SMOOTHING ANALYSIS OF PLS STORAGE RING MAGNET ALIGNMENT

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ABSTRACT

The relative positional accuracies of 0.15mm for transverse and vertical direction were obtained in positioning the quadrupoles of PLS storage ring. The positional error consists of positioning error and offset error. The former is shown in the form of error ellipse which is calculated using a GEONET program. The latter is the statistical observation of magnet offsets from actual beam orbit which is estimated by a smoothing analysis. A low-path filtering method using a z-transform, which is widely used for control engineering, was applied to the PLS smoothing analysis. The z-transform, which is applied to processing discrete data, is a Laplace transform. A smoothing technique and the results of case studies are described in this presentation.

1. INTRODUCTION

The estimation of the offset errors of magnets is one of the most important processes in accelerator alignment. The results of storage ring magnet survey often show that the major part of the magnets are located nearby design path, and the offsets of the magnets are similar to those of their adjacent magnets, as if they have been aligned to slightly deformed path. In the case of PLS storage ring alignment, this phenomenon was found mostly in vertical measurements, which may be induced by the inequable settlement of foundations. In order to reduce manpower and work period for alignment by the effective calculation of offset errors, we applied a ‘Smoothing’ technique to the adjustment of magnets in the PLS storage ring. We choose a low-pass filtering method for the smoothing technique, and found that it reduce the offset errors effectively by eliminating systematic errors.

2. DIGITAL LOW-PASS FILTERING

In smoothing process, an averaging method and fitting methods with polinorms, fourier series and spline functions have been studied. The averaging method shows a weak point in finding a smooth curve, that is the smooth curve is deformed while reducing random errors. The fitting methods does not determine the smooth curve effectively, because they must use predefined functions. Therefore we have introduced a low-pass filtering method for PLS smoothing method. It works similar to a hardware filter which is usually found in various electronic instruments. This method is based on a z-transform, which is widely used for control engineering. The definition of Laplace transform is

$$F(s) = \int_{-\infty}^{\infty} e^{-st} f(t)\ a \tag{1}$$

The role of z-transform in digital filter analysis is equivalent to that of the Laplace transform in analog filters.[2] The definition of the z-transform is

$$F(z) = \sum_{n=-\infty}^{\infty} f(n)\ z^{-n} \tag{2}$$

An infinite impulse response filter(IIR filter) is a kind of digital filters. The definition of the IIR filter is

$$H(z) = \frac{\sum_{i=0}^{M} b_i\ z^{-i}}{1 + \sum_{i=1}^{N} a_i\ z^{-i}} \tag{3}$$

The fourth order equation of Chebyshev was used for designing a low-pass IIR filter.[3] The characteristics of the digital low-pass filter are as follows;

(1) This method is not a kind of curve fitting. It does not use any kind of predetermined functions of polinorms, fourier series and splines.
(2) Input data for this method must be discrete and its intervals must be equal. Therefore, the pre-processing of interpolation is required.
(3) In the case of the closed orbit of storage ring, data expansions are necessary to satisfy periodic boundary conditions.

3. SMOOTHING OF PLS STORAGE RING

A low-pass filter program has been developed with a commercial software. MATLAB[4]. Discrete data are necessary for digital filtering. By interpolating with a cubic method, the offsets at the position of quadrupoles were distributed to a new series at equal-spaced discrete points. The step distance of the new series is 0.25 meter and the new 1122 points reconstructs the electron beam path of the PLS storage ring. The number of these divided points is more than 7 times of the number of quadrupoles, and the step distance is shorter than a half of the minimum distance of adjacent quadrupoles.

The revolution frequency of the PLS storage ring is about one mega-hcrz. Therefore, if the cutoff frequency of filter is about one mega-herz, an evaluated smooth curve becomes a sine wave. The higher the cutoff frequency is, the more sine waves are represented. This cutoff frequency must be chosen carefully, because too higher frequency can induce an operational problem of the storage ring.

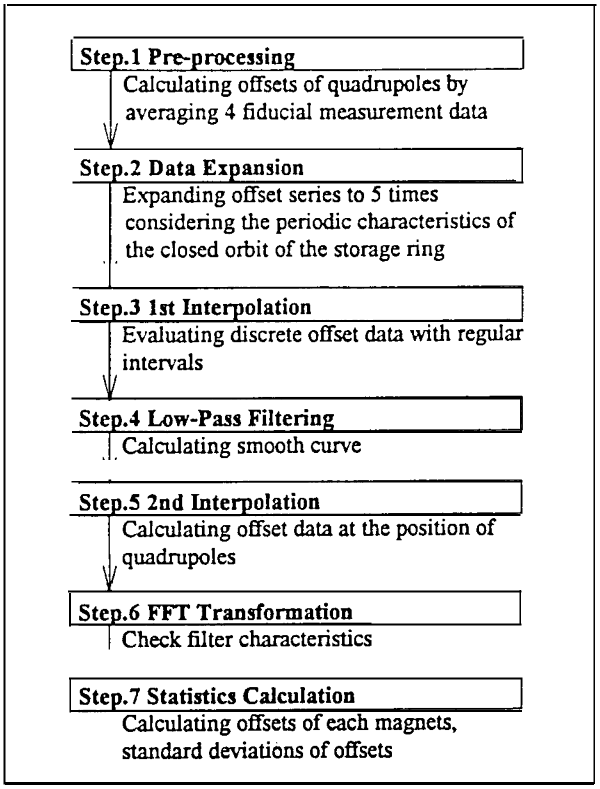


Fig.1 Smoothing Procedure of PLS Storage Ring

Table.1 Major Parameters

Circumference	: 280.5 m
Orbital Period	: 0.93585 micro-sec
Revolution Frequency	: 1.06855 MHz
Interpolation Method	: Cubic interpolation
Step Distance	: 250 mm
Sampling Period	: 0.83409 nano-sec
Sampling Frequency	: 1.1989 GHz
Filter Type	: 4th order Chebyshev low pass filter
Filter Passband Ripple	: 0.1 dB
Filter Cutoff Frequency	: 1, 2, 3, 4, 5, 6 MHz

4. CASE STUDY OF SMOOTHING ANALYSIS

Three data sets have been analyzed by the smoothing technique. These sets contain systematic errors for Case.I, systematic errors and random errors for Case.II, and random errors for Case.III.

Table.2 Profile of Data Sets

Case.I (Oct.1994):	Measured after 2 months operation
Case.II (Mar.1995):	Measured after 4 months operation and vacuum chamber baking
Case.III (Apr.1995):	Measured just after full adjustment

The result of the Case.I, which contains mainly systematic errors, shows that the smoothing analysis reduced offset errors effectively. In the Case.II, the smoothing did not have the effect of reducing offset errors to the standard deviation criteria of 0.5 mm for the quadrupoles. The cause of this result was that a vacuum chamber baking had made a lot of random errors. In the final case, the smoothing scarcely reduced the offset errors, because there were no systematic errors just after full adjustment during the shutdown period. The phase shift or distortion which can be occurred by the filter, was not found. By the above case studies. we concluded that the filter eliminated only higher frequency waves of random errors.

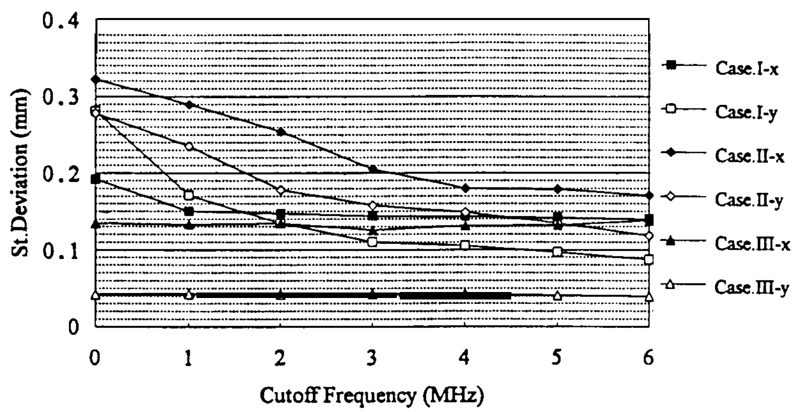
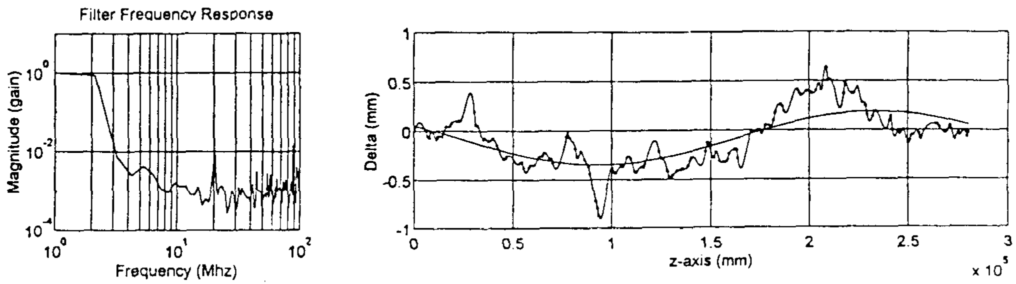


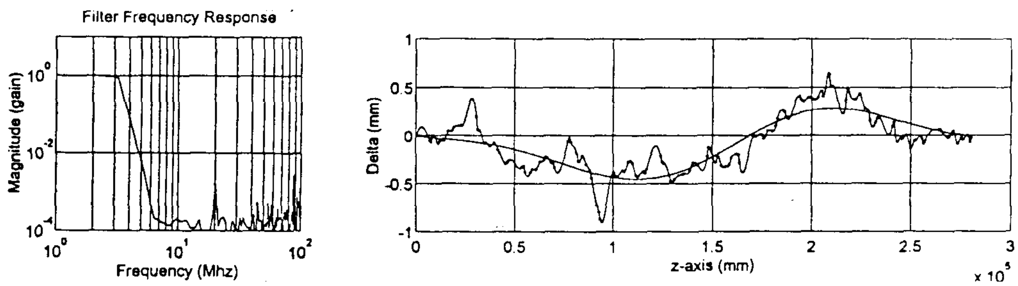
Fig.2 Case Study Result of PLS SR Quadrupoles

Table.3 Summary of Smoothing Analysis, for Quadrupole Vertical Alignment as of Oct.94 (Case.I)

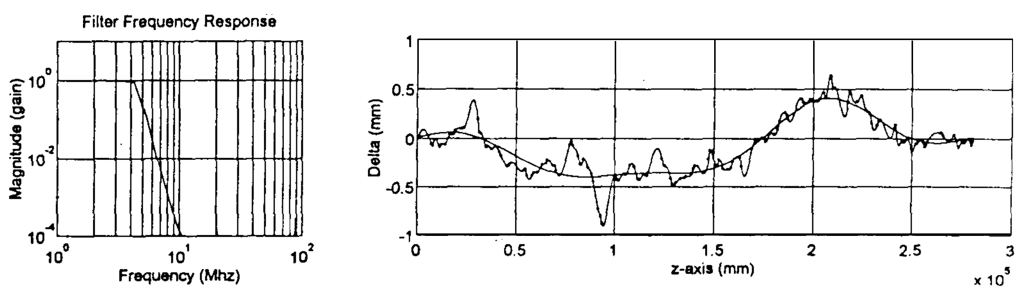
Cutoff Frequency (MHz)	Offset of Smooth Curve From Design Path		Offset Error From Smooth Curve		Number of Outlers (>0.3mm) (ea)
	St.Dev (mm)	Max. (mm)	St.Dev (mm)	Max. (mm)	
1	0.191	0.350	0.171	0.525	12
2	0.235	0.454	0.134	0.466	4
3	0.253	0.407	0.110	0.484	6
4	0.257	0.449	0.105	0.464	4
5	0.258	0.456	0.097	0.439	2
6	0.262	0.503	0.087	0.381	2
8	0.265	0.571	0.077	0.305	1
16	0.269	0.752	0.057	0.156	0
32	0.275	0.861	0.034	0.118	0
Measured Data	-	-	0.281	0.875	52



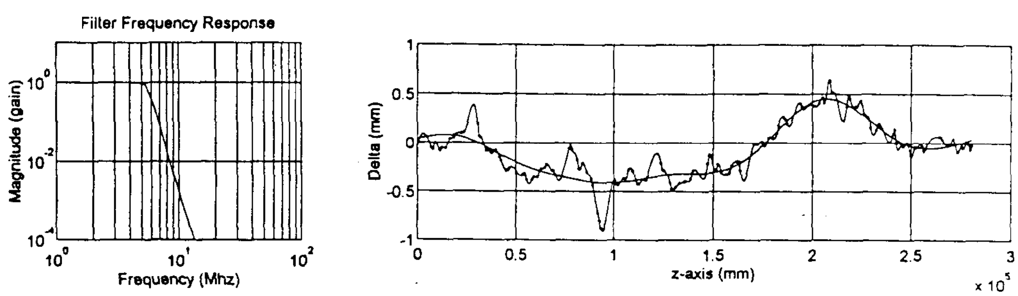
(a) Cutoff Frequency = 1 MHz



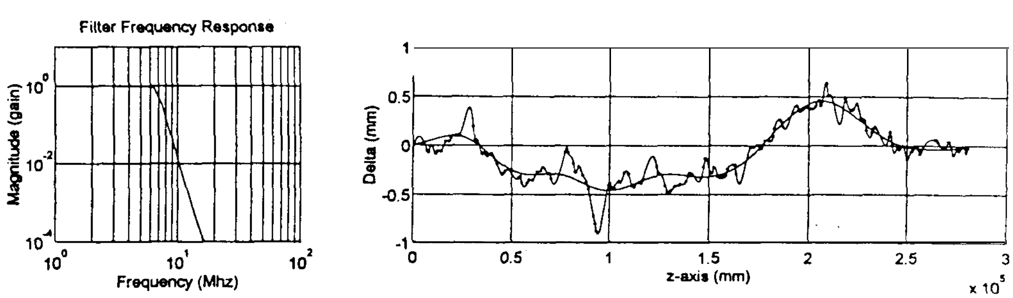
(b) Cutoff Frequency = 2 MHz



(c) Cutoff Frequency = 3 MHz



(d) Cutoff Frequency = 4 MHz



(e) Cutoff Frequency = 5 MHz

Fig.3 Smoothing Results of Various Cutoff Frequencies

5. ADJUSTMENT OF PLS STORAGE RING MAGNETS IN AUG. 1995

There was a short shutdown period in Aug. 1995. It was the first time to apply the smoothing analysis to estimating the offset errors of the PLS storage ring quadrupoles. The cutoff frequency of 3 mega-herz was chosen by compromization of error reduction and operational conveniences. Figure.4 shows the cutoff frequency of more than 4 mega-herz does not reduce the offset errors effectively. For the safety of operation, magnets of which the offset is bigger than 0.2 mm were mostly adjusted to the smooth curve. The offset errors of sextupoles and bending magnets were estimated on the basis of the smooth curve. The history of adjustment was recorded. Finally, verification by operation is required.

In the results, the smoothing analysis reduced the number of outler magnets, which should be adjusted, to about 5 percents of original number. But actually, about 25 percents of original outlers were mostly adjusted, and the PLS storage ring has been being operated successfully since the adjustment.

Table.4 Procedure of Adjustment at Aug. 1995

(1) smoothing analysis for cutoff frequency selection
- outler criteria : 0.3 mm
- cutoff frequency : 1,2,3,4,5,6 MHz
- object : QP

(2) smoothing analysis for adjust amount calculation
- outler criteria : 0.2 mm
- cutoff frequency : 3 MHz
- object : QP, SP, BM

(3) adjustment of outler magnets

(4) smoothing analysis for final error estimation
- outler criteria : 0.3 mm
- cutoff frequency : 3 MHz
- object : QP, SP, BM

(5) calculation of BPM offset

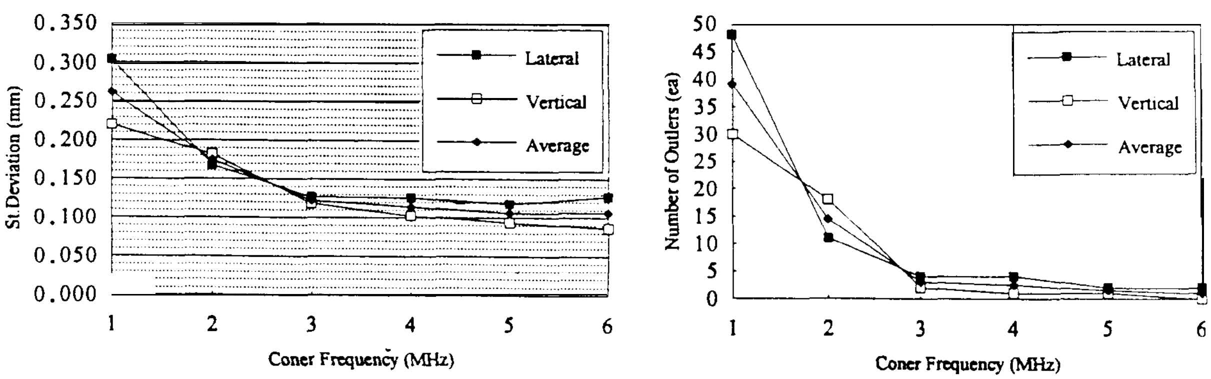


Fig.4 Analysis Results for Cutoff Frequency Selection

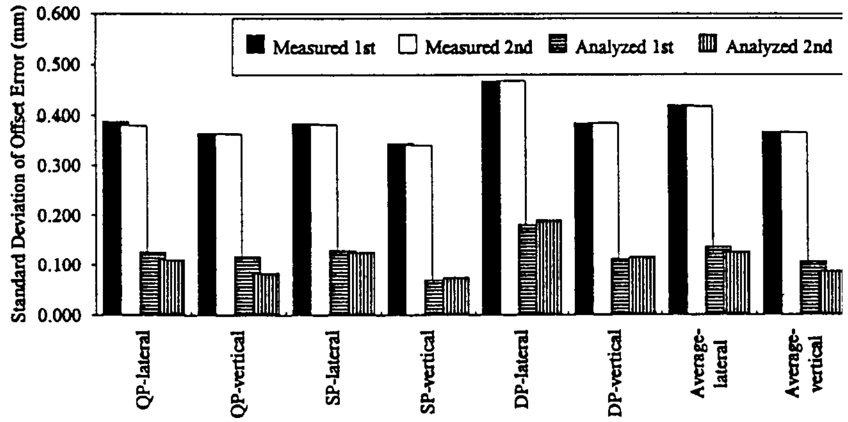


Fig.5 Standard Deviations of Offset Error in August 1995

Table.5 Outler numbers of Smoothing Analysis in August 1995

Magnet Type	Quad	ıpole	Sextupole		Bending		SUM (Ratio)
Directions	lateral	ertical	lateral	vertica	ateral	vertical	
Number of Total Magnet	144	144	48	48	36	36	456 (-)
Number of Outlers (>0.3mm) -basis : design path	44	66	14	22	0	0	146 (100%)
Number of Outlers (>0.3mm) -basis : smooth curve	4	2	2	0	0	0	8 (5%)
Number of Adjust (>0.2mm) -real work objects	18	14	4	1	0	0	37 (25%)

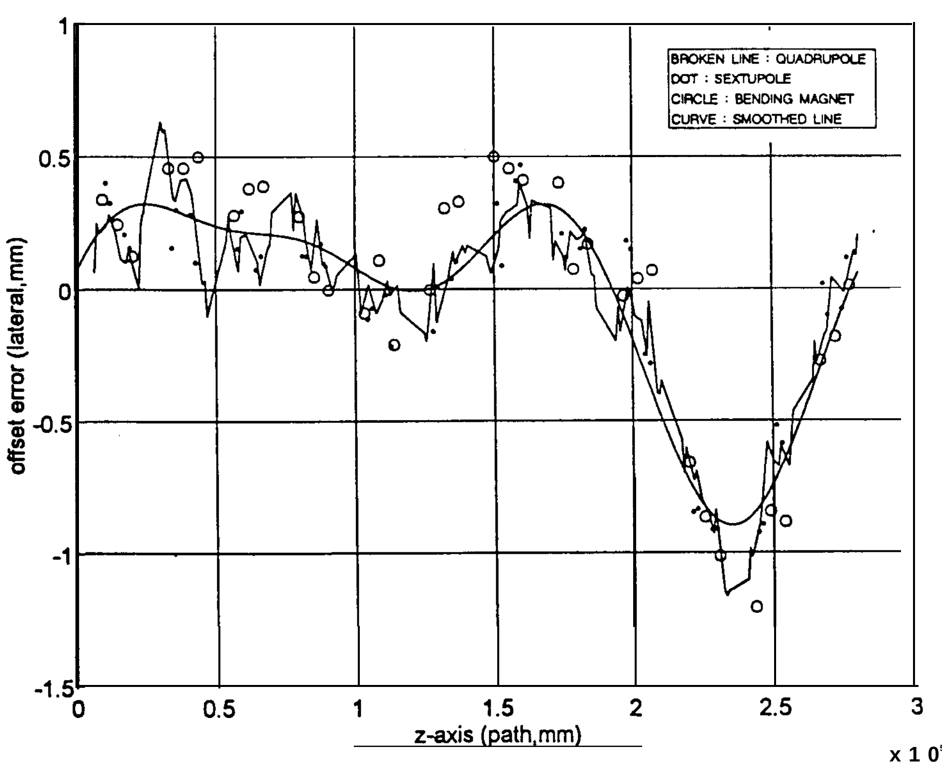


Fig.6 Results of the Smoothing Analysis in August 1995 (lateral,x)

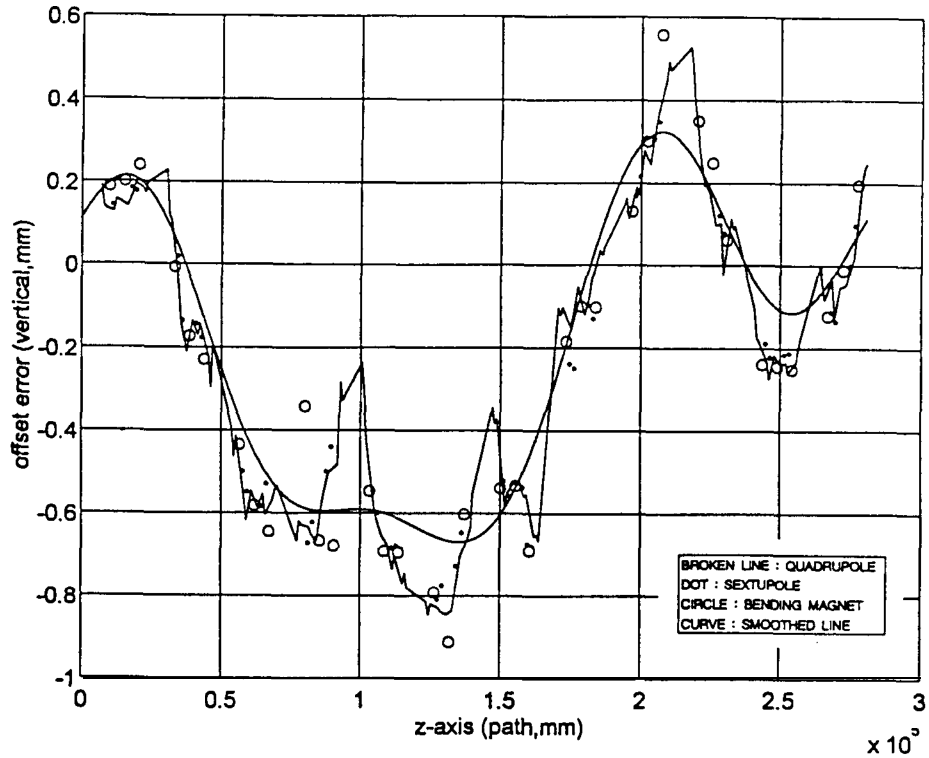


Fig.7 Results of the Smoothing Analysis in August 1995 (vertical,y)

7. CONCLUSION

By the study on the smoothing analysis of the PLS storage ring magnet alignment, We have concluded as follows;

(1) The smoothing method of the low-pass filter only reduces systematic errors like settlement, while it does not significantly reduce random errors like baking induced errors. Therefore this method is recommendable for the storage ring magnet alignment.
(2) Using the smoothing technique, we aligned successfully the PLS storage ring magnets during the 3 weeks shut-down period in August 1995. and the machine has been being operated successfully since the alignment.

And some verification using a beam dynamics software and the case studies which help the selection of cut-off frequency are recommended.

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