ADJUSTMENT AND MEASUREMENT OF A HYBRID UNDULATOR

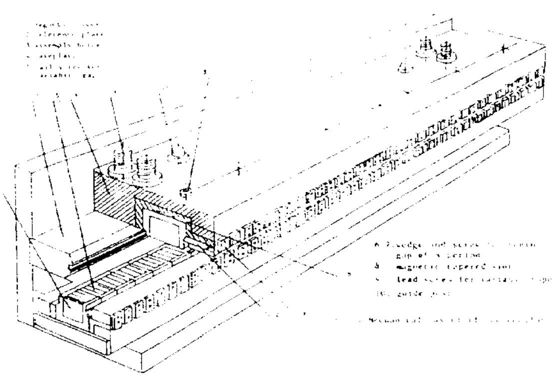
Wu Bing, Ma Youwu, Liu Bo, Zhang Zhaoming
China Institute of Atomic Energy
P.O.Box 275(17), Beijing 102413, P.R.China

Abstract

Adjustment and measurement of a hybrid undulator have been discussed. The magnetic field quality is limited by factors such as inhomogeneities of the permanent magnets, fabrications and assembly errors. Considering these factors, re-sorting of aluminum holders using Simulated Annealing method and iron shimming have been used for the adjustment of undulator. The measured rms field error was reduced from 3% to 0.3%, the electron trajectory deviation is around 0.1mm. During our magnetic measurement, small variation of magnetic period length was observed. An approach to reduce the deviation of relative phase of electrons in the ponderomotive potential, which will lead to the reduction of laser gain degradation due to magnetic field errors have also been discussed.

1. INTRODUCTION

A typical Halbach REPM-steel hybrid undulator is under construction for a free electron laser(FEL) project in CIAE. It is 1.5m long, including 50 magnetic periods, each 30mm. The magnetic field on axis is 3 KG at 1.3cm gap. Fig.1 shows its mechanical layout. Two permanent magnets ($SmCo_5$, 2:17) and two steel blocks are glued in an aluminous holder which



we call as a magnetic period unit. 100 units are in turn bolted into the magnetic taper slots, three sections of the slots are fixed into the baseplate. Before its construction, possible assembly and fabrication imperfectness which would result in magnetic field errors had been analyzed [1], and necessary strict mechanical tolerance were required: the tolerance of thickness of the magnet(or pole) was limited in 0.08mm, the gap tolerance was 0.03mm. In the meantime, magnetization strength of 400 magnet blocks(45mm$\times$30mm$\times$8mm) were measured, and 200 blocks were sorted and optimized using Simulated Annealing method [2]. Unfortunately, the quality of measured magnetic field after the first assembly is poor, the rms peak field error is around 3%. The poor quality results from following reasons: (1) inaccurate measurement of the permanent magnets before sorting; (2) imperfectness of fabrication and assembly, the real mechanical tolerances are much higher than what we required; (3) large deflexion(around 0.4mm) in the middle of two aluminous baseplate.

Generally, less than 0.5% of rms field errors is required for a high quality undulator. Special adjustment must be adopted to reduce the rms error from 3% to 0.5% for our undulator. In the second section of this paper, we will introduce our process of adjustment. In the third section, we will discuss the small variation of magnetic period length we found during measurement. Finally, an approach to correct the magnetic field errors for reducing the gain degradation have been presented.

2. ADJUSTMENT

At present, two effective methods of tuning an undulator to the desired field quality are tuning of magnetic gap [3] and iron shimming [4]. Tuning of magnetic gap does not work well in our undulator because of mechanical difficulties, and it is impractical to reduce field errors from 3% to 0.5% only by means of shimming. So, at first we disassemble our undulator to re-sort the aluminous holders.

(1) re-sorting of aluminous holder

After disassemble the undulator, we again use Simulated Annealing method to re-sort the magnetic period units so that the rms field error is reduced to a much lower value. As presented in section 1, field errors result from inaccurate measurement of permanent magnets and imperfection of assembly and fabrication, quantitative relationships between these errors will be useful for the calculation of cost function in Simulated Annealing calculation. Careful measurement of mechanical errors, including: deflexion of aluminous baseplate, the flatness of the magnet and steel pole surface of a magnetic period unit, are completed. these two factors are the main reasons of magnetic gap error. Empirical formula have been developed and described elsewhere [5]. Much more accurate magnetic measurement of magnetic period units can be achieved now, because a new magnetic measurement system [6] have been completed in 1991. Measurement of single magnet is impossible because it is glued in the magnetic period unit. Fig.2 shows the sketch

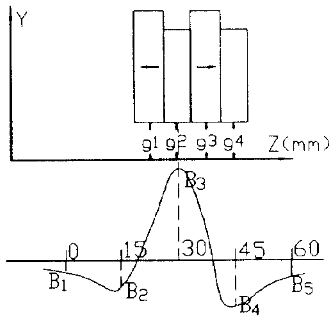


Fig.2

of measurement of magnetic field and surface flatness of a unit. 5 special points of magnetic fields B_1,B_2,B_3,B_4,B_5, containing the information of inhomogeneity of permanent magnet and g_1,g_2,g_3,g_4, indicating the gap errors, are all used in the evaluation of magnetic errors along the axis of undulator [5]. Considering all these mechanical errors and inhomogeneity of magnets, peak magnetic fields calculated by the empirical formula well correspond with the measured peak magnetic fields. So, in the calculation of cost function of Simulated Annealing technique, these empirical formula can be reliably used.

After the magnetic period units were resorted, the undulator was reassembled. The measured rms peak magnetic field error is reduced to 1.3%.

(2). Shimming

Shimming is widely adopted as an efficient technique in adjustment of undulator. Through shimming, the rms error of our undulator is easily reduced to 0.3%. Fig.3 shows the measured magnetic field. Then, little extra shimming was carried out, which reduced the deviation of electron trajectory to around 0.1-mm, as shown in Fig.4.

3. THE VARIATION OF LENGTH OF MAGNETIC PERIOD

The variation of magnetic period length λ_w have rarely been mentioned before. During measurement of our undulator, we discovered that, λ_w is not strictly equals to 30mm. As designed, there should be a zero magnetic field point every 15mm. In fact, there is small variation of distance between two zero magnetic field point, demonstrating the small

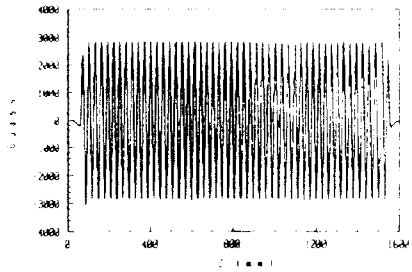


Figure 3

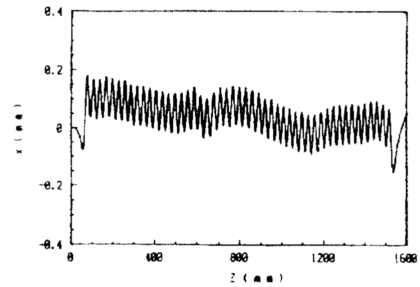


Figure 4

variation of λ_w. In our magnetic measurement system [6], a photo-electric encoder is adopted to detect the displacement of the GaAs hall probe with the precision 0.005mm. In a scan of our measurement, we acquire 1 magnetic data every 0.1mm, 300 data points per period. Some 0.1mm variation of λ_w were observed. In several periods, variation reached 0.3mm. From $a_w=eBw\lambda_w/2\pi mc$, we can see, λ_w of 1% variation will equally change the value of a_w with the Bw of 1% variation. This should be paid attention to, it means that variation of λ_w is also an important reason for the error of a_w.

It is possibly because of insufficient measurement data points in a period so that the variation of λ_w has rarely been mentioned. For example, if λ_w=30mm, 1 data point is acquired per 0.3mm, the variation of λ_w can not easily be observed. Though we have not scan our undulator with 0.1mm per step before shimming, we think shimming should be an important reason for the variation of λ_w.

4. AN APPROACH TO REDUCE THE GAIN DEGRADATION

The effects of random field errors on the performance of free electron laser have become a topic of recent concern. The random magnetic field errors will result in [7]:(1) Random walk of the electron beam centroid, δx; (2) Deviations of the relative phase of the electrons in the ponderomotive potential, $\delta\Psi$, both leads to the loss of radiation gain. Steering can be used to reduce the gain degradation results from δx [8]. Another method--floating wire technique has been developed and facilitate the adjustment of undulator in reducing δx. Though adjustment of $\delta\Psi$ has been suggested [7] and discussed in more detail [10], it has not been tried before and should be highlighted because reduction of δx does not indicating smaller $\delta\psi$, and $\delta\psi$ contributes a large part of gain loss due to magnetic field errors. In section 2, we have demonstrated the reduction of δx through shimming, now we want to reduce $\delta\psi$ through shimming too.

a_w, instead of Bw, is the magnetic parameter we will adjust, because it directly relates to the gain and efficiency of our free electron device, and as shown in section 3, the error of a_w included the variation of both Bw and λ_w which are both the main reasons of $\delta\psi$. The same value of rms errors but different distribution of errors of a_w may result in different $\delta\psi$. Our approach is to adjust the variation of Bw(here we use the amplitude of 1st harmonic) and λ_w, on condition that this adjustment does not result in large change of δx, so that the distribution of a_w is changed, $\delta\psi$ is reduced and loss of gain decreased.

Here, for the first step of our approach, we only consider the small signal gain G_0. We use formula of Gain function [11] to calculate G_0. Some parameters used in the simulation are following:

Average electron energy	24.89 MeV
Energy spread	1%
Density of beam current	300 A/cm^2
Length of undulator	1.5 m
Length of a period	30 mm
Ideal aw	0.86
Wavelength of laser	10.6 μm

Fig.5 shows calculated G_0 as a function of undulator length (in terms of period number). Curve 1 is the result when using ideal a_w.

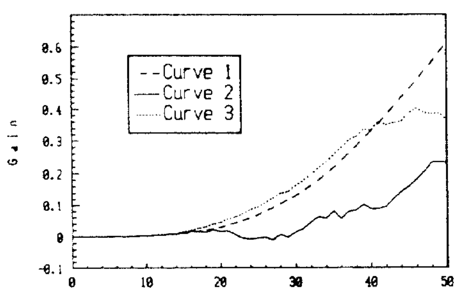


Figure 5.

Curve 2 is the result of using real magnetic data (a_w of each period). obviously the gain is reduced. Now, we simulate change of a_w within 1.5% in 10 different period, we think this can be managed in our adjustment without obviously changing the δx. Curve 3 shows the calculated G_0, the gain loss is obviously decreased, and G_0 is near the ideal value. Now a verifying numerical simulation code is under developing.

5. CONCLUSIONS

Our adjustment of undulator is efficiently proved, the quality of undulator is good both in rms peak magnetic field error and in amplitude of transverse trajectory wander δx. Variation of λ_w is observed, and variation of both Bw and λ_w are reasons of gain degradation. If the distribution of errors of Bw, λ_w is rearranged, the deviation of relative phase of electrons in ponderomotive potential can be reduced and loss of gain can be reduced. Here we emphasize the practicality of adjustment of $\delta\psi$, and we will try it in our next step of adjustment of our undulator.

6. REFERENCES

[1] M.Youwu, et al., "Hybrid Undulator Design and Field Error Analysis, Proc. of 2nd EPAC, 1990, France, Vol 2, P1377

[2] Wu Bing, et al., "Optimization of Magnets in an Hybrid Undulator", Young Men's First Professional Conference of China Laser Science and Technology. 1991, YanTai, China(in Chinese)

[3] Varfolomeev, et al., "Large-field-strength Short-period Undulator Design". Proc. of 13th International Free Electron Laser Conference, Santa Fe, NM, USA, 1991, P813

[4] S.C.Gottschalk, et al., "Wiggler Error Re duction Through Shim Tuning", Nucl. Instr. & Meth. A296(1990), P579

[5] Wu Bing, et al., "Field Error Analysis During Adjustment of a Hybrid Undulator". Proc. of 5th Particle Accelerator Confer ence of China, 1992, Beijing, China(in chi nese)

[6] Liu Bo, et al., "A Magnetic Fields Measure ment System for Undulator". to be pub lished in China Nuclear Science & Tech nology Re port.

[7] E.Esarey, et al., "The Effects of Wiggler Errors on Free Electron Laser Performan ce", Nucl.Instr. & Meth., A 296(1990), P423

[8] C.J.Elliott, et al., "Detrapping from Magnet ic Field Errors as a Random Walk Escape", Proc. of 14th International Free Electron Laser Conference, Kobe, Japan, 1992

[9] L.H.Yu, et al., "Reduction of FEL Gain Due to Wiggler Errors", Proc. of 13th Interna tional Free Electron Laser Conference, Santa Fe, NM, USA, 1991, P500

[10] Charles.A.Brau, "Free-Electron Lasers", Academic Press, 1990, P105