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UNDULATOR AND WIGGLER OF UVSOR

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Abstract

A 600 MeV electron storage ring whose nickname is UVSOR (Ultra Violet Synchrotron Orbital Radiation) was constructed at Institute for Molecular Science to be a synchrotron radiation source for the research of molecular science and its related fields. New light sources, a permanent magnet undulator and a wiggler were installed in the ring. The undulator has 35 periods and its maximum magnetic field is 0.3 T . The maximum magnetic field of the wiggler is 4 T. Electron beam could be injected and stored in the ring when these devices were excited with the maximum magnetic fields, individually. Results of the measurement of the magnetic field distributions of them, and tune shifts and closed orbit distortions due to them are presented.

Undulator

Intention

Quasi-monochromatic light is gained with an electron passing through a periodic magnetic field, when the velocity of the electron is close to the light velocity. If this light is able to be used for some aims without some diffraction elements, the undulator light can be made use of the large brightness. An undulator was setteled in UVSOR storage ring and the wavelength of the fundamental harmonic light was selected to be a few hundred Å.

Selection of the Parameters

The vertical inner size of the beam duct at the undulator was decided to be 20 mm because the beam size in the ring. Since the horizontal size of the electron beam is larger at the injection, aperture of the duct in this direction can not be smaller than those of the other ducts. Following these reasons the undulator was decided to be planner type and the narrowest gap width is 27 mm.

Strength of the remanent field of a permanent magnet made by $SmCo_5$ is usually 8500 - 9000 gauss and the strength decreases in time. Supressing the change of the magnetic field, the magnetized $SmCo_5$ blocks were demagnetized with the thermal decreasing process. With the process the decreassing rate of the strength is reported to be 0.7 %/year.

One period of the closed magnetic circuit is composed with 8 blocks, and the magnetized directions of these blocks are different as 90°. The length of the period was chosen to be 60 mm because the wavelength of the fundamental harmonic decided as 400 - 500 Å. The blocks were fastened to holders made by aluminum with glue and the accuracy of the holders are $15^{-0.02}_{-0.05}$ mm for keeping the accuracy of the periods. Following this reason, the size of the blocks in the longitudinal direction were made to be $14.9^{+0}_{-0.03}$mm. In order to suppress the growth of the manufacturing error with arrangement of a lot of the blocks, the length between one end of the undulator bed and some blocks were measured per a few period and each block was fastened to the bed. The allowance of the beds as the gap width is less than 5/100 mm as a whole. The upper bed and the lower of the undulator are supported in one side with two ball-screws and two ball-ways, and the pitches of the upper half and the lower of the ball-screws are wound in the opposite directions. Then the both beds are moved at the same time and the same gap against the center plane of the undulator, and the total gap width will be selected between 27 mm and 80 mm. The undulator light can be utilized with the fundamental harmonic of the wavelength between 580 Å ~ 240 Å. When the electron is accelerated upto the maximum energy of 750 MeV, the wavelength of the light is down to 150 Å.

As following the parameters of the undulator as described before, the brightness of the undulator light is shown in Fig. 1 against the harmonics where

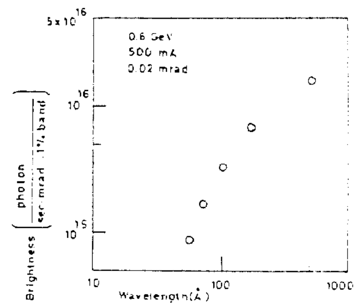

Fig. 1 Brightness of an Undulator.

the gap is 27 mm. The brightness of the second harmonics is expected to be less 7/16 than that of the fundamental as shown in Fig. 1. And the spreads of the peak spectra at some harmonics are related to the number of the periods N as

$$\frac{\Delta\lambda}{\lambda} \simeq \frac{1}{nN} \qquad (1)$$

(n : harmonic number),

the spectral width of the fundamental peak is expected to be 3 %.

The undulator is constructed following the parameters as described before, and the side view is shown as Fig. 2. In this figure the half blocks of the

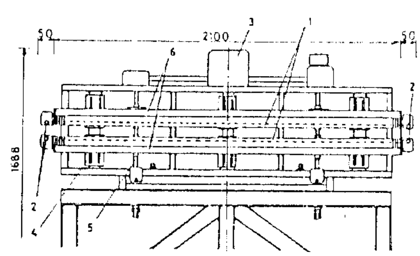

Fig. 2 Sideview of the Undulator. 1) array of the permanent magnets, 2) correction magnets, 3) driving motor of the total gap, 4) ball-way, 5) ball-screw and 6) beds.

permanent magnets are arranged for the auxiliary field and the rotatable permanent magnets for the field correction are settled on both ends of the upstream and downstream of the undulator. The magnetized direction of the correction magnets is perpendicular of the rotating axis and the vertical magnetic strength will be selected by rotating the magnet with driving motor.

Measurement of the Undulator Field

Method

To supress the effect of the insertion of the undulator into the ring to the electron beam, the

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integral value of the magnetic field along the longitudinal direction has to be adjusted to be negligibly small. The strength of the remanent field of permanent magnet made by $SmCo_5$ has usually a fluctuation as about ± 3 %. This fluctuation was achieved to be less than ± 1 %, exchanging the stronger blocks with the weaker ones after arrangement and measurement of the undulator field. For this aim a measuring equipment was designed and manufactured, which uses a hall probe as the sensor of the magnetic field. This hall probe was installed at an end of a pipe of 40 cm length and 8 mm ϕ and its angle of the probe to the field was adjusted to take the maximum output at a maximum field. The stage which holds the other end of the pipe is moved in 3 directions with 3 motors independently and the movement is controlled with a microcomputer. The 3-positions are read out with magnescales respectively. Especially in longitudinal direction, in order to achieve the measurement at a high speed and prevent the pipe from shaking the movement is continuously carried out by the servo-motor. The speed with operation was 4 mm/sec and the field measurement was carried out at each 1 mm. The output of the hall probe was transformed by an A/D converter with 5 msec/1 datum. And these data were stored to FD by the computor.

Result of Measurement

As shown in Fig. 3 all values of the peak fields

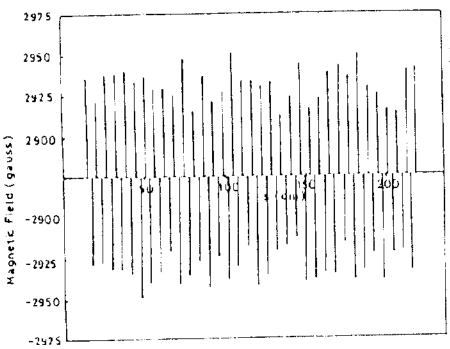

Fig. 3 Vertical Magnetic Distribution of the Undulator.

were fallen in ± 0.7 % of the peak values after the re-arrangement of the blocks. The field distributions along the vertical direction were measured as shown in Fig. 4 and the midplane which was established

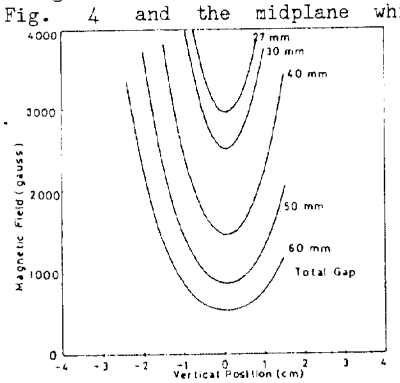

Fig. 4 Vertical Magnetic Field.

mechanically for the field measurement is agreed with that of the field.

The spread of the peak spectrum of the undulator light due to the fluctuation of the magnetic field can be derived by the equation,

$$\lambda = \frac{\lambda_0}{2\gamma^2}\left(1+\frac{K^2}{2}\right) \quad (2)$$

to

$$\frac{\Delta\lambda}{\lambda} = \frac{K\,\Delta K}{1+\frac{K^2}{2}} \quad (3)$$

where $K = 0.09337\, B_0\, \lambda_0$

$\Delta K = 0.0118$

$\lambda = 577$ Å .

This value is gained as 8×10^{-3}, and this is enoughly small compared with the value estimated with the number of the periods.

Influence on the Beam

The orbit of the beam gravity was measured by the position monitor system and as the result the beam was forced to change the angle of 0.22×10^{-3} rad at the undulator when the integral of the field was about 100 gauss·cm. This value has been achieved to be less than 50 gauss·cm. The closed orbit distortion due to the undulator is expected to be corrected and the experiment with the undulator light can be utilized at the same time with some experiments using the normal synchrotron radiation.

Superconducting Wiggler

Intention

An wiggler was planned to insert into the ring as a source of the light of the wavelength from 2 Å to 3 Å. For this region the maximum wiggler field is necessary to 40 kG at the electron energy of 600 MeV and the magnets were made with superconducting magnetic coils.

Outline of the Coils

The space for the wiggler was permitted to be 700 mm as the total length. In this length the 3 coil sets are arranged and the main field is excited upto 40 kG, and the electron orbit is distorted about 10 mm in the radial direction. Designing the wiggler field, the field distribution in the radial direction are expected to be flat around the center. Due to the limitation of the length, the shape of the coils was chosen to be racetrack which has long axis in the radial direction. The arrangement and the areas of the cross sections of the main and auxiliary coils was calculated using "TRIM" and "POLBOB"[2], and these parameters were adjusted the integral of the vertical field along the s-direction to be zero. The vertical field distribution along the center axis calculated by "POLBOB" is shown as Fig. 5. The inner size and outer

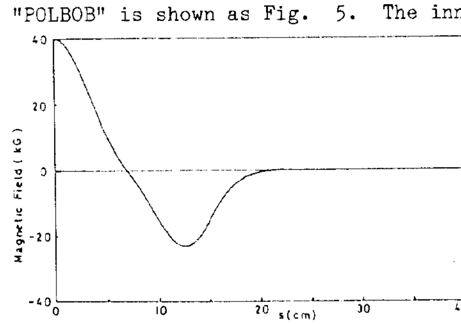

Fig. 5 Vertical Magnetic Field of the Wiggler.

size of the main coil are 30 mm W x 110 mm L x 55.8 mm H and 118.4 mm W x 198.4 mm L x 55.8 mm H. Those of the auxiliary coil are 30 mm W x 136 mm L x 40.8 mm H and 97.4 mm W x 203.4 mm L x 40.8 mm H. These coils were tightly inserted with some impregnant into the outer frames by shrinkage fit method in order to prevent the coils from shaking at the excitation.

Cryostat

The beam duct is surrounded with vacuum heat insulation layer and at the outer side the vessel of liquid helium is arranged. The coils are installed in and located to the vessel. The coils are come into direct contact with the liquid helium and cooled to the superconducting temperature. The beam duct has routes at both sides and is cooled by liquid nitrogen through the routes. The duct is located by some arrowlike insulators to the wall of the helium vessel to be placed at the midplane of the magnets. The vessel is surrounded by vacuum insulation layer and a heat shield wall taken the thermal anchor of liquid nitrogen. The helium and nitrogen vessels have the large vessels at the upper side of the magnets, respectively.

When the duct is baked, liquid nitrogen is poured into the helium vessel to protect the magnets from baking heat and evaporated nitrogen is collected. The nitrogen gas is heated upto about 200°C and passed through the rout of the duct, and the temperature is upto 150°C.

Operation

Operating Method

Before exciting the wiggler field, the coils have to be cooled to the superconducting temperature. After pre-cooling the coils by liquid nigtrogen, liquid helium is poured into the vessel for about 6 hours and the coils are begun to be cooled by the helium until the temperature, and liquid helium is stored in the vessel. The wiggler has not like a liquefing system of helium gas and nitrogen gas, these liquefied gases for cooling the coils are supplied with movable containers, respectively. The remainder of the liquid nitrogen is monitored by a level meter which is settled in the receptacle and supplied from the container to the level automatically. The necessary volume of the liquid helium for one day is supplied into the vessel at one time before the operation.

At the first stage of the wiggler excitation, the main field is excited upto 30 kG and the auxiliary coils are excited upto the values corresponding to the main field. At this excitation the electron beam is easily injected and stored in the ring. After the injection and storage the field is gradually excited upto some value keeping the position of the electron beam.

Consumption of the Liquid Helium

As described before, liquid helium of less than 100 l is consumed for the pre-cool of the magnets and it is necessary for about 6 hours that the volume of the helium is poured into the vessel. The consumption is 3 l/hour on the average and the volume for one day is about 70 l. This transferring time is 30 min. The level in the vessel and evapolation of the liquid helium are constantly monitored to know the remainder.

The quench of the coils has happened only one time until today and at the time the consumption of the helium increased to be larger a few times than that of the normal operation.

Measurement of the Wiggler Field

For measuring the exciting wiggler field, the vacuum duct which has hollowness for inserting the probe in the atomosphere was made. The distribution of the wiggler field along the radial direction was measured as shown in Fig. 6 and the integral values at some values of r are shown in Fig. 7. As following Fig. 6 the flatness of the field at the center and 10 mm apart from the center is estimated as 0.4 %. This value is caused by the limit for utilizing the space for the wiggler and the integral values in Fig. 7 is varing at every r values. The beam orbit is disturbed with the excitation.

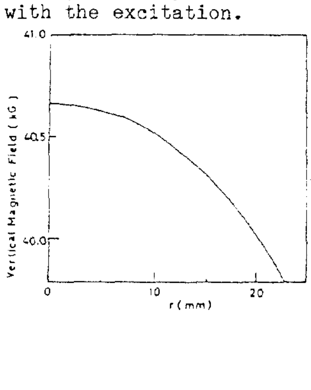

Fig. 6 Vertical Magnetic Field along the Radial Direction.

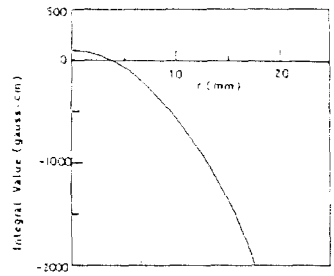

Fig. 7 Integral of Magnetic Field.

Influence on the Beam

As described before Q-value is varing with the exciting the wiggler and the rate ΔQ_x and ΔQ_z of the variations was measured as -0.04 and +0.01. These values is related with the k-value of the quadrupole magnet as

$$\Delta Q = \frac{1}{4\pi}\beta k l \qquad (4)$$

and the beta functions β_x and β_z is used for the values of the ring as 10.6 m and 3.0 m. The values of $|kl|$ is gained as 0.047 (1/m) and 0.042 (1/m), respectively. This value can be corrected and one normal conducting quadrupole magnet was settled at the downstream in the ring. The parameters of the magnet are $B\rho$ = 0.909 T x 2.2 m r_0 = 0.047 m, l_Q = 0.15 m and N = 297 turn and using these values the current for the correction per 10 kG excitation is estimated as about 2 A. And this value is good agreed with the experiment as shown in Fig. 8.

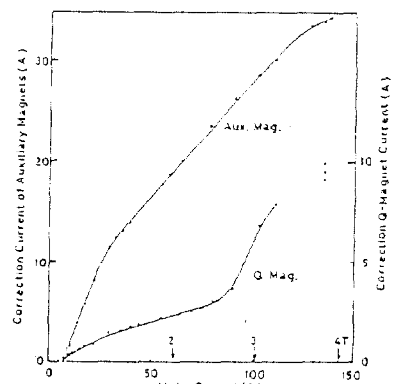

Fig. 8 Correction of the Wiggler Field.

The electron beam is injected and stored at the 30 kG excitation and the wiggler is excited upto 38 kG. At this time the orbit amplitude of the beam gravity is larger than that without the operation. This distortion is expected to be improved by COD-correction with the trim coils settled on the bending magnets. And the injection and storage of the beam at the maximum field is hoped after these corrections.

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The programs of "POLBOB" and "TRIM" were carried out with the computer of the computer center at IMS.

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