STATUS OF THE ROBINSON WIGGLER PROJECT AT THE METROLOGY LIGHT SOURCE

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Abstract

The beam lifetime in electron storage rings concerns machines running in decay mode as well as machines doing top-up. A standard procedure to increase the lifetime is via bunch lengthening as the lifetime depends on the electron density in the bunch. Bunch lengthening is typically achieved with higher harmonic (Landau) cavities. As noted in [1], there are several advantages in using a different approach: it is possible to increase the bunch length by installing a Transverse Gradient (Robinson) Wiggler, which allows to transfer damping between the horizontal and the longitudinal plane. While increasing the bunch length, the horizontal emittance is being reduced yielding advantages regarding the source size depending on the magnet optics. At the Metrology Light Source, a primary source standard used by Germanys national metrology institute (Physikalisch-Technische Bundesanstalt) [2], such a scheme is being investigated. The current state of the project including dynamic aperture effects and synchrotron radiation issues of the device is being presented in the following.

INTRODUCTION

The lifetime at the MLS is Touschek dominated and it is 6 h for a beam current of 150 mA. To improve the lifetime, the prospects of installing a Robinson Wiggler (RW) are being investigated. The RW transfers damping between the horizontal and the longitudinal plane. Therefore, it will allow tuning of the energy spread σ_δ, and by that the bunch length σ_s as $\sigma_s \propto \sigma_\delta$. Hence, the bunch density can be decreased via bunch lengthening, resulting in an increased lifetime. Increasing the bunch length is usually achieved by installing higher harmonic (Landau) cavities. Installing a RW at the MLS is an option, as the users of the synchrotron radiation are not as sensitive to an increased energy spread as in other facilities.

THEORY

The damping partition number D describes how the damping is divided between the horizontal and the longitudinal plane. It is the ratio between the fourth and the second synchrotron radiation integral, I_4 and I_2:

$$D = \frac{I_4}{I_2}, \tag{1}$$

$$I_2 = \oint \frac{1}{\rho^2} \mathrm{d}s, \tag{2}$$

$$I_4 = \oint \left(\frac{\eta_x}{\rho^3} + \frac{2\eta_x k_1}{\rho}\right) \mathrm{d}s, \text{ with } k_1 = \frac{1}{B\rho}\frac{\partial B_y}{\partial x}, \tag{3}$$

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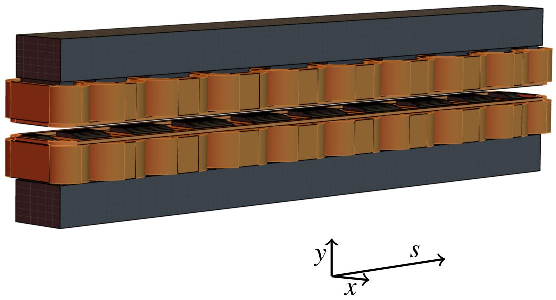

Figure 1: Robinson Wiggler as described in RADIA [3]. The poles have a hyperbolic shape in the horizontal direction, giving rise to a linear, horizontal field gradient (comp. Fig. 4). Field and gradient depend on the current in the coils.

where ρ is the bending radius, η_x is the horizontal dispersion function and k_1 is a horizontal gradient to the field. The damping partition D can be manipulated by introducing a magnetic field B and a gradient $\partial B/\partial x$ simultaneously in a dispersive section. The contribution to I_4 is negative when choosing B and $\partial B/\partial x$ to be of opposite sign (for a positive dispersion). Chains of alternating combined function magnets yield such fields (compare Fig. 1).

In Fig. 2 the development of σ_x, the averaged beam width along the circumference, the hor. emittance ε_x, the bunch length σ_s (and with that the energy spread σ_δ) and the beam lifetime $\tau_{1/2}$ are shown as a function of the damping partition D. The lifetime includes gas lifetime, the different quantum lifetimes and the Touschek lifetime. The gas lifetime was assumed to be constant with a value of $\tau_{\text{gas}} = 25$ h, which is the result of measurements performed in 2013.

The lifetime is calculated for two scenarios: τ_1 represents the lifetime calculated for a constant vertical source size, independent of the horizontal emittance; τ_2 represents the lifetime as it would be for a constant emittance coupling between the horizontal and the vertical plane of $\varepsilon_y/\varepsilon_x = 0.5$ %. The graphs show that for $D = -1.75$, a lifetime improvement between 60 % (τ_2) and 100 % (τ_1) seems achievable.

DESIGN STATUS

Number of Poles and Drift Correction

As the available space for the device is limited to 1740 mm, the maximum length of an individual pole is defined by the number of pole pairs. The longer a pole, the higher the achievable fields. But the longer the poles the larger the particles amplitude. Taking the constraints at the MLS into account, the optimum seems to be 9 to 10 poles (including end poles). In order to preserve the aperture, it is worthwhile to have the beam oscillating around the central

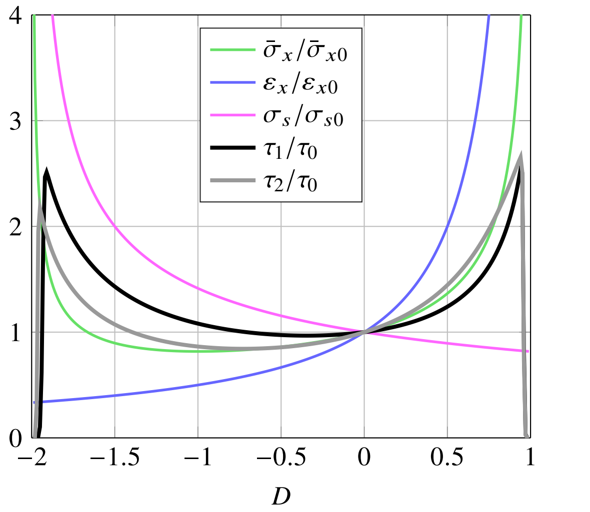

Figure 2: Average bunch width around the ring $\bar{\sigma}_x$, hor. emittance ε_x, bunch length σ_s and lifetime $\tau_{1/2}$ as a function of damping partition D, divided by corresponding $D = 0$ values. Lifetime calculated for: τ_1: constant vertical beam size $\sigma_y(D) = \text{const.}$; τ_2: for constant emittance coupling $\sigma_y(D) \neq \text{const.}$.

axis of the vacuum chamber, instead of an off axis oscillation, as the amplitudes of the oscillations are in the order of several mm. Hence, it was decided to go for a design with 10 poles (including end poles of 1/4$^{\text{th}}$ and 3/4$^{\text{th}}$ standard pole length).

Due to the gradient in the field, an electron beam will experience a drift towards the smaller absolute value of the field. The reason for this is that the kick, the electrons experience in the higher field regions can not be compensated by the smaller kick gained in the smaller field regions if the polelength is kept constant. One way to compensate this for comparably small energy spreads (several permille) is to introduce an additional dipole field. The additional dipole field is realised by an additional coil spanning the whole length of the wiggler.

Field and Gradient

In the envisaged design, which has been optimised with the help of the company Scanditronix[1], the yoke material consists of 49 % Fe, 49 % Co and 2 % V, as it yields high fields for normal conducting electromagnetic devices. Issues regarding induced radioactivity due to beam losses remain to be studied. The device is simulated with `RADIA` and in Fig. 3 and Fig. 4 the calculated vertical field along the longitudinal and horizontal axis respectively are presented.

RADIATION EFFECTS

In Fig. 5 the photon spectrum of the Robinson Wiggler as described above is presented together with the spectra of dipole radiation as observed at two beamlines, optimised for the IR and EUV spectral region. The spectrum of the

[1] www.scanditronix-magnet.se

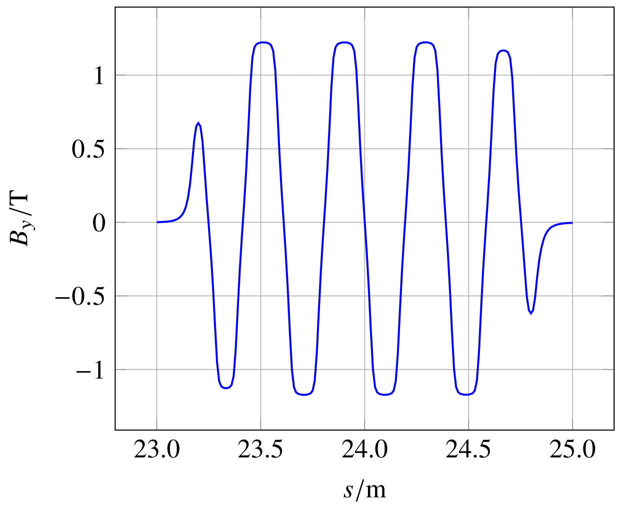

Figure 3: Vertical field B_y as a function of the longitudinal position on the beam axis.

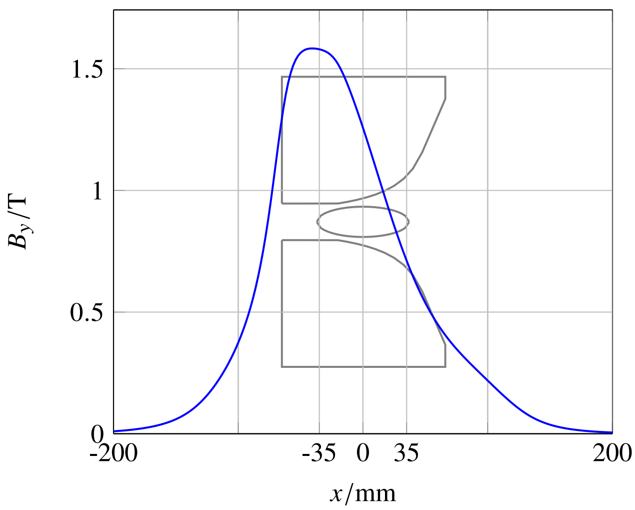

Figure 4: Vertical field B_y as a function of the horizontal position in the longitudinal center of one main pole. The pole curvature is indicated as well.

Robinson Wiggler was calculated with the program `WAVE` [5]. The acceptance of the EUV-beamline pinhole and the Robinson Wiggler pinhole are comparable to each other. As the wiggler consists of 10 poles with on axis field strengths in the same order of magnitude as the standard MLS dipole, on would expect approx. 10 times the initial dipole intensity. The heating of the downstream vacuum chamber has been studied without finding any alarming results.

DYNAMIC APERTURE

The dynamic aperture for the Robinson Wiggler was calculated using a self-written tracking code which is able to track through arbitrary accelerator lattices and field maps. The tracking code has been benchmarked with the standard user operation mode in `MAD-X` [4] (comp. Fig. 6) and the field map routine has been benchmarked with several field

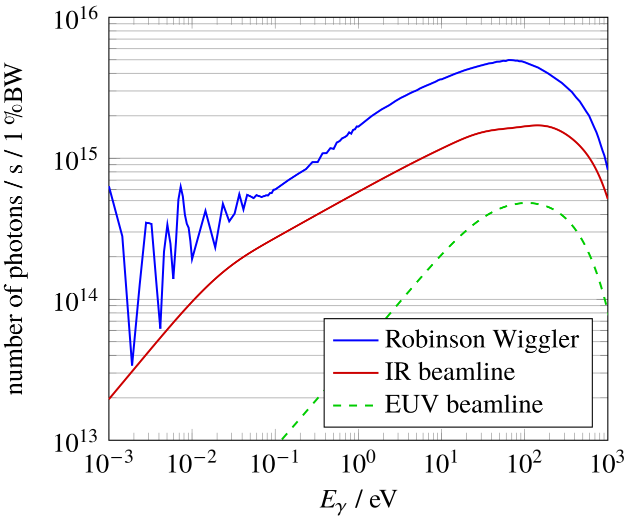

Figure 5: Calculated spectrum for Robinson Wiggler, IR-dipole and EUV-dipole at the MLS with the existing apertures and a beam current of 200 mA.

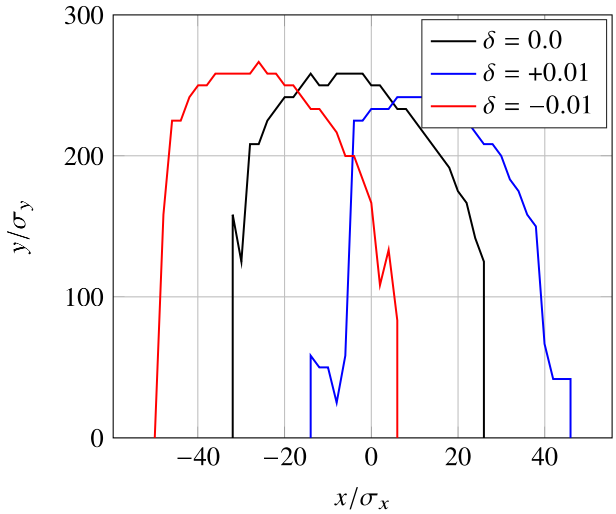

Figure 7: Dynamic aperture for the MLS with Robinson Wiggler calculated for different energy deviations.
$\sigma_x = 701\,\mu\text{m}$, $\sigma_y = 36\,\mu\text{m}$, $\eta_x = 0.54\,\text{m}$

maps from dipoles (analytically calculable) or Halbach-like Wigglers. The point of observation for each of the following calculation is the cavity at the MLS. In Fig. 6 the dynamic aperture for the MLS without Robinson Wiggler is presented. The calculations were done in `MAD-X` and the self-written code. The slight differences can be compensated with a slight adjustment of the sextupole strengths, but here the authors want to present the outcome of the exact same parameters for the two codes. Fig. 7 shows the dynamic aperture for the MLS with the Robinson Wiggler. The horizontal shift of the apertures for off-energy particles is due to large dispersion at the point of observation and non zero slope in the dispersion function ($\eta_x = 0.54\,\text{m}$, $\eta'_x = 0.076$).

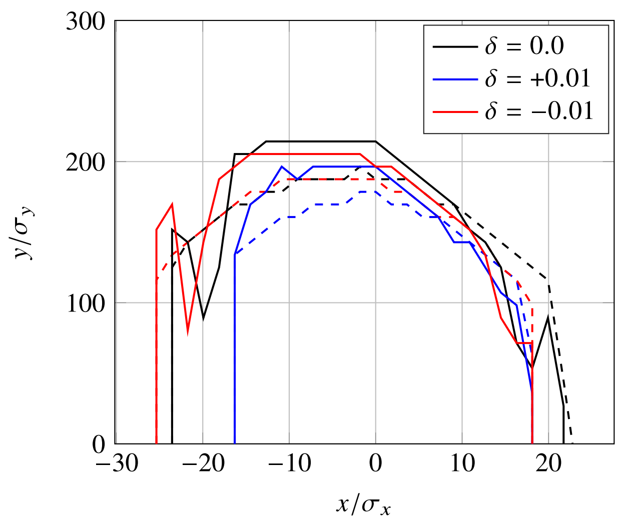

Figure 6: Dynamic aperture for the MLS without Robinson Wiggler calculated with `MAD-X` (dashed) and the self-written code (solid) for different energy deviations.
$\sigma_x = 966\,\mu\text{m}$, $\sigma_y = 42\,\mu\text{m}$, $\eta_x = 0.17\,\text{m}$

CONCLUSION AND OUTLOOK

The installation of a Robinson Wiggler at the Metrology Light Source would yield a lifetime improvement between 60 % to 100 % depending on the operation mode. Additionally it offers useable synchrotron radiation with higher intensities than the regular dipoles at the MLS. Ongoing studies of the dynamic aperture show no obstacles so far.

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