MAGNET SORTING ALGORITHMS FOR A PROTOTYPE OF THE SRRC EPU

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Abstract

The Synchrotron Radiation Research Center (SRRC) is constructing a prototype of Sasaki-type elliptically-polarizing undulator (EPU) characterized by its four longitudinal movable magnet rows, whose shifting determines the polarization of synchrotron radiation. A total of 280 pure NdFeB blocks with square cross-section of 40 mm x 40 mm and thickness of 14 mm are magnetized into two types identified by the main field orientation. To minimize field errors, the blocks are sorted and assigned appropriate locations on the rows. Due to the special symmetry of the blocks, the 40 mm x 40 mm square face, and rows structure, the orientation and locations of blocks can be assigned freely. However the cutting on one pair of opposite angles on each square face for rigid clamping reduces the freedom of permutation. Moreover, the perturbation of the field from the shifting of rows must be taken into account. The authors would like to present the sorting algorithm and address its contribution to field performance.

1 INTRODUCTION

The Synchrotron Radiation Research Center (SRRC) will construct a 3.9 meter long Sasaki-type elliptically-polarizing undulator (EPU). The period length of this device is 56 mm. Therefore we name it EPU 5.6. A prototype of one meter long is being fabricated to evaluate the concept design [1]. The schematic view of one period (of length λ_u) of the magnetic structure for generating the elliptically polarizing light is provided in Fig. 1. Each of the four magnet rows can move with a range of ± 28 mm, i.e. one quarter period along two opposite direction each, independently. Therefore all the combination of the rows movement, and all kinds of planar- and elliptically-polarized X-rays with various energies can be achieved [2]. A gap adjustment mechanism supported by a drive train system can also tune the magnetic field strength.

The EPU 5.6 is a pure type device using NdFeB permanent magnet blocks with square cross-section of 40 mm x 40 mm and thickness of 14 mm. For rigid clamping under the strongly magnetic force, there are cuttings on one pair of opposite angles on each square face. Due to the special symmetry of the blocks, they need to be magnetized into only two types, V- and H- types, identified by the main field orientation. Because of the 40 mm x 40 mm square face, and arrays structure, the orientation and locations of one type of blocks can be assigned freely. However, the angle cuttings mentioned above and the periodical magnetic structure reduce the freedom of permutation. In Fig. 2 we summarize the allowed rotation of each type.

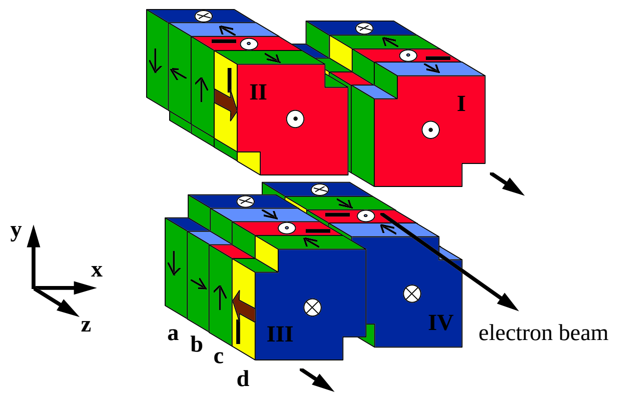

Figure 1: One period of magnets: The magnet blocks can be located at four quadrants (I, II, III and IV) and four quarter periods (a, b, c and d). The small bars indicating the series numbers and broad arrows are marked by vendor.

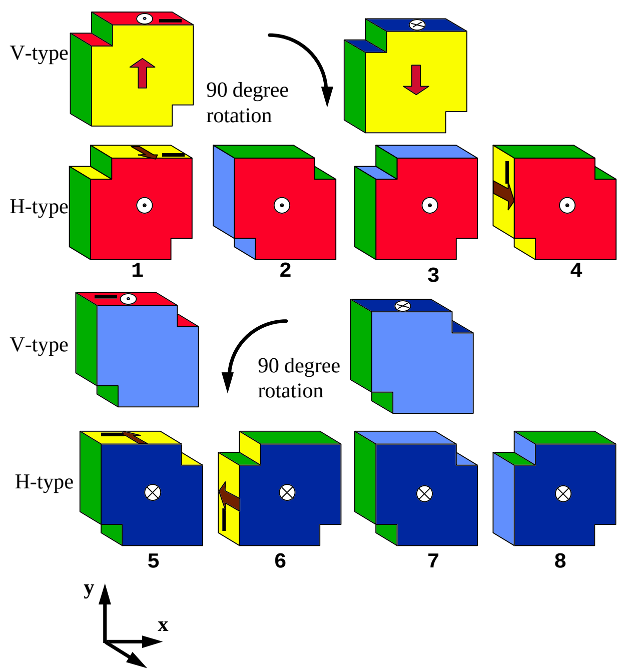

Figure 2: The allowed block rotation of two types of magnetization.

The demand on the quality of magnet blocks and the sorting results are diverse at different laboratories. Some purchase the best magnet blocks commercially available but costly. Some develop sophisticated sorting code with enormous measurement data and tremendous computer running time. There are also a few laboratories put much effort on shimming or field correction techniques [3-4]. Though the passive field correction is most demanding, most of the field correction techniques are effective only when the field error is reasonable small. Under the limited budget, the suitable sorting algorithms are quite feasible.

For insertion devices with hybrid structure, there is a magnet sorting algorithm to establish uniform pole excitation by reducing the deviation of the average Mz of each unit cell [5]. Mz is the magnetic moment in the direction of magnetization. Each unit cell comprises one pole and six magnet blocks. However, in such non-iterative algorithms, the multipole field can not be controlled effectively. Therefore, that algorithm has been improved to control the effect from minor components [6]. On the other hand, the techniques of annealing have been applied to magnet sorting [7].

In pure permanent magnet structures such as EPU 5.6, we have an advantage of ignoring the nonlinear component. The field distribution can be calculated by superposition of the magnet field. In this prototype, we will try two approaches of sorting. One is just to use the magnetic moments measured by Helmholtz to minimize the total magnet moments, the other is to sort the magnets by multipole field measured by flip coil eliminate the field error.

2 SORTING CONSIDERATION

Before the algorithm of sorting for the prototype EPU 5.6 is deduced, we have some considerations as the following:

2.1 About the Magnet Blocks

An amount of 174 V-type and 176 H-type magnets have been purchased for this prototype EPU. Only 280 of them will be used. The maximum principal dipole variance and inclination angle is required to be ± 1% and 2° respectively. Fig. 3 shows an example of the population of the magnetic moment My of V-type magnets. By removing the magnets with extremely high or low field, we can get an acceptable group to sort. The magnetic moment was measured by a Helmholtz coil system with a resolution and reproducibility of 4 Gauss. With the sorting of a large amount of magnets, it is evident that an average effect will diminish a part of effect from measurement error.

A magnet keeper is designed to allow easy adjustments in the vertical and transverse positions. This adjustment can also serve as magnetic field tuning.

2.2 First Stage Sorting

To simplify the modeling, we separate the sorting algorithm into two stages. At first stage, we try to make a reduction of first integral of field at the axis of electron beam as the following steps:

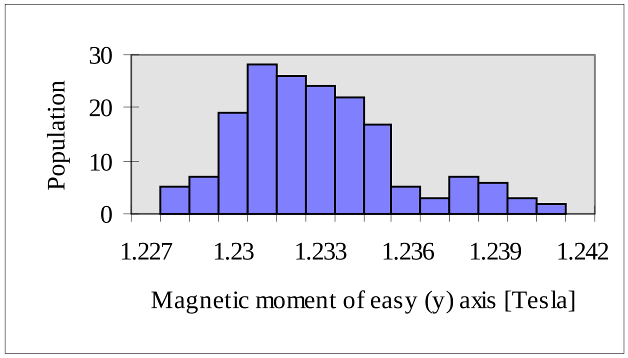

Figure 3: The vertical magnetic moment of V-type blocks. The total number of the blocks is 174.

1) The V- and H-type blocks are monotonically ordered in ascending values of My and Mz respectively.
2) The V-type blocks are assigned to rows I and II alternatively from upstream to downstream in proper order. The left ones are assigned to rows III and IV in the similar way, but from downstream to upstream.
3) The H-type blocks are assigned to rows in reverse order, i.e. to rows III and IV from upstream to downstream in proper order and to rows I and II from downstream to upstream.

If we can ignore the minor moments, Mz and Mx for V-type but My and Mx for H-type, we would have a beautiful sinusoidal vertical and horizontal fields at each period of each row by calculation. Because of the linearity of the magnets, the "row phase shift” will keep the sinusoidal fields with field phase shift. The "yaw phase shift” and "pair phase shift” also have sinusoidal fields only with the amplitude change. The terminology of these three "phase shifts” are defined in [2].

If the minor moments have no dependence on the main moment, the order of the main moment at each quarter period would not cause any systematic errors of multipole fields. This dependence has been checked. The example in the Fig. 4 is the only one, which can be identified. The correlation between the main and minor moments is quite weak however.

2.3 The Second Stage

After all the magnets are assigned to locations and the zeroth order of field is constructed, the next step is to face the multipole problem. To look at one period as a unit, we can exchange the locations or rotate the orientation of magnets in each unit. In order not to destroy the sinusoidal field obtained at the first step, some exchange and rotation are forbidden. The rules of permutation and rotation turn out be as follows:

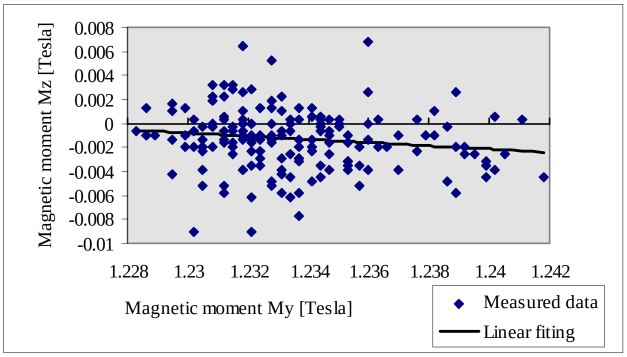

Figure 4: One example of the correlation between the main and minor moments.

1) The upper rows (upper jaw) of magnets can not be interchanged with the lower rows owing to the large difference of Main moments. The magnets of the same jaw can, since the difference is quite small according the first stage ordering.
2) There are 4! / (2! x 2!) permutations of V-type permutation in each period of upper or lower row. After an iteration of calculation of all combination, one can find an optimum of the three total moments (so that the absolute value is closest to null). The interchanged configuration shall be recorded for the final step.
3) Besides the same 4! / (2! x 2!) permutations of H-type permutation in each period of each jaw, there are two more 180° rotation freedoms along z-axis. So the total number of permutation is 12. The calculation and recording is the same as item 2).
4) In each period of each jaw, by reversing the process of 2) or 3) according to the record, one may find a less number.
5) In each jaw, one can reverse some period process according to the record to find a minimum multipole field.

2.4 Multipole Field Sorting

Similar to the two-stage sorting of the magnet moments, we can measure and calculate the dipole field at the axis of electron beam and take the place of Mz. We can use the same permutation procedure to minimize the multipole field.

3 CONCLUSION

Although there are many complicated phase shift modes in EPU, thanks to the linearity of the pure permanent magnets, it is feasible to sort the magnets directly to reduce the error effect on the spectrum and beam dynamics.

4 REFERENCE

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