OPTIMIZATION OF THE FIELD INTEGRALS OF TWO SMALL GAP IDS FOR CLS

Maofei Qian, Hongfei Wang, Wei Zhang, Yongzhou He, Qiaogen Zhou, SINAP, Shanghai, China

Abstract

An in-vacuum undulator and an in-vacuum wiggler have been developed for CLS at SSRF recently. The period lengths of the undulator and the wiggler are 20 mm and 80 mm respectively. Both IDs have a minimum gap of 5.2 mm. The field integrals were measured for each magnet block with two poles ad were sorted in-situ as they were installed onto the girders. Finally the field integrals of the undulator and the wiggler were shimmed by using the “Magic Fingers” at the ends with a special algorithm. This paper reports the procedure and the results of the measurement and the optimization for the field integrals.

INTRODUCTION

Insertion devices(IDs), include undulators and wigglers, are essential parts third generation synchrotron radiation sources. Recently Shanghai Synchrotron Radiation Facility(SSRF) have developed two in-vacuum IDs for Canadian Light Source(CLS), including an 80-periods 20-mm-peroid length undulator(IVU20) and a 17.5-periods 80-mm-period-length wiggler(IVW80), both of them have a minimum operating gap of 5 mm. Field integrals of IDs should be controlled within specific ranges to avoid the degradation of beams that pass through them. Two kinds of methods were adopted to reduce the field integral error: in-situ sorting method used during installations of magnet blocks and magic finger method used after magnet blocks installed, we describe these two in following two sections. Some of final results on field integrals will be presented in the last section.

MEASUREMENT AND INSTALLATION

Three sets of long-coil magnetic field measurement systems were used during the installation of magnetic structures and shimming of field integrals [1], two translating coil systems and one rotating coil system. Among them, a shorter translating coil system for measuring the field integral of individual magnet block, another longer one for in-situ sorting when the magnets were installed onto the girders. A rotating coil system was used when conducting magic finger shimming, because this kind of systems have better precision as well as they can measure the second field integral easily.

All magnet blocks of each of the IDs fall into two categories: end blocks and common blocks, common blocks are with same dimensions and can be replaced by each other, while the end blocks are with variable dimensions and less interchangeability. Before being installed on girders, the first field integral of each common block was measured across a transverse range of ±30 mm with a step of 2 mm using the short translating coil system, to simulate the environment of being install on the girder, each block was measured with two poles attached to its two side, and the height from the translating coil’s center to the surface of the pole was set half of the height of the minimum aperture of the two IDs. Two coils, one located in horizontal plane and another in vertical plane worked simultaneously, measuring the normal component (vertical or y-direction), and skew (horizontal or x-direction) correspondingly. The two coils were designed to be motionless, while the magnet block moved along with poles on a platform mount on a translation stage. The precision of the system is 5 $G\cdot$ cm. Each common block was measured twice, for each one has two sides that can face the ID aperture. Fig. 1 shows the measured field integrals of magnet blocks of IVU20.

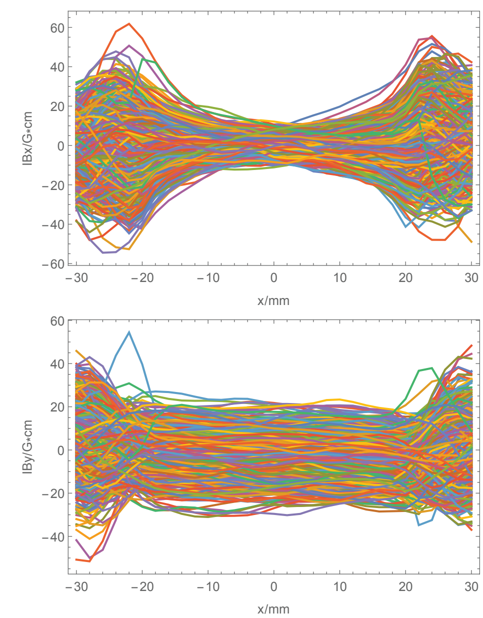

Figure 1: Field integral of all magnet blocks of IVU20, top panel: skew component, bottom panel: normal component.

Only the first field integral was considered during the installation. End blocks of a girder were installed firstly and the field integral was measured. Based on the acquired data a Labview based program then searched in the database that stores field integral data of each common magnet block to choose an available candidate that compensates the current first field integral error best. After the chosen block was installed on girder, a long coil measurement was taken to find the current field integral errors again and the measured data served as the start point of the installation of the next common block. This procedure was repeated until all the two girders were filled up. The first field integral errors were within the range of ±200 $G\cdot$ cm for IVU20 when the installation finished. However for IVW80 some points exceeded ±1000 $G\cdot$ cm.

ISBN 978-3-95450-147-2

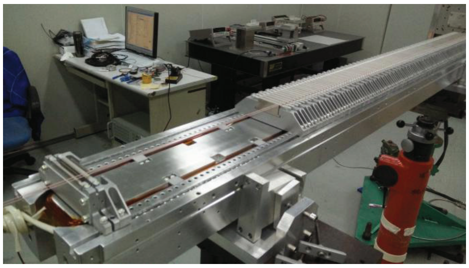

Figure 2: Magnet blocks being installed on a IVU20 girder, the translating coil is visible above the pole faces.

MAGIC FINGER SHIMMING

After installation, the remanent first and second field integral errors of the two IDs were reduced by transverse arrays of small permanent magnet cylinders installed in Aluminum holders, which were usually called the “Magic Fingers”. Both the two IDs were designed to have magic fingers attached to their both ends that can correct first field integral errors, whiles the ones at the inlets can also correct second field integral errors.

Figure 3: Picture of magic finger attached to a IVW20 girder end.

Cost function

To guide the magic finger shimming, a cost function should be defined and minimized. A commonly used cost function can be expressed as following [2]:

$$F_c = \sum_{i=1}^{ng} W_g \cdot F_{cg}$$

where ng is the number of gaps under consideration, F_{cg} is the sub-cost-function of the gap g, while W_g is the corresponding weight.

$$F_{cg} = \sum_{i=1}^{n} IB_i^2 \qquad (1)$$

$IB_i = IB_{err,i} + IB_{mf,i}$ denotes shimmed field integral at i-th of the n horizontally spaced points when the ID gap is g, $IB_{err,i}$ denotes the field integral error measured at that point, $IB_{mf,i}$ denotes the field integral generated by magic fingers at the same point. Both $IB_{err,i}$ and $IB_{mf,i}$ includes its normal and skew component.

This cost function require that the final integrals in the solution to be as close to zero as possible. However a saw-tooth-shaped field error distribution may not be excluded for its RMS is small although a saw-tooth like distribution will produce a large multipole.

In order to meet the multipole requirements better, we modified Eq. (1) and the following cost function was constructed:

$$F_{cg} = \sum_{i=2}^{n} (IB_i - IB_{i-1})^2 + IB_{x=0}^2$$

where $IB_{x=0}$ denotes the shimmed field integral at point $x = 0$. First term of the right hand side favors the potential solutions with smaller point-to-point variations, while the second term keeps the baselines at different gaps small.

Algorithm

Simulated Annealing algorithm was employed to determine the arrangement of the small magnets. Simulated annealing is derived from hill climbing algorithm. We conducted a comparison between these two algorithms to evaluate their efficiencies when being applied to magic finger optimizations. Codes for magic finger shimming with these two algorithm were executed 512 times separately with same input, but initiated with different random seeds. The final results of the cost functions were counted and their distributions were displayed in Fig. 4. The histogram indicates that simulated annealing performed slightly better than hill climbing, while special attention should be paid to the large span, which means that for both algorithm, when initiated by different random seeds, the variations of the qualities of solutions are notable.

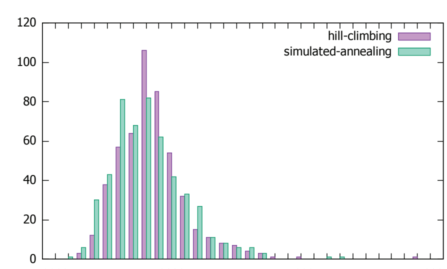

Figure 4: Distribution histogram of the final values of cost function of hill climbing and simulated annealing algorithm, there are 512 samples in each set, all the samples have identical input, but were initiated by different seeds, the initial value of cost function is 100380.

Code Parallelization

In order to get the best solution, many operation runs can be done to select the “best-of-the-best”. However, many runs require intense computation power. Computation power can be significantly enhanced by the parallelization of computing code. We parallelized our C++ optimization code using OpenMP [3]. OpenMP is a flexible interface for developing parallel applications which supports shared memory multiprocessing.

In order to simplify the access of shared memory, and to avoid wasting time on IO operations, we did not print or save any information about an individual optimization run when conducting massive runs, other than the seed and the final value of cost function. After all random optimizations finished, the final values of cost function were compared and the best one was chosen, the corresponding seed was fed to the same optimization subroutine, A same final value of cost function was obtained, while the only difference is that the subroutine printed detailed information of the solution that can direct the installation of magnet cylinders, such as the quantity and direction of magnets in each hole in each magic finger, as well as the predicted magnitude of shimmed field integral errors.

Pseudo-code for implementing OpenMP parallelization are listed as following:

```
#include <omp.h>
#pragma omp parallel for num_threads(8){
        seed=rand();
        final_err=Simulated_Ann(seed);
#pragma omp critical{
        save_record(seed,final_err);
        }
}
```

By adopting the above method, a speedup of 5.9 of our code was obtained on a 4-cores-8-threads processor.

RESULTS AND DISCUSSION

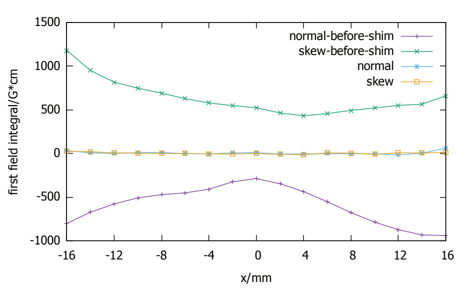

Figure 5: First field integral of IVW80, before and after magic finger shimming.

Fig. 5 shows the first field integrals before and after magic finger shimming of the IVW80 at the its minimum gap, the errors were reduced significantly. Fig. 6 shows the second field integral measurement results at $x = 0$, under different gaps, all are under 6000 $G\cdot$ cm^2.

Fig. 7 shows the integrated multipoles, including quadrupoles, sextupoles and octupoles of IVU20, all are within specifications. The multipoles were obtained by applying polynomial fitting to a set of horizontally spaced points in the range$-16 < x < 16\,mm$.

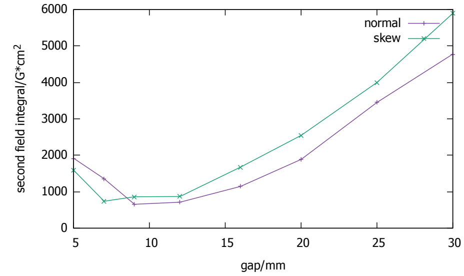

Figure 6: Second field integral of IVU20 at x=0 mm.

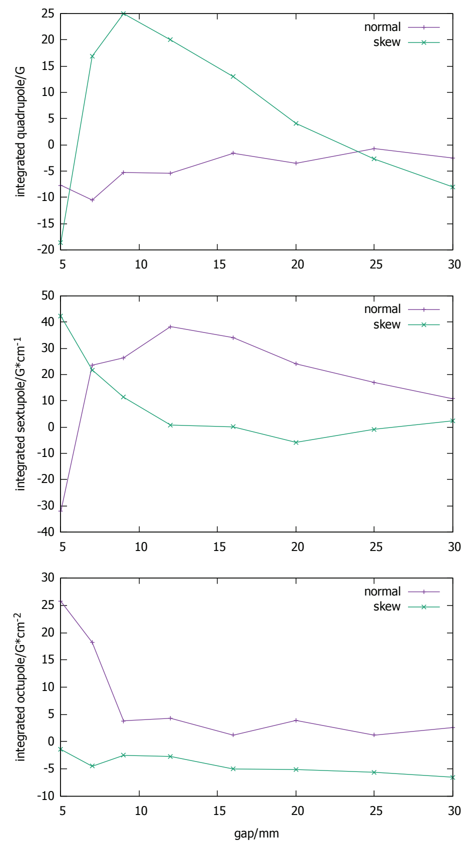

Figure 7: Final results of integrated multipoles of IVU20 at different gaps.

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ISBN 978-3-95450-147-2