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BEAM DYNAMIC EFFECT OF MULTI-PERIOD ROBINSON WIGGLER IN TAIWAN PHOTON SOURCE

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Abstract

Robinson wiggler is a special insertion device that can be used to decrease natural emittance of the Taiwan Photon Source (TPS) storage ring. This Robinson wiggler can change damping partition number and then affect the emittance. This study will evaluate practicability of reducing the emittance of TPS storage ring by Multi-period Robinson Wiggler (MRW) in the 7 m long straight section. One period of the traditional Robinson Wiggler include four poles with different field polarity. In the same length, the multi-period Robinson Wiggler has been over four poles in one set of Robinson Wiggler that is different from the traditional Robinson wiggler. Due to the traditional Robinson wiggler cannot be effective to improve emittance in TPS storage ring (the efficiency is only 7% with 6 straight sections). So we adopt to use multi-period Robinson Wiggler, the efficiency can be up to 30% with 6 straight sections, and the linear matching result is better than traditional Robinson Wiggler.

INTRODUCTION

As the application of synchrotron accelerator light source has been mature, the requirement of high brilliance photon source for users become more and more important. So the most direct method is to reduce the effective beam size and divergence of the electron beam in the storage ring. The only way to reduce the effective beam size and divergence is to reduce the natural emittance and Bata function. Herein, the natural emittance depends on three main elements; (1) electron beam energy, (2) bending angle of dipole and (3) horizontal damping partition number. However, when the basic parameters of the storage ring magnet lattice are fixed, the only way to reduce the emittance is to increase the damping partition number. We can install the special insertion device such as Robinson Wiggler to increase the damping partition number and then it will reduce the emittance [1]. SOLEIL and HLS-II are also developing Robinson wiggler to improve emittance right now [2,3].

This paper will evaluate practicability of reducing the emittance of TPS storage ring by traditional and multi-pole Robinson wiggler, respectively. There are four poles in one set of the traditional Robinson Wiggler and each pole has combined with dipole and quadrupole field strength. The dipole field strength multiply quardupole field strength in each pole should be negative in the Robinson wiggler structure. In accordance with the conclusions of the study, we try to develop, design a Robinson wiggler to meet the low emittance requirement of the TPS storage ring. At the same time, we try to understand the impact for the entire TPS storage ring lattice, like as dispersion function and the dynamics aperture, when we use the Robinson wiggler in the 7 m long-straight section of the TPS storage ring. If we are able to effectively use Robinson wiggler, and thus provide higher brilliance photon source of the accelerator storage ring.

GENERAL DESIGN CONCEPT

The brilliance is a very important factor to judge the light source. So how to improve the brilliance become a hot issue in whole world. The equation of brilliance is as below:

$$B = \frac{flux}{4\pi^2 \sigma_x \sigma_y \sigma_x' \sigma_y'}$$

here the σ_x means horizontal electron beam size and is proportional to square root of emittance. The amplitude of Emittance is determined by equilibrium between quantum exciting and radiation damping. Horizontal emittance of non-achromat mode of TPS is 1.6nm-rad. The formula of horizontal emittance of storage ring is given by

$$\varepsilon_x = \frac{C_q \left\langle \mathrm{H}/|\rho|^3 \right\rangle}{J_x \left\langle 1/\rho^2 \right\rangle}$$

Here, ε_x is so-call horizontal emittance and, $C_q = \frac{55\hbar}{32\sqrt{3}mc} = 3.83 \times 10^{-13}$m, the electron relativistic factor $\gamma = 5871$ in 3GeV TPS storage ring, ρ is bending radius, H is H-function, J is damping partition number, the equation of damping partition number is shown as below:

$$J_x = 1 - D_p$$

$$D_p = \left(\oint \frac{D}{\rho}\left[2K(s) + \frac{1}{\rho^2}\right] ds\right)\left(\oint \frac{1}{\rho^2} ds\right)$$

where D_p is damping factor, D is dispersion function , ρ is bending angle, K is quadruple strength. If we increase damping partition number from former equation, then we can decrease emittance. In order to raise the horizontal damping partition number, we use quadruple magnetic field and the bending radius of electron of opposite sign to each other, then damping factor will become negative, so we adopt Robinson wiggler [4].

TRADITIONAL ROBINSON WIGGLER

A Robinson Wiggler is different from general ID. It's composed of four combined function magnet which has

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dipole and quadruple magnetic field, and the value of product of dipole and quadruple magnetic field is negative. A traditional Robinson wiggler (TRM) only has one period. In this session, we will discuss effect of traditional Robinson wiggler (TRM). To draw a sketch of its structure is shown in Fig. 1.

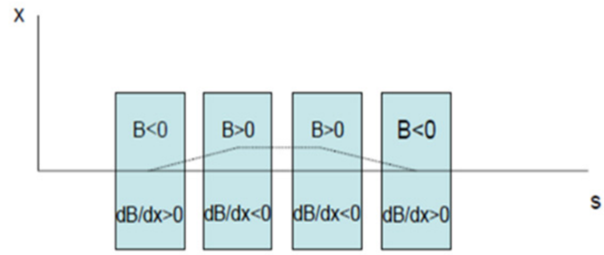

Figure1: There are four combined function magnet in one set of Robinson wiggler, the value of product of dipole and quadruple magnetic field in Robinson wiggler is negative ($\frac{dB}{dx} < 0$), it's used to change damping partition number to achieve the goal of decreasing horizontal emittance.

From simulation result, Robinson wiggler is installed at 7m long straight section of TPS. There are four combined magnets which length is 0.7 meters, bending angle 0.12 rad, quadruple field strength of 0.01 T/m . However, the matching results cannot effectively increase damping partition number on horizontal axis, so we try to install new quadruple magnets and increase the length of each pole of Robinson wiggler to 1m. The bending angle is 0.12 rad and quadruple field strength is 0.45 T/m. In order to make both sides of the Twiss parameter can be matched , we put three quadruple magnets between each pole of Robinson wiggler, two of them are 0.3 m and the other one is 0.6 m. Figure2 shows damping partition number increased to 1.08 , the beam emittance reduce to 1.46 nm-rad , the reduction ratio is about 8.4%.

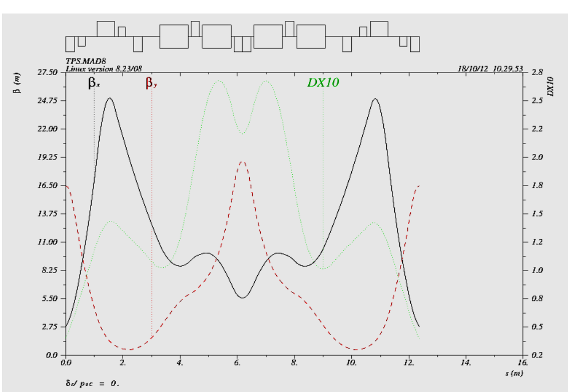

Figure 2: In order to improve damping partition number, we try to install three quadruples between each pole of Robinson wiggler. From matching result, the beam emittance reduce to 1.46 nm-rad , the reduction ratio is about 8.4%.

ESTIMATE THE AFFECT OF MULTI - PERIODS ROBINSON WIGGLER ON EMITTANCE

Here we consider two methods to roughly simulate the affect of Multi-periods Robinson wiggler on emittance. For the TPS case, Method 1 is use original formula of emittance as below:

$$\varepsilon_x = \frac{C_q \gamma^2 \langle H \rangle_{dipole}}{J_x \rho_x} = 1.6nm - rad$$

As the dipole and quadruple field or length of Robinson wiggler are verified, the damping partition number J_x will be changed too, and furthermore we can decrease emittance. In Method 2, we introduce the radiation integral formula to calculate the effect result. if we install IDs at the straight section of the ring, we can rewrite the formula of radiation integral as below:

$$I_2 = I_{20} + I_{2w},\ I_4 = I_{40} + I_{4w},\ I_5 = I_{50} + I_{5w}$$

where I_{20} , I_{30} , I_{50} are radiation integrals evaluated in bending dipoles, I_{2w} , I_{3w} , I_{5w} are radiation integrals evaluated in Roninson wiggler[5], so the equation of effective electron beam size can be written down as below

$$\frac{\varepsilon_x}{\varepsilon_{x0}} = \frac{(I_{50} + I_{5w})/I_{50}}{(I_{20} + I_{2w} - I_{40} - I_{4w})/(I_{20} - I_{40})}$$

$$= \left(1 + \frac{I_{5w}}{I_{50}}\right)\left(1 + \frac{I_{2w} - I_{4w}}{I_{20} - I_{40}}\right)^{-1}$$

For example, the case in TPS with high energy and non-combined function dipole $I_{20} \gg I_{40}$, assume the K in Robinson wiggler is 0.8 m^{-2} and maximum of dipole field is about 1.3 T, so the minimum radius will be 7.7 m. the effective emittance formula will become

$$I_{4w} = \int_{wiggler} \frac{D}{\rho}\left(\frac{1}{\rho^2} + 2K\right) ds \approx \int_{wiggler} \frac{2DK}{\rho} ds$$

$$= 2D \int_{wiggler} \frac{1}{B\rho^2} \frac{dB}{dx} ds \approx 2D \left(\frac{3}{10E(Gev)}\right)^2 \int_{wiggler} B \frac{dB}{dx} ds$$

$$= 2D \left(\frac{3}{10E(Gev)}\right)^2 \left\langle B \frac{dB}{dx} \right\rangle L_w$$

Here, $\langle \ldots \rangle$ means average value of Robinson wiggler, form above equation, we can rewrite effective emittance formula

$$\varepsilon_x = \varepsilon_{x0} \left(1 + \frac{I_{5w}}{I_{50}}\right)\left(1 + \frac{I_{2w} - I_{4w}}{I_{20}}\right)^{-1}$$

$$= \left(1 + \sum_w \frac{8B_w}{3\pi f_h B_0} \frac{U_w}{U_0}\right)\left(1 + \sum_w \frac{U_w}{U_0} - \frac{9\rho_0 D}{100\pi E^2[GeV]} \left\langle B_R \frac{dB_R}{dx} \right\rangle L_w\right)^{-1}$$

We compare both methods result with verified dipole field, find out the emittance will decrease as dipole field increase linearly in Method 1; but in Method 2, there is a minimum emittance 1.452 nm-rad when the dipole field is about 1.1 T as shown in Figure3.

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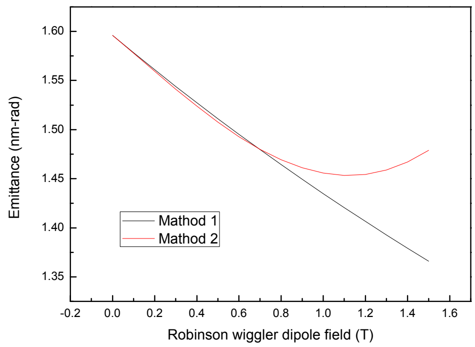

Figure 3: we consider the verified dipole magnetic field and find out the most effective magnetic filed form Method2 formula. The value of magnetic field is about 1.1T.

MULTI-PERIOD ROBINSON WIGGLER (MRW)

Like the traditional Robinson wiggler structure, but the MRW has muti-period set, each set has four combination combined magnets. Each pole of MRW is shorter than traditional Robinson wiggler. It has an advantage that the electron beam won't shift too much form the original orbit, and make matching simulation process easier. From effect of ID formula, if the dipole field of MRW is larger than 1.1T, it will cause emittance increase. After simulation, we chose magnetic field of MRW is 0.88T. In the other hand, the limit of technical work on quadruple strength is about 8T/m in the normal conductor dipole magnet. Then we assume the total length of MRW is 6m, one period is 0.4 m, there are 15 periods in one set, Figure4 shows the design results after matching.

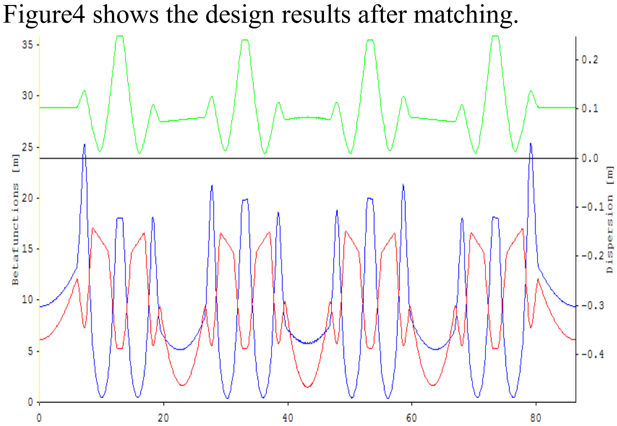

Figure 4: Beta function of MRW at short straight session of 1/6 superposition of TPS. we use left and right sides of three quadruple magnets separately to simulate matching.

The simulation result shows emittance can decrease from 1.6 to 1.121 nm-rad , the decay ratio is about 30% , the efficiency is better than traditional Robinson wiggler 3.6 times.

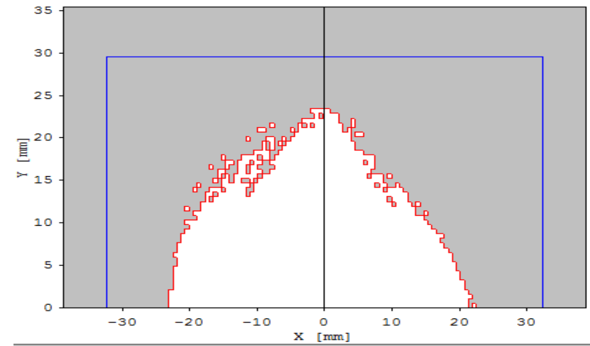

Figure 5: This figure shows the beam aperture with MRW by nonlinear optimization, the beam aperture size is about 20mm.

CONCLUSION

Countries are competing to develop high-brightness in medium-energy accelerator ring, especially the brilliance of the light source provided by the accelerator is more important to user. NSRRC is developing and building the Taiwan Photon Source right now , its beam emittance can reach 1.6 nm-rad, how to improve the emittance will become next issue. We try to use MRW to reduce emittance, and from the simulation result can approach 1.121 nm-rad after nonlinear optimization. We expected to complete the program, which provides higher brilliance to users and improve Taiwan's competitiveness in scientific research.

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