DESIGN AND TUNING OF NSRL UNDU1ATOR UD-1*

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Abstract

The design, construction, and tuning of the first undu1ator UD-1 in NSRL are described. The magnetic field design and requirement are given. The results of the magnet blocks measurement and the magnetic field tuning by interchanging magnet blocks are presented

One important content of phase II project of Hefei Light Source (HLS) is build a new Undulator (UD-1) [1,2], which is the first undulator for HLS. UD-1 is designed according to the requirement of the atomic and molecular science users. The wavelength range and light flux (at sample) demanded by users are 160～30*nm*, 10^{11} Ph./(sec*0.1%BW) and 70～10*nm*，10^{9}Ph./(sec*0.1% BW) for molecular experiment and atomic experiment respectively. The new undulator is installed in one of the four straight sections of NSRL storage ring. The straight section length is 3.36meter, where available length is 2.75meter. The parameters of UD-1 are list in the Table 1. The corresponding light source parameters are given in Table 2. Considering transport efficiency of beam line，the designed Flux is about 10^{3} higher than required at the sample.

Table 1: Parameters of UD-1

Type	PPM
Periods λ_u (*cm*)	9.2
Number of Periods *N*	29
Gap rang (*mm*)	36～96, (maximum140)
Peak field B_u(T)	0.456～0.06
K	3.9～0.5
L (*cm*)	267

Table 2: UD-1 light source（E=0.8GeV, I=300mA）

wavelength (*nm*)	162-21(fundamental)	54-10 (third)
photon energy (eV)	7.6-58	23-124
maximum photon Flux (Ph./s.0.1%BW)	$1.19*10^{15}$	
maximum brilliance (Ph./s.mm^2 $mrad^2$ .0.1%BW)	$7.85*10^{15}$	

REQUIREMENT FOR MAGNETIC FIELD

The magnetic field must satisfy the requirements of both the users and the machine, the aim is to obtain the radiation spectrum as ideal as possible, and to minimize the disturbing effect of the device on the electron beam.

Demanding the angular deflection ΔX' and the orbital transverse displacement ΔX of the electron beam after passing the undulator to be smaller than the *rms* angular spread $\sigma_{x'}$ and the radius σ_x of the electron beam, gives the requirement for the first and second integral of the magnetic field. Demanding bandwidth of the radiation due to angular spread to be smaller than the natural bandwidth, i.e. has $\Delta x' < \sqrt{\lambda_s / L}$, gives the requirement for the field first integral

$$I(Gs.m) < 17\sqrt{(1+\frac{K^2}{2})\frac{1}{2N}} \quad (1)$$

For *K*=0.5，it has I≤2.37G**m*.

We require the first integrals of the magnetic field I< 2Gs**m*, and the second integrals II<2Gs*m^2, correspond ΔX'<0.075*mrad*, ΔX<0.075*mm* respectively, (while $\sigma_{x'}$=0.0766*mrad*, σ_x=1.65*mm*), and the corresponding closed orbit distortion X_{cmax} < 0.84*mm*.

Peak field error, also from bandwidth requirements, it gives

$$\frac{\Delta B}{B} < (\frac{1}{2} + \frac{2}{K^2})\frac{1}{nN} \quad (2)$$

For *n*=3 gives ΔB/B< 0.6%~5%.

Phase error is more meaningful scale parameter than Peak field. The reduction factor of spontaneous radiation is $R_n \cong e^{-n^2\sigma_\phi^2}$ [3,4]. For phase error σ_φ=10°, we have R_3=0.76.

TECHNICAL DESIGN

The pure permanent magnet (PPM) type with Halbach configuration was chosen, that every period have 4 magnet blocks with square cross-section to give free choice of block location within the arrays.

The material of pure permanent magnet block we chose NeFeB, NNF35SH. The specifications are B_r=12.1KGs, H_{cb}=11.4KOe, H_{cj}≥20KOe, and $(BH)_m$=35MGOe. The tolerance of magnet blocks are： the *rms* magnetization intensity (M_y) error：σ < 1%; the magnetization direction error： $M_{x,z}$ / M_y ≤1°; The magnet pole width we taken is 100*mm*，the transverse good-field (|ΔB/B| ≤ 0.5%) region is |Δx| ≤ 5.2*mm* and 9*mm* for g=96*mm* and 36*mm* respectively [5].

For field tuning, the local magnet gap can be slightly adjusted by individually adjusting the height of the magnet block with its holder on the baseplate, the magnet blocks with their holder can be interchanged with each other; and self's orientation in X direction of each magnet block with the holder can also be turn around.

The magnet gap can be varied from minimum 36*mm* to maximum 140*mm*，while the working range is 36~96 *mm*, the maximum magnetic force is 1.34T. The tripe safeguards are set: the software stops, the limit switches and the hard stops.

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Table3: The main mechanic requirement

	Specification	As-build
two direct tracks parallelism (*mm*)	<0.02	<0.01
two glide beam parallelism		
longitudinal (*mm*)	<0.06	<0.05
transverse (*mm*)	<0.02	<0.08
two glide beam moving symmetry		
lengthways (*mm*)	< 0.03	< 0.005
transverse (*mm*)	< 0.01	< 0.01
reproducibility (*mm*)	< 0.015	< 0.01

MAGNET BLOCKS MEASUREMENT

Total of 234 standard magnet blocks are required, about one and half times blocks are prepared for selection. The strength and angle of magnetization are measured for every one individual magnet block [6].

The points measurement method using a Hall plate probe system is adopted. The magnetic fields at a number of points around the magnet block are measured. The positions of the measurement points are chosen carefully: to reduce the effect of systematic errors the field component to be measured should be sufficient strong; at the same time to reduce the effect of the locating error the field gradient variation should be as small as possible and the distance from the magnet block should not be too small. Therefore the peak positions are chosen for the field component to be measured, and some symmetrical points are chosen to cancel the contribution of the other field components and remove the potential systematic errors. In measurement of a certain component of magnetization, we change the magnet block setting instead of the position of Hall Probe.

For magnet blocks measurement a measurement stand with a aluminium support bracket, copper platform and jig is specially designed and made; and also a locating magnetic pin is specially designed and made to locate the coordinate of the center of Hall probe sensitive area.

The strength distributions are given for the three magnetization components of the permanent magnet blocks respectively. The measured results shows: the average magnetization intensity (M_y) is 1.21T, the *rms* relative error is 0.7%; and the magnetization direction error (*rms*) is 0.47 °and 0.126 ° for M_z / M_y and M_x / M_y respectively.

MAGNET BLOCKS BONDING & SORTING

Each magnet block is fixed (glue and mechanical clamp) into an individual aluminium holder, which is then assembled onto a baseplate. The Glue we choose LOCTITE Company Product 324. To solve adhesive strength problem, the bonding procedure must be strictly executed. (e.g. the face treat including cleaning, sandblast and anodise.) Meantime the rigidity of the holder was found inadequate, the design was modified and the holders were remachined. After several times bonding test experiments, at last the pull test result reach 20KN/23cm^2. The mechanical clamp use stainless steel depressor, which were annealing treated to decrease the permeability.

The magnet blocks are sorted by Simulated Annealing technique. A large discrepancy between measured results and calculated is found, the causes are: the mechanical errors (blocks dimension error, fabrication and assembling error) were not included; and that the glue layer is non-uniform were not considered.

MAGNET FIELD MEASURING & TUNING

The undulator magnet field is measured point-by-point by Hall probe scanning. Using the measurement system in existence in our Lab.: Gauss meter is Group3-151-DG, the Hall Probe is MPT-141, its sensitive area is 1×0.5mm^2.

The magnet field at gap = 36, 70, 96*mm* are measured. For g=36*mm*, the step Δz=0.5*mm*, the scan speed is 1.1*mm*/s; For other gaps the step Δz=1*mm*, and the scan speed is 2.4*mm*/s. The scan length is 3150*mm* with position precision 0.01*mm*.

The uncertainty in the zero-field offset has large effect on the value of field integrals [7]. Care must be taken to accurately calibrate the Hall plate and keep the environment of measurement stable.

We performed the magnet field fine tuning by interchanging magnet blocks and no shimming, basing on aborative analysis of the measurements results. A special appliance is designed and made for interchanging magnet blocks. In the whole process of field tuning near 1/4 magnet blocks of all were exchanged, among them five blocks are found being mistakenly glued.

The measured peak field error and the phase error are given in table 4, in which N_p is the number of magnet poles. The phase error is about 3°, the best case is smaller than 2°, that much better than expected and will extends application area. The higher harmonic can be used , e.g. for the fifth harmonic, the shortest wavelength is 4.*nm*, already enter the "water window", the flux is two order higher than bending magnet, is very useful to the related experiments.

Table 4: Peak field error and Phase error

Gap (*mm*)	K	σ_B/B(%) (N_P)	σ_B/B(%) (N_P-2)	σ_φ(degree) (N_P)	σ_φ(degree) (N_P-2)	σ_φ(degree) (N_P-4)	σ_φ(degree) (N_P-6)
36	4.18	0.64	0.37	3.92	3.73	3.46	3.39
70	1.277	2.45	0.55	4.70	3.65	2.81	2.67
96	0.513	5.43	1.24	2.69	2.47	1.77	1.67

The integral of field are given in table 5. For horizontal magnet field B_x measurement, owing to the undulator locating direction difference between measurement position and install position is 110°, the effect of geomagnetism field must be considered. Measured geomagnetism field background modify factor is ΔB_X =(-0.25)-0.30=-0.55Gs, the values in the brackets of table 5 are modified results.

Table 5: the Field Integral

Gap (*mm*)	I_y (Gs**m*)	II_y (Gs*m^2)	I_x (Gs**m*)	II_x (Gs*m^2)
36	0.73	0.43	0.06(-1.67)	2.43(-0.30)
70	0.09	-0.31	0.99(-0.74)	2.63 (-0.10)
96	-0.23	-0.88	1.02(-0.72)	2.12 (-0.61)
140	-0.69	-1.38	0.90(-0.83)	1.51 (-1.21)

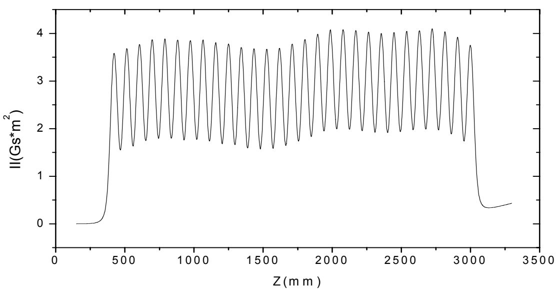

Figure 1: the second integral as function of Z at minimum gap.

The integrated multipoles were measured at y=0, x= 0,±5, ±10,±15,±20,±25 *mm* for normal, and at y=0, x= 0,±5, ±10,±15,±20 *mm* for skew. As reference the skew integrated multipoles were also measured at x=0, y=0,±5*mm* (the data in the brackets of table 6), it can be seen that the two methods agree well.

Table 6: integrated multipoles

Gap (*mm*)	36	70	96
Quadrupole,normal (Gs)	47	0.8	11.5
Sextupole,normal (Gs/*cm*)	16	-7	-3
Octupole,normal (Gs/cm^2)	20	5.7	0.93
Quadrupole, skew (Gs)	106.4 (113.6)	78 (74)	58.4 (50.5)
Sextupole, skew (Gs/*cm*)	3.86	4.96	-3.37

For the quadrupole component, the maximum equivalent focusing parameter dk =6.58*10^{-4} m^{-2}, is much smaller than the undulator inherent focusing parameter dk_0=0.0168m^{-2}. The maximum sextupole parameter $\lambda=b_2/L_u$=0.05T/m^2, is much smaller than the parameter of sextupole magnet on the storage ring λ=150.T/m^2.

The normal and skew first integrals variations with x are shown in Fig.2 and Fig.3.

On line measurement: the maximum closed orbit distortion $X_{cmax} \le 0.25$ *mm*; the measured photon flux at the experiment station with 100*m*A beam current are lager than 10^{12} (phs/sec.0.02%BW).

The things to be improved are: the magnet field measurement system should be faster and more accurate; heighten precision of machining and fabrication, that will help optimisations process programmed.

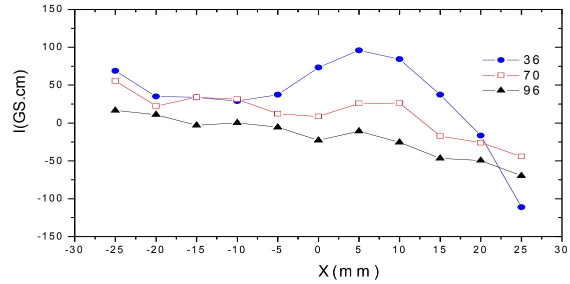

Figure 2: Normal first integrals variations with x.

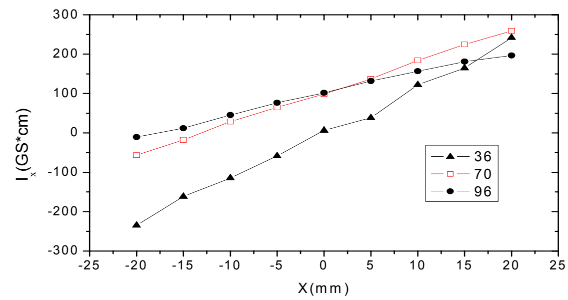

Figure 3: Skew first integrals variations with x.

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