

3. STORAGE RING DEFORMATION AND SMOOTHING ANALYSIS

For the determination of the storage ring deformation, the storage ring magnets positions for the lateral and vertical directions were surveyed with the general survey instruments such as theodolites(E2, T3000) and levels(N3). We surveyed the storage ring two times a year and determined the change of positional errors from 1994 to 1997. The storage ring deformation, the maximum deviation of magnet from the ideal position, proceeded by ±1.5mm per year, while the relative positional errors(rms) of magnets estimated by the smoothing method remain within the tolerance of 0.15mm, and all magnets are placed within the 2 σ range(±0.3mm).

When the storage ring installation was completed in August 1994, the magnets were aligned to the ideal beam path with the positional accuracy(rms) of 0.15mm in both transverse and vertical direction. Then it was found the storage ring had deformation in the end of 1994. We realigned the storage ring to the ideal beam path in February 1995. At that time we found the tunnel deformation which are discussed in the above chapter coincided with the storage ring deformation as a whole. Therefore we felt we had to devise a tool for the determination of the relative positional errors which could eliminate systematic errors due to the tunnel deformation.

Considering a few schemes of smoothing analyses using the first data set of the storage ring deformation survey in August 1995, we decided to employ the smoothing analysis by the low-pass filter. The smoothing method by the low-pass filter is believed to have a convenience in selecting parameters to explain the relation between the storage ring operation status and positional errors due to the deformation. The results of the case studies for the smoothing analysis in August 1995 were presented at the 4th IWAA at KEK, Japan in November 1995. The storage ring was deformed from the ideal beam path as much as 1.0mm and 0.8mm in the lateral and vertical direction, respectively. In applying the smoothing method in 1995, we selected the filtered frequencies of 3MHz and the outlier criteria of 2 σ range(±0.3mm). The relative positional errors(rms) were 0.13mm transverse and 0.12mm vertical, and the maximum deviations from the smoothed curve were -0.27mm transverse and 0.22mm vertical direction, well within the criteria. Therefor there was no major adjustment of the storage ring magnets in 1995[3].

The storage ring was resurveyed in July 1996. The maximum deviation of quadrupole magnets from the ideal position was 2.2mm in the vertical direction, while the operating status of storage ring showed normal. The smoothing method was applied for the determination of the relation between the operation status and positional errors. As the filtered frequency was increased by 1MHz interval, the relative positional errors and the number of outliers decreased as shown in Table 1. When the filtered frequency was 6MHz, the errors became smaller than the positional tolerance of 0.15mm and there was no outlier. At this point the systematic tendency in the spread of deviation faded away, and even though the fliltered frequencies were increased several steps more the change of errors was not remarkable. Considering these results, we estimated that the relative positional errors(rms) were 0.14mm transverse and 0.13mm vertical, and the maximum deviation from the smoothed curve was 0.27mm transverse and 0.22mm vertical.

Table 1 Results of the smoothing analysis
for the PLS storage ring deformation in August 1996

Freq. (MHz)	Relative Positional Errors (1 σ;mm)		Number of Outliers		Remarks
	Lateral	Vertical	Lateral	Vertical	
0	0.456	1.087	81	113	
1	0.300	0.742	51	92	
2	0.250	0.538	40	91	
3	0.217	0.294	32	59	
4	0.171	0.199	7	21	
5	0.153	0.162	6	9	
6 *	0.136	0.130	2	3	≤0.15mm
7	0.130	0.127	2	2	
8	0.126	0.115	2	1	
9	0.125	0.104	2	1	
10	0.125	0.089	2	0	

The results of the smoothing analyses are shown in Figures 3 and 5 for the transverse and vertical direction, respectively. The smoothed curve deviates from the ideal position by ±2mm. As shown in Figures 4 and 6 for the histograms of the transverse and vertical deviations, two quadrupole magnets have been displaced out of 2 σ range(±0.3mm) in lateral direction, and three in vertical direction.

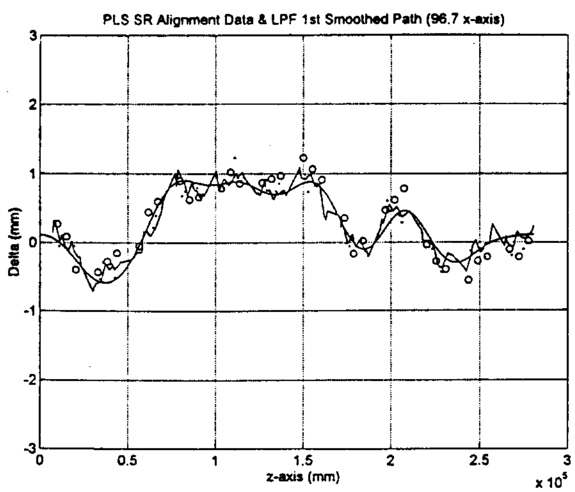

Fig. 3 Transverse displacements of all storage ring magnets

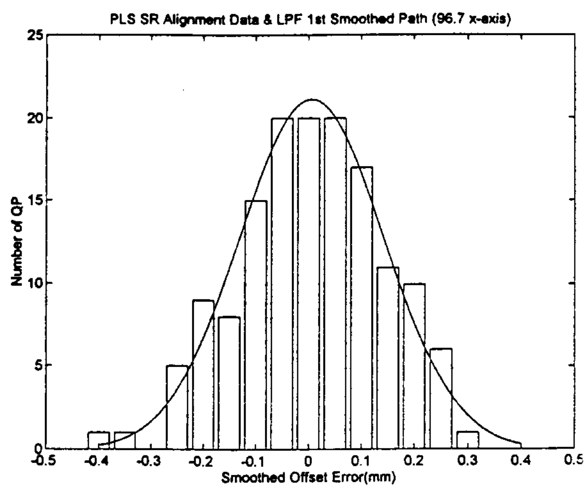

Fig. 4 Histogram of the transverse displacements of quadrupole magnets

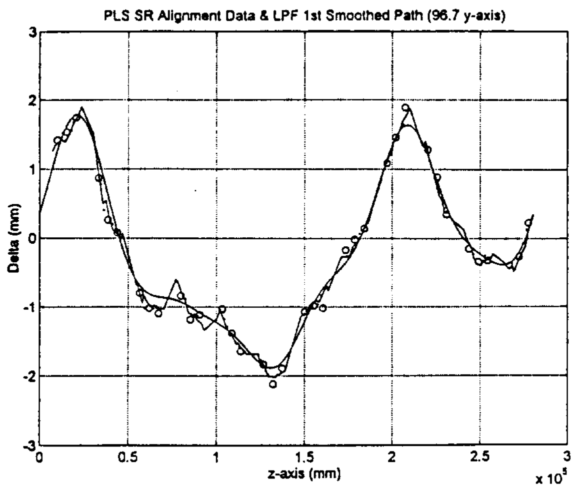

Fig. 5 Vertical displacements of all storage ring magnets

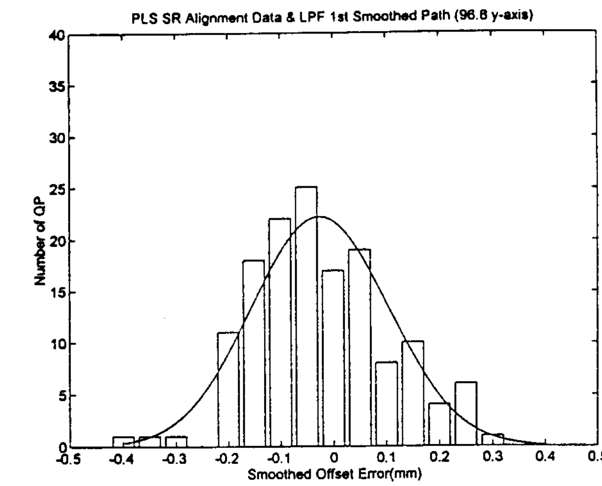

Fig. 6 Histogram of the vertical displacements of quadrupole magnets

As discussed in the above, considering the facts that 1) the storage ring was being operated normally, 2) the relative positional errors were within the tolerance of 0.15mm, and 3) the deviations from the smoothed curve were within 2 σ range($\pm$0.3mm) except for 2-3 magnets, we could have left the storage ring as it was without magnets adjustment. The issue of the magnet adjustment was discussed with beam physicists. The maximum deviation from the ideal beam path was required being maintained within $\pm$3mm range. As long as it was expected that the continuous settlement of the tunnel floor by 3mm(peak to valley) per year would result in the vertical deformation of $\pm$1.5mm in the machine, the maximum deviation might become about $\pm$3.5mm in 1997 and the relative positional errors be deteriorated. After all, the storage ring was realigned to the ideal beam path in August 1996[5].

Table 2 Results of the smoothing analysis for the PLS storage ring deformation in August 1997

Freq. (MHz)	Relative Positional Errors (1 σ;mm)		Number of Outliers		Remarks
	Lateral	Vertical	Lateral	Vertical	
0	-	-	-	-	
1	0.337	0.570	56	85	
2	0.207	0.456	24	86	
3	0.147	0.238	6	31	
4	0.131	0.166	4	9	
5	0.126	0.132	1	5	
6 *	0.126	0.102	0	0	

When the summer shut-down was started in July this year, we expected that the maximum deviation of the quadrupole magnets from the ideal position should be about $\pm$1.5mm and the relative positional errors remain within the tolerance of 0.15mm. The results of the storage ring deformation measurements and smoothing analyses are shown in Table 2, and in Figures 7 through 10. As shown in Table 2, at the 6MHz of filtered frequency the relative positional errors were 0.13mm transverse and 0.10mm vertical and there was no outlier. Figures 7 and 8 show the displacements of all magnets in the transverse direction from the ideal position and the histogram of the deviations of the quadrupole magnets from the smoothed curve. And figures 9 and 10 show the results of the smoothing analysis in the vertical direction. One can see all magnets have been placed within the expected maximum deviation range of ±1.5mm from the ideal beam path, and the quadrupole magnets are placed within 2 σ range(±0.3mm).

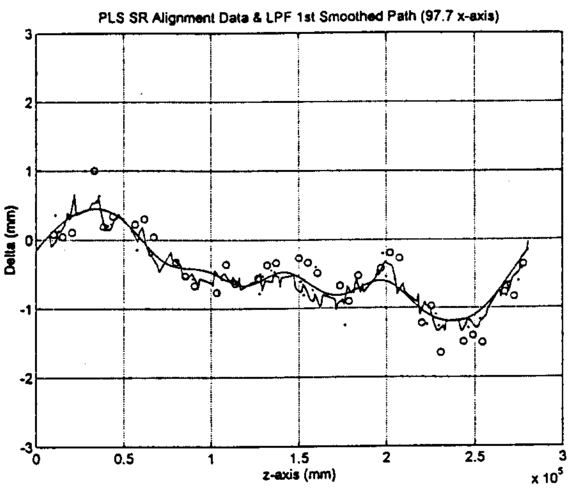

Fig. 7 Transverse displacements of all storage ring magnets

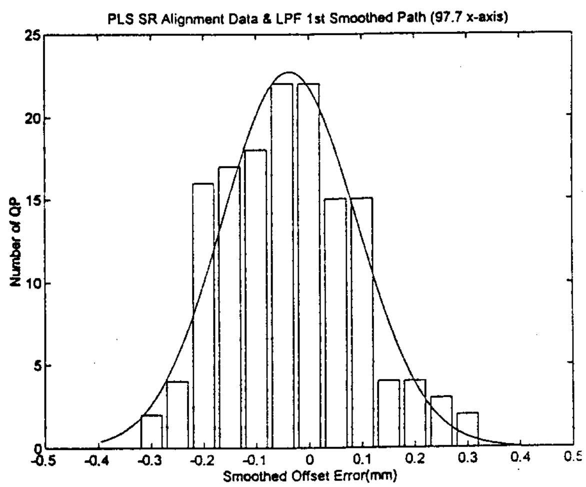

Fig. 8 Histogram of the transverse displacements quadrupole magnets

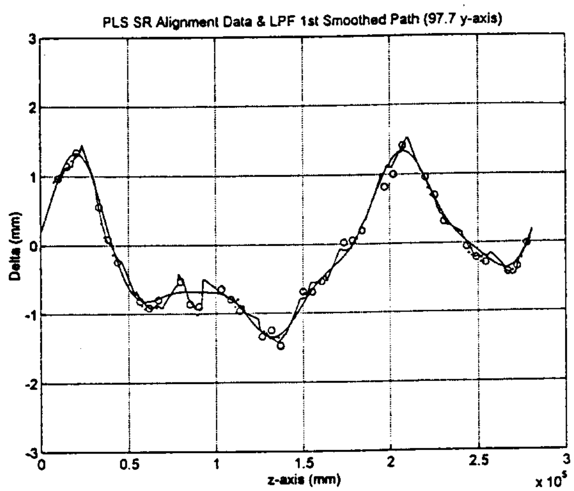

Fig. 9 Vertical displacements of all storage ring magnets

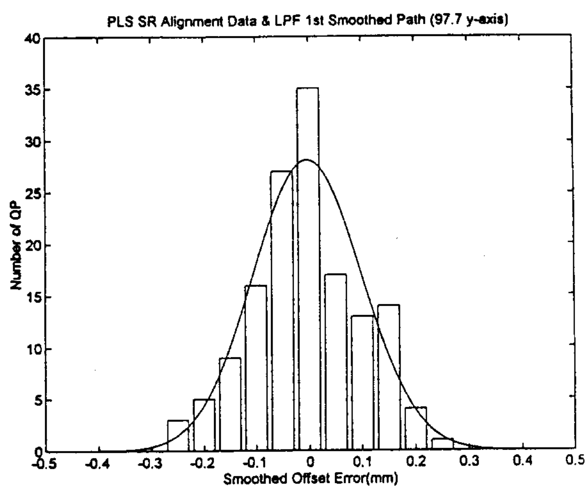

Fig. 10 Histogram of the vertical displacements of quadrupole magnets

4. CONCLUSION

The results of the case studies for the smoothing analyses by the low-pass filter method from 1995 to 1997 are summarized as follows; the number of cutoff frequencies is enlarged to 6MHz, the quadrepole magnets are placed within 2 σ($\pm$0.3mm) range from the smoothed curve, and the relative positional errors(rms) remains well within tolerance of 0.15mm for the last 3 years.

The surveys of the tunnel settlement from August 1993 show the storage ring has been deformed unequally in the vertical direction about 3mm(peak to valley) a year and the trend is expected to keep going on. We found the tunnel deformation coincided with the storage ring deformation as a whole. The tunnel floor settlement results in the storage ring vertical deformation of $\pm$1.5mm a year.

The absolute positional tolerance, the range of maximum deviations of all magnets from the ideal beam path, is set to $\pm$3mm, which was required by beam physicists in PLS. Therefore it is expected the PLS storage ring should be realigned in every two years.

5. REFERENCES

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