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CALCULATION OF THE HEAT LOAD ON DOUBLE MINI-BETA Y UNDULATORS

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Abstract

Two collinear in vacuum undulators (IU22) are adopted for the light source of the coherent X-ray beamline in Taiwan Photon Source. Each undulator has length 3 m and the drift space between the two undulators is 3.991 m. The synchrotron radiation propagates in a longitudinal direction and results in a serious heat load problem for an undulator downstream. The magnet array of an undulator downstream receives synchrotron radiation of power 142 W from an upstream bending magnet and undulator. This heat load is a critical challenge for an in vacuum undulator in a double mini-β Y lattice and this paper therefore presents a detailed analysis.

INTRODUCTION

In Taiwan Photon Source, a 3-GeV synchrotron light source in Taiwan, a decision was taken to equip with two collinear undulators in vacuum in a long straight section to enhance energetic X-rays. The double mini-β Y lattice is therefore designed to operate the undulator with a small gap. [1] Table 1 lists the parameters for the TPS double mini-β Y long straight section.

Table 1: Parameters for the TPS Double mini-β Y Lattice

	DMBY lattice
Beam energy	3 GeV
Beam Current	500 mA
Emittance	1.6 nmrad
Energy spread	8.4 10^{-04}
β Y	1.788 m
β X	10.447 m
Coupling factor	1 %

An in vacuum undulator is designed to have no vacuum chamber between the magnet arrays, and allows optimal minimization of the gap to achieve continuous energy spectra. A long undulator with a small gap cannot operate in a long straight section because of a decreased life time of electron beam. A double mini-β Y arrangement yields a benefit of using segmented undulators with a small gap.

Table 2: Parameters of TPS in Vacuum Undulator

	IU22x2
Period length	22 mm
Allowed minimal gap	5 mm
Maximum K_y	2.07
Magnet length	3.124 m
Number of periods	142
Number of segments	2
Interval D	7.115 m

Two identical in vacuum undulators will be installed in a minimum vertical β function location. As a double mini-β Y lattice is designed, the minimum undulator gap can operate at 5 mm. The parameters of undulators used in Taiwan Photon Source are listed in table 2. Two undulators must operate at the same undulator gap to enhance the photon source. The distance between the centres of the two undulators is 7.115 m.

HEAT FROM SYNCHROTRON RADIATION

Heat from synchrotron radiation in general depends on only an upstream bending magnet. If an undulator is perfectly aligned, the radiant power from a bending magnet striking a magnet array is generally small.[2] In a double-undulator system, the undulator downstream receives radiation from not only the bending magnet but also the undulator upstream. With increasing distance from an undulator source upstream, greater radiant power irradiates a magnet array in an undulator downstream. The minimum gap 5 mm of the undulator is discussed here to evaluate the scenario of the maximum heat load.

Radiation from a Bending Magnet

Synchrotron radiation from a bending magnet (BM) is a source of heat for a magnet array in an in vacuum undulator. The linear power density from a bending magnet is expressible as

$$\frac{\mathrm{dP_{DB}}(\psi)}{d\psi} = 5.420E^4BI\frac{1}{(1+\gamma^2\psi^2)^{5/2}}\left[1+\frac{5}{7}\frac{\gamma^2\psi^2}{(1+\gamma^2\psi^2)}\right] \quad (1)$$

Radiation from a bending magnet is emitted in a direction tangent to the beam orbit ,so in a transverse direction only half the magnet foil can be irradiated. A horizontal absorber is typically situated to prevent synchrotron radiation from striking the side wall of the vacuum flange, and most synchrotron radiation upstream becomes intercepted by the absorber. Only a certain horizontal angle of the radiation from the bending magnet passes the absorber and irradiates a magnet array. In the TPS double-undulator system, the horizontal angles allowed for radiation from the passed bending magnet are 7.36 and 2.75 mrad for IU1 and IU2 respectively.

The radiant power on a magnet array and a magnet head is calculated in equations 2 and 3, respectively. The power is integrated over a range of vertical angle. Figure 1 illustrates that IU1 receives a large angular range of BM radiation at large vertical angles relative to IU2, but IU2 receives more radiant power because of high energy in the centre of radiation.

$$P_{B\,Foil} = \left(\int_0^{\psi_2}\frac{\mathrm{dP_{DB}}(\psi)}{d\psi}d\psi - \int_0^{\psi_1}\frac{\mathrm{dP_{DB}}(\psi)}{d\psi}d\psi\right)\theta \quad (2)$$

$$P_{B\,Head} = \left(\int_0^{\infty} \frac{dP_{DB}(\psi)}{d\psi} d\psi - \int_0^{\psi_1} \frac{dP_{DB}(\psi)}{d\psi} d\psi\right)\theta \quad (3)$$

in which θ is the opening angle between the beam axis and the point of interest.

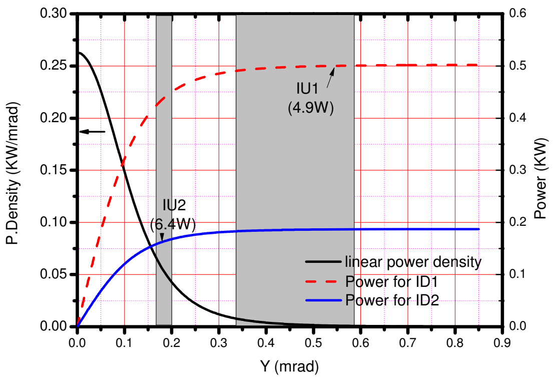

Figure 1: Radiant power density from a bending magnet.

Undulator Radiation

The undulator radiation has a small opening angle, and the central core of radiation has greater photon energy and power density. In a double-undulator system, an undulator downstream might be separate a large distance. With increasing distance from a source of undulator radiation upstream, greater energetic radiation from an undulator upstream irradiates a magnet array in an undulator downstream. To evaluate the irradiated power on a magnet array undulator downstream, we first calculate the angular power density from an undulator upstream in both transverse and vertical directions. Figure 2 shows the angular power density from IU1 in transverse and vertical angles.

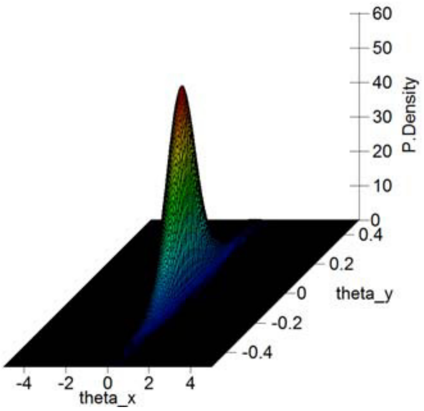

Figure 2: Power density from IU1 (calculated with SPECTRA 9.0 [3]).

The vertical linear power density is calculated from an integration of angular power density over the transverse direction and is expressed in equation 4.

$$\frac{dP_{DU}(\psi)}{d\psi} = 2\int_0^{\infty} \frac{dP_{AU}(\theta,\psi)}{d\theta d\psi} d\theta \quad (4)$$

Figure 3 shows that the vertical power density varies with vertical angle. Radiation in a particular range of angle striking the magnet array can be calculated in equation 5. The integrated power at a particular angle can also be seen in figure 4. The grey area indicates the angles at which the magnet array is struck.

$$P_U = \left(2\int_0^{\psi_2} \frac{dP_{DU}(\psi)}{d\psi} d\psi - 2\int_0^{\psi_1} \frac{dP_{DU}(\psi)}{d\psi} d\psi\right)/2 \quad (5)$$

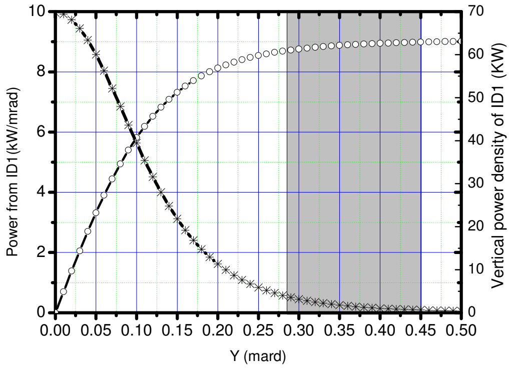

Figure 3: Radiant power density from IU1.

HEAT POWER ON A MAGNET ARRAY

The heat load of synchrotron radiation on a TPS double undulator is evaluated at gaps 5 and 7 mm with equations (2), (3) and (5), and is presented in table 3. When the gap is closed at 5 mm, the heat load on the magnet foil and the magnet head increases greatly. A total heat load as power 142 W on the magnet array in an undulator downstream is expected; details appear in Fig. 4.

Table 3: Radiation Heat Power on TPS Double Undulators

Location	**Gap 5 mm**	**Gap 7 mm**
BM @ IU1 magnet foil	4.9 W	1.6 W
BM @ IU1 magnet head	0.84 W	0.13 W
BM @ IU2 magnet foil	6.4 W	3.0 W
BM @IU2 magnet head	5.5 W	2.3 W
SR IU1 @ magnet foil	135 W	23.9 W
SR IU1 @ magnet head	41.3 W	7.2 W

If we consider the error of magnet block manufacture and assembly, the error is about 20 µm. The local slope on one undulator period (22 mm) is about 2mrad on the magnet foil. The radiation angle from IU1 irradiated on the magnet array is 0.29~0.45 mrad. At these local slope positions, the SR heating increases 4.5~7 times, which further downstream in IU2 has a greater impact from the IU1 radiation. The angular power density is distributed in a narrow transverse angle and is shown in Fig. 2. If the foil becomes fused by the radiation from an undulator upstream, a narrow and thin fused area in the center of magnet foil is expected.

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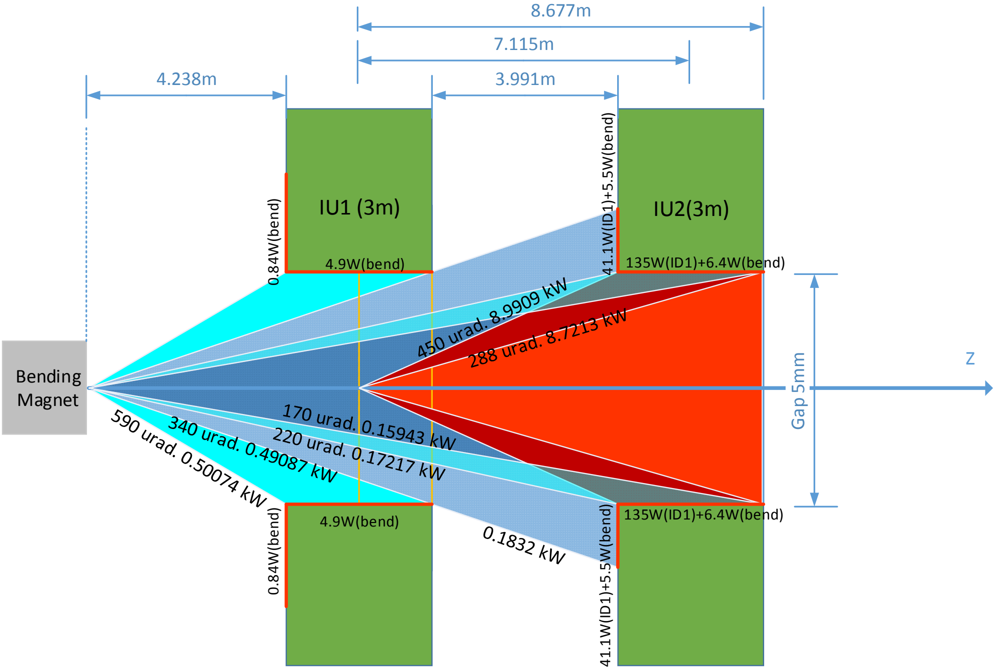

Figure 4: Radiant heating of a magnet array in TPS double undulators (gap 5mm).

UNDULATOR MISALIGNMENT

The radiation position or direction depends on only the position or direction of the electron beam in the undulator. If two undulators are misaligned, radiation from the undulator upstream heats the magnet array more near the electron beam. We consider the misalignment of maximum ± 1 mm between two undulators. At undulator gap 5 mm, if the misalignment of the electron beam between two undulators is 1 mm, the magnet array near the electron beam receives 430 W (325 % of the perfectly aligned case). At gap 7 mm, the misalignment of two undulators in 1 mm has maximum radiation power 67 W (282 % of the perfectly aligned case). The radiant power on a magnet array is strongly affected by the accuracy of alignment between two undulators, as shown in Fig. 5.

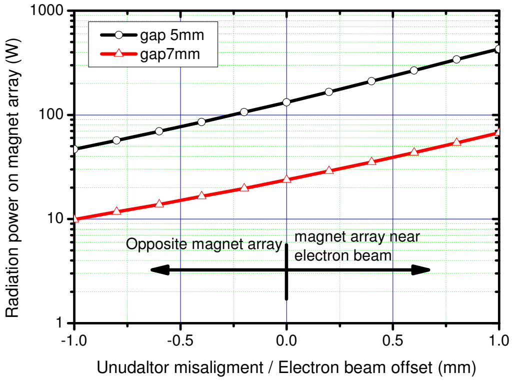

Figure 5: Radiant power from IU1 due to misalignment.

SUMMARY

The large radiant power from a bending magnet and an undulator upstream irradiating a magnet array of an undulator downstream results in a fused magnet foil. A vertical absorber can hence avoid the radiation from the bending and the undulator as well as the mis-directed heating on the foil. The design of a vertical photon absorber for an undulator downstream is continuing. Taking into account the life time of the beam, the minimum gap of an undulator should open to 7 mm and allow a vertical photon absorber of minimum gap 5 mm.

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