HYBRID UNDULATOR DESIGN AND FIELD ERROR ANALYSIS

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Abstract- A 1.5 m hybrid tapered undulator has been designed and built at IAE, Beijing.The magnetic gap and taper of undulator are variable. The undulator serves as the experiment of 10 μm free electron laser(FEL) and the benchmark for future long undulator designs for advanced FEL. The feature of designs, optimization of the magnetic parameters and field error analysis will be disscused.

1. Indroduction

Since 'A FEL project at IAE' was reported in the proceeding of ninth international FEL conference [1],a 1.5m hybrid tapered undulator has been designed and built at IAE. The magnetic gap is continuously varied.The magnetic taper is independently tuned in three section.First, the undulator serves as the experiment of 10 μm FEL.Then,the performance of magnetic field serves as benchmark for future long undulator design for advanced FEL.The undulator design utilizes the REC-steel hybrid planar configuration .The permanent magnetic material $SmCo_5$(2:17)was chosen. The remanent field Br is 1 T, the coercive force is 8500 Oe. The reversible temperature coefficient is 0.03%/°c. In this paper,the salient features of undulator design, optimization of magnetic parameters, and field error analysis will be disscused.

2.The IAE undulator design

The undulator is a REC-steel hybrid tapered planar configuration.The length of undulator is 150 cm.The period is 3 cm.The number of periods are 50. Fig. 1 shows the mechanical layout of the undulator.

The magnet blocks will be glued into aluminum assembly holder. The holders in turn are bolted into the magnetic tapered slots. The baseplate supports three section of magnetic tapered slot. The magnetic gap may continuously varied from 4 mm to 40 mm by means of four ball screws with opposite handed threads. The gap tuning of each period will be variable between 0 and 1.5 mm by rotating screw with the wedge and the spring sheet. It is very advantageous to obtain the homogeneity of magnetic field. The magnetic taper may independently tuned in per section of magnetic tapered slot by means of the screw by varying the gap at one end relative to the other.

The high quality of the undulator field was achieved by (1)the simulation calculation of field,(2)the careful selection and pairing of magnet blocks,(3) strict limit for mechanical tolerance during fabrication and assembly (4) precise measurement of magnetic field.

The permanent magnet used in the undulator is $SmCo_5$(2:17) Four hundred blocks of magnet have been manufactured and tested . Its dimension is 45X30X8 mm . The tolerance is better than 0.05 mm. The spread of the remanent field is ±3%. The deviation of the magnetizing angle is ±2°.

The undulator has been specifically designed . The tolerance of the magnetic blocks is better than -0.05 mm . The flatness of the baseplate and the reference plate is better than ±0.05 mm.The precision of the ball screw is 0.01mm.the baseplate, reference plate, magnetic tapered slot, and magnetic assembly holder are all made from stable cast aluminum alloy.

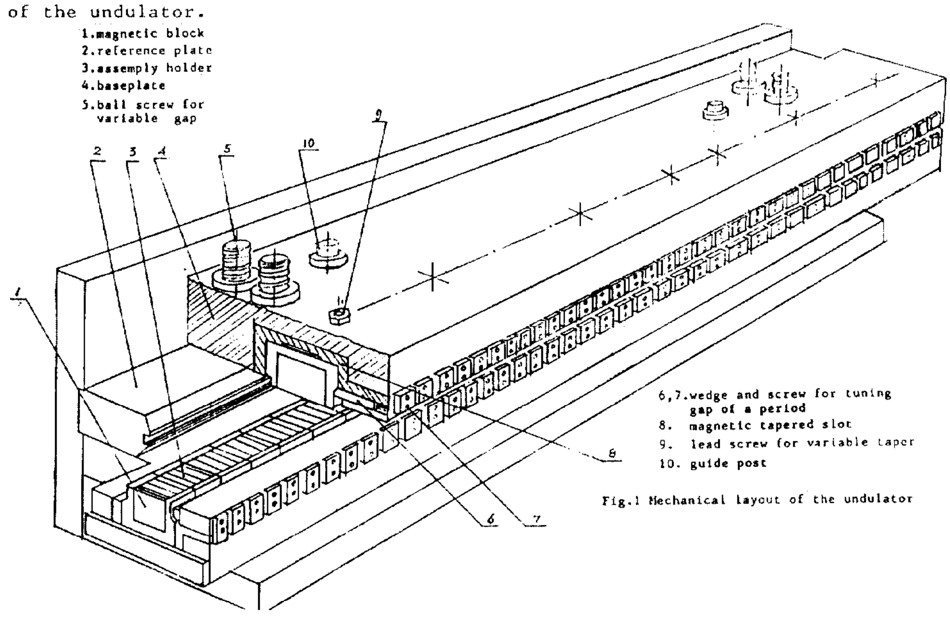

Fig.1 Mechanical layout of the undulator

In order to measure magnetic field of individual magnet and undulator, we installed an automatic magnetic measurement device. It consists of the grating location, digital display, step motor driver, data sample system, and computer control system. The HALL-effect probe has been selected for the measurement device. The dimension of probe is 0.1x0.1 mm. The precision of the measurement must be good to about $3x10^{-4}$. The sample density is greater than 100 points per undulator period. Therefore, it is possiable to reduce the integral error.

The Hall probe is mounted on a short post which moves through a lead screw. The step motor drives the screw to rotate. The location of the probe is determined by the grating and is displied on the digital display. The resolution of the digital display is 0.005 mm.

3. Undulator field design

The undulator field design utilizes the REC-steel hybrid configuration. Fig.2 is an elevation cross-section of a period. The basic arrangement of the poles and REC is shown. The REC-steel configuration was optimized using the PANDIRA computer code [2]. The optimization of the pole height/REC height ratio, h_2/h_1, pole width/REC width ratio, a/b, the pole overhang and chanfering, and end configuration of the undulator were carried out through computer simulation.

The peak field decrease exponentially with increasing gap, which can be seen in Fig.3. While the gap vary 1 mm, the variation of the field 10%. Therefore, in order to maintain the homonigenity or the taper along undulator, the precise ball screw for variable gap was chosen.

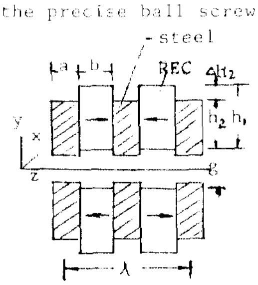

Fig.2 hybrid undulator erros section

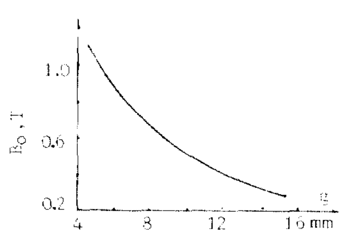

Fig.3 Peak field Vs gap

Fig.4 shows the relation between the peak field and the height of the blocks. The dimensions of the height h_1 and h_2 were chosen to maximize the peak field and to minimize the weight of the REC. When $h_1/\lambda < 1$, the rising speed of the field will increase fastly with the increase of the height h_1. When $h_1/\lambda > 1$, increasing h_1, the peak field will increase slowly. Therefore, it is not worth to increase the peak field using the increase of the height h_1, when $h_1/\lambda > 1$.

The peak field will increase with rising height of top pole, Δh_2. However, when $h_2 > h_1$, the field will decrease obviously with a rise of height of top pole. It is because the magnetic flux has been leaked out. The pole overhang is not beneficial. The peak field is small compared with the field of the flat pole at equal gap.

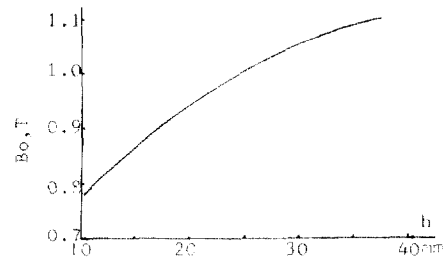

Fig.4 peak field as a function of the height of REC

The dimensions of the width a and b were determined to maximize the peak field and to reduce the harmonics. The width of the magnetic block is a little more wider than that of the steel pole.

The field homogeneity in Y driction is given in Fig5. When magnetic gap increase, the homogeneity will go bad.

For the operation of the undulator, the field integral must be equal to zero. The half blocks at both ends of the undulator are used to accomplish the field integral. However, when REC blocks are arranged at the ends of the undulator, the integral error is small. If the steel poles are arranged at ends, the integral error is great.

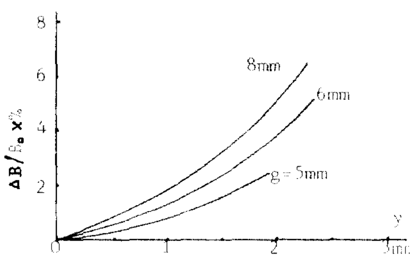

Fig.5 the homogeneity of the field in y direction

4. Field error analysis

Though the hybrid undulator results in the relaxation of individual magnet requirement, the mechanical tolerance becomes a critical issue. In computer modeling, we worked out several aspects of tolerance design by PANDIRA computer code. For instance, the computer modeling is allowed to determine the error of the remanent field and the magnetizing orientation of magnets, the width tolerance of the blocks, the variation of the magnetic gap, and the shift of the assembling placement of magnetic array. From these calculation it is clear that the effect of the gap tolerance on peak field is especially sensitive.

Fig.6 shows the field error as a function of the spread of remanent field of REC. The error varaies with the spread of remanent field. If the variation of remanent field is symmetry in a magnetic period, the error is symmetry.

That is, the maximum peak field is equal to minimum peak field. If the symmetry of the error is destroied, it results in the variation of the magnitude and the symmetry of the peak field.

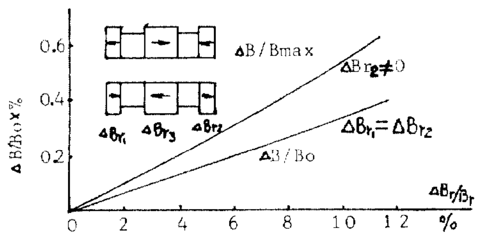

Fig.6 Field error Vs the spread of remanent field

Fig.7 presents the field error produced by the variation of the magnetizing angles. The field error relates to the magnitude and direction of the variation of the magnetizing angles. However, from these we see that the field quilty of the undulator has a relaxation for the magnetic property of the individual permanent magnet in hybrid undulator.

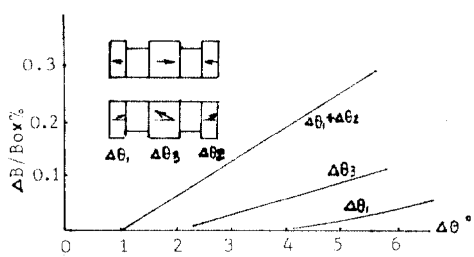

Fig.7 Field error Vs the variation of the magnetizing angles

The field error produced by width tolerance of blocks is given in Fig.8 and Fig.9. The tolerances of the poles result in the variation of the magnitute and the symmetry of the peak field. However, the field dissymmetry is not obvious when the tolerances of the REC width exist. In order to meet the requirement, the width tolerance of the blocks is controlled within 0.05 mm.

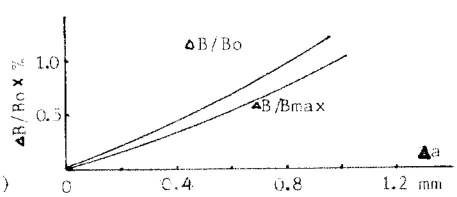

Fig.8 (steel)

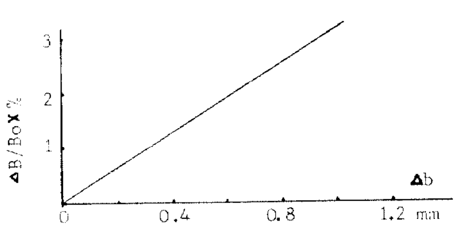

Fig.9 Field error Vs the tolerance of the width of block

When the magnet array was moved to large enough in z direction, the peak field, the location of the peak field, and the period will vary, which is shown in Fig.10. The field distribution keep the symmetry in shape.

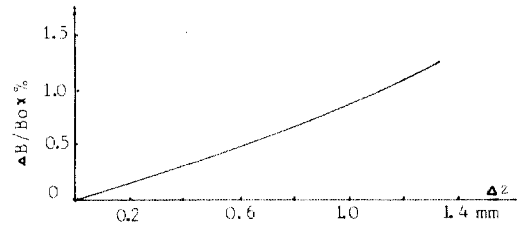

Fig.10 Field error Vs the shift of the magnetic array

The relation between the field error and the tolerance of the gap is shown in Fig.11. It will be seen from this the effect of the tolerance of the pole gap on the peak field is obviouser than that of REC gap. the tolerances of the pole gap result in the variation of the magnitute and the symmetry of the peak field. Thus, it is necessary to limit the gap tolerance of the pole to pole.

The gap tolerance is controlled using four ball screw and precise assembly. The adjustment of the gap uniformity is achieved tuning the gap of each period.

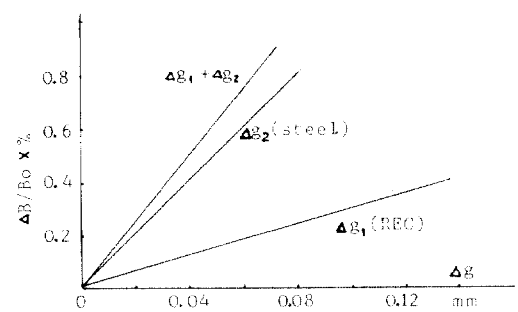

Fig.11 Field error Vs the tolerance of magnetic gap

From the modeling design it is clear that the careful simutation, precise mechanical design, and adjustment are still essential. The field measurement and the optical experiment will be attemped in the next step.

references

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[3] Ma Youwu, Zhang Zhaoming, Liu Bo, IAE Internal Report, 1989.