APPLICATION OF SMOOTHING ANALYSIS IN THE ALIGNMENT AND INSTALLATION PROCESS OF PARTICLE ACCELERATOR

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Abstract

With the development of technology and theory of particle accelerator, the new particle accelerators will be built in the near future. Comparing with the running accelerators, higher efficiency and accuracy of installation and alignment are required. It is necessary for all the storage ring magnets to be placed with a high relative accuracy to meet the stringent demands of accelerator physics. Smoothing analysis is a practical method considering both relative accuracy and work efficiency. This article mainly introduces the principle and application of smoothing analysis.

INTRODUCTION

Recently, with the development of modern synchrotron sources represented by free-electron lasers (FELs) and diffraction-limited storage rings and large particle collider, higher-accuracy position and higher efficiency are required. It is necessary for all the storage ring magnets to be placed with a high relative accuracy to meet the stringent demands of accelerator physics. We also emphasize the work efficiency and propose many advanced approaches. Experience from other accelerators and synchrotrons all around the world suggests that smoothing analysis is a practical method considering both relative accuracy and work efficiency.

An averaging method based on the Root Mean Square (RMS) has been extensively studied in the general smoothing process. It has a drawback in terms of finding smooth curve, and it deforms when the random errors decrease. A low-pass filtering smoothing method has been studied in depth for the Pohang Light Source (PLS) storage ring in Korea. However, the smoothing method only reduces systematic errors, such as settlement and so on, but does not significantly reduce random errors. In accelerator laboratories in the USA and Europe, fitting methods with Fourier series and spline functions have been widely studied, and these methods all need derivations of complex mathematical formulas and predefined functions[1-2].

This paper presents an attempt to introduce different smoothing methods and develop a reliable and simple smoothing method based on the curve fitting of least squares and iteration by considering the structural characteristics of different particle accelerators.

THEORY ANALYSIS

Smoothing analysis is mainly used in the particle accelerators construction process and running process. During the construction, all the elements will has a smoothing alignment according to the measurement data of laser tracker and other coordinate acquisition systems after two or three precise alignment. During the run-time, smoothing analysis will be applied according to different position monitoring sensors and auto feedback adjusting system to ensure the smooth running of particle accelerator as shown in Fig.1.

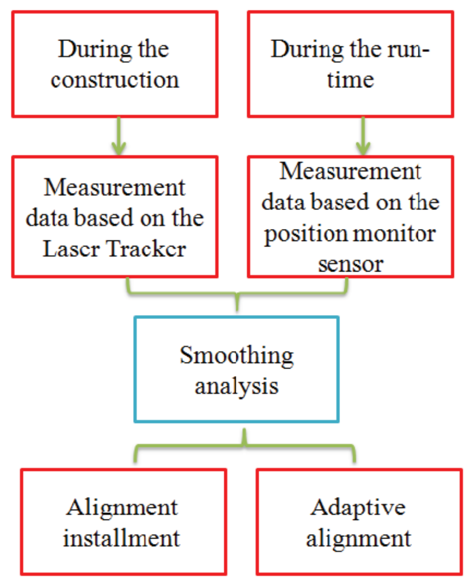

Figure 1: Application of smoothing analysis.

Comparing the actual position with the theoretical position, almost all of elements have slight errors. The statistical nature of installation errors appears to be a Gaussian distribution, where the aligned elements are randomly and normally distributed around this mean trend curve as shown in Fig.2.

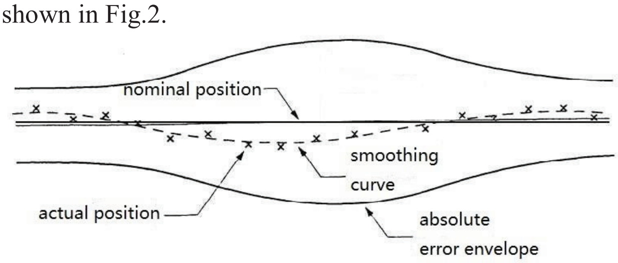

Figure 2: Position of magnets with respect to theoretical orbit.

Different smoothing methods should be adapted according to the structural features of different particle accelerators. The PLANE software is a CERN developed tool that calculates a "smooth" curve based on the deviation from the nominal position and identifies the magnets

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to be realigned. The algorithm is based on a sliding window of variable length. Within this window all the points except the one in the window centre are fitted to a fifth order polynomial. The centre point is 'rejected' if its deviation from the polynomial exceeds a specified tolerance. The process iterates by sliding the window point-by-point and continues until the end of the sector is reached. Then PLANE re-iterates the whole process until no further points are rejected and recalculates the deviation to the latest 'smooth' curve for all the magnets. This method, just like a carpenter shove a piece of wood with a plane [3-7].

Meanwhile, we have developed a reliable and simple smoothing method based on the curve fitting of least squares and iteration by considering the structural characteristics of Hefei light source (HLS Ⅱ). The method takes into account random error and systemic error simultaneously, and has simple implementation and similar work efficiency to the low-pass filtering and spline function smoothing method. Firstly, according to the closed orbit distortion formula and the simulation code MAD developed by CERN, the effect of the alignment error of magnets can be studied. Studies have shown that the most significant closed orbit distortion is caused by the error of quadrupoles and sextupoles in the transverse directions and the error of rotation of the dipoles. We consider the transverse directions rather than the longitudinal direction in the smoothing process because of the small effect of longitudinal direction on the closed orbit distortion. We also simplify the smoothing process by considering all magnets as points and neglecting their length and rotation. Secondly, by using the measured values of the reference marks, the magnetic field centre of the magnets can be obtained indirectly by backward analysis, which is based on coordinate transformation. Thirdly, we can smooth this elements after performing the alignment twice or thrice. The basic principles of the curve smoothing and bulldozer are quite similar. We smooth the downstream magnets by reference to the upstream smoothed magnets [8].

Comparing the above two smoothing methods, the first method is good for smoothing accuracy but lower productivity. The second method has higher productivity, on the other hand , it is easy to make a distortion because of the end of orbit is free. The distortion can be eliminated at the circular particle accelerators because of loop iteration, but it maybe cause the distortion of line at the linear particle accelerators[9-11]. The first smoothing method is better adapted at the linear particle accelerators. As shown in the Fig.3.

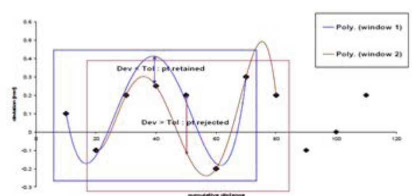
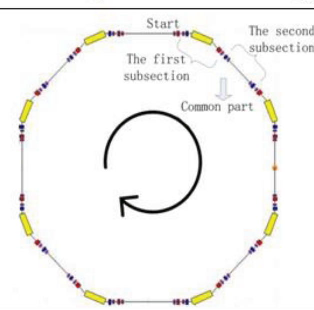
Smoothing Method:	PLANE software method	NSRL method
Features:	Smoothing one point just one time	Smoothing several points one time
Mathematic Model:	Polynomial fitting	Least squares curve fitting
Window figure:		
Analogy:		
Application:	Linear Accelerator	Circle Accelerator

Figure 3: Comparing of different smoothing methods.

SOFTWARE PROGRAMMING

We have coded a smoothing software named "Smooth" by Java programming language according to the smoothing theory on the context. The software can smooth different style accelerators by selecting different parameters.

There are two factors that need to be considered in this unique smoothing method: sliding windows and polynomials. The sliding windows include the length and acceptance threshold as shown in Fig.4.

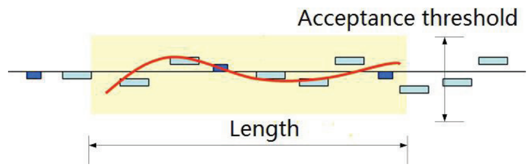


Figure 4: Length and acceptance threshold of sliding windows.

The selection of length has a crucial effect on the work efficiency. Longer lengths indicate that higher-order polynomials are required to fit a smooth curve. Shorter lengths lead to low work efficiency as well. From the optimization simulation and analysis, it can be concluded that a length of eight or nine magnets is a good fit that balances the trade-off. The acceptance threshold is determined according to the actual requirements. Polynomial fitting based to the least squares method is a good candidate because least squares is one of the most reliable methods and is easy to implement using computer programs. If the order of the polynomial is greater than three, few magnets need to be re-aligned at the selected length. The beam current cannot cross through smoothly in such a high-order orbit. Third order is considered as a suitable order, but we still set the free order in the software that users can select order according to their need [12-14].

We will expound the detail method and artifice on the other IPAC2017 article TUPIK065 as shown in Fig.5.

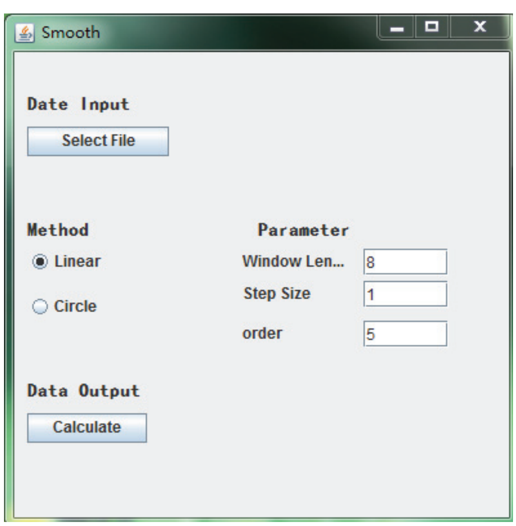


Figure 5: Software of Smooth.

We used the actual measurement data to test the software, comparing the process result with the MATLAB smooth code. It is proved that the programming is reliable.

CONCLUSION

In this paper, we introduce the smoothing method and theory. Meanwhile, we also talk about the application area about different smoothing methods match with different type particle accelerators. We have tested the second method in the Hefei light source storage ring to establish its effectiveness. The research about smoothing method is important about the future accelerators establishment because of its benefit about improvement of effectiveness.

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