A ROBINSON WIGGLER PROPOSAL FOR THE METROLOGY LIGHT SOURCE

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Abstract

The Metrology Light Source (MLS), situated in Berlin (Germany) is owned by the Physikalisch-Technische Bundesanstalt and was built / is operated by the Helmholtz-Zentrum Berlin. It is an electron storage ring operating from 105 MeV to 630 MeV. The MLS serves as the national primary source standard from the near infrared to the extreme ultraviolet spectral region [1]. Users of synchrotron radiation demand an improved lifetime which is Touschek dominated at the MLS. A possible solution to meet this demand is to lengthen the electron bunches. By installing a Robinson Wiggler (RW), damping effects can be transferred from the longitudinal to the horizontal plane [2, 3], thereby increasing the energy spread and reducing the horizontal emittance. By varying the energy spread, the bunch length can be increased and thus the scattering rate decreased, resulting in an improved lifetime. According to preliminary estimations a considerable increase in lifetime seems achievable, while preserving the source size.

INTRODUCTION

In order to improve the beam lifetime, the magnet optics at the MLS were changed such that the dispersion vanishes at the place of the septum [4]. With this, and by centering the orbit at that same place, the lifetime was improved by a total of 80 %. Today the lifetime at the MLS is 6 h for a beam current of 150 mA at 630 MeV beam energy.

To further improve the lifetime, the prospects of installing a RW are investigated. The RW aims to transfer damping between the horizontal and the longitudinal plane. Therefore, it will allow free 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 3rd harmonic (Landau) cavities. Installing a RW instead of a Landau cavity 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. The advantages of installing a RW instead of Landau Cavities for bunch lengthening are described in the following: The horizontal emittance can be reduced by a factor of two to three. The RW will be easily tunable by varying the field strength. When it is switched off there is no interaction with the beam and its performance is not beam current dependent. The beam stability is better as it is not sensitive to fill pattern and does not contribute to impedances. Some of these points are solvable, but would require actively powered Landau cavities.

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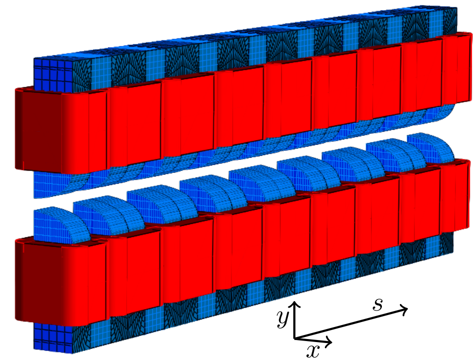

Figure 1: Robinson Wiggler model in RADIA [5]. The poles (blue) have a hyperbolic shape in the horizontal direction, giving rise to a linear, horizontal field gradient.

THEORY

Transferring damping between the horizontal and longitudinal plane means changing the damping partition D:

$$\varepsilon_x \propto \frac{1}{1-D}, \tag{1}$$

$$\sigma_\delta^2 \propto \frac{1}{2+D}. \tag{2}$$

D is the ratio between the fourth and the second synchrotron radiation integral, I_4 and I_2:

$$D = \frac{I_4}{I_2}, \tag{3}$$

$$I_2 = \oint \frac{1}{\rho^2} \mathrm{d}s, \tag{4}$$

$$I_4 = \oint \left(\frac{\eta_x}{\rho^3} + \frac{2\eta_x k_1}{\rho} \right) \mathrm{d}s, \tag{5}$$

with

$$k_1 = \frac{1}{B\rho} \frac{\partial B_y}{\partial x},$$

where ρ is the bending radius, η_x is the horizontal dispersion and k_1 is a horizontal field gradient. The damping partition D can be manipulated by introducing a magnetic field B_y and a gradient $\partial B_y / \partial x$ simultaneously in a dispersive section ($\eta_x k_1/\rho \neq 0$). The contribution to I_4 is negative when choosing B_y and $\partial B_y/\partial x$ to be of opposite sign (for a positive dispersion). A chain of alternating combined function magnets yields such fields (compare Fig. 1).

The dependency of ε_x and σ_δ on the value of D is shown in Fig. 2. Currently, the MLS is operated at $D = -0.055$

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and it is intended to work with a D in the range of −1 to −2. For D close to −2, the energy spread increases rapidly because of the singularity in Eq. 2, whereas the emittance decreases slowly. Additionally tracking results are plotted with crosses. Tracking was done with `MADX-PTC` [6]. The RW was described as a chain of misaligned quadrupoles consisting of 9 poles. Quadrupoles have the advantage that they do not change the reference orbit in `MAD-X`. Bends in `MAD-X` do change the reference orbit, which becomes problematic when a horizontal gradient is introduced.

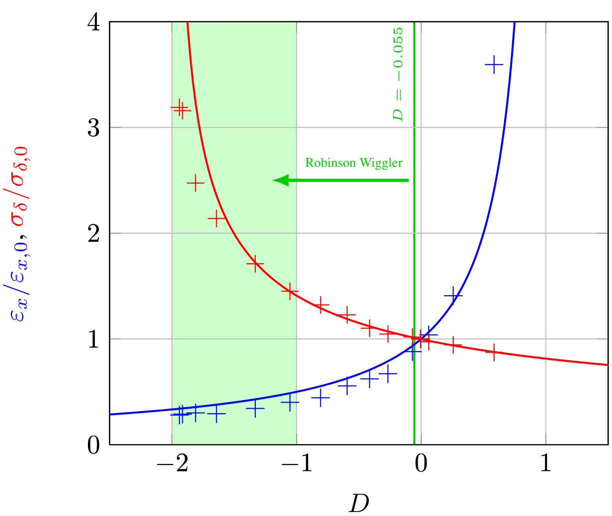

Figure 2: Effect of changing the damping partition D on energy spread σ_δ and horizontal emittance ε_x.

MEASURING DAMPING EFFECTS IN QUADRUPOLES

Damping effects by combination of field and gradient can also be observed without the action of a RW by steering the beam off centered through quadrupole magnets. In first order approximation, the change in I_4 from a single quadrupole is

$$\Delta I_4 \approx 2\eta_x l_{\text{quad}} k^2 \Delta x, \qquad (6)$$

where Δx is the horizontal displacement of the beam inside the quadrupole of length l_{quad} and strength k. The experiment was carried out in the standard user operation optics at the MLS. The beam was displaced by approximately ±10 mm in the horizontal plane and all places using steerers. Therefore, each quadrupole contributed to the change of I_4. The energy spread was deduced from bunch length measurements with a streak camera. As the bunch length is linearly dependent on the energy spread, a change in I_4 leads directly to a change in bunch length.

In Table 1 the expected and measured changes in bunch length are presented. The predictions are of the same order of magnitude as the measured changes in bunch length.

REQUIREMENTS AND DESIGN

The RW shall be placed in a short straight section of 2.5 m length at the MLS. Altogether the RW's length should not exceed 1.74 m. There are different combinations of dispersion, B-field and gradient which yield the desired change in damping. In Fig. 3 the value of D is shown as a function of gradient and on-axis B-field for a fixed dispersion of $\eta_x = 1.2$ m, which is a feasible value at the MLS, and an assumed "good field length" of $l_{\text{RW}} = 1.1$ m. As shown in Fig. 3, for an on-axis field of $B_y = 1$ T, a gradient of $\partial B_y/\partial x = 14.4\,\text{T}\,\text{m}^{-1}$ would be required to achieve $D = -2$.

Table 1: Expected and Measured Changes in Bunch Length via Off Centered Orbit

Δx / mm	$\Delta\sigma_{s,\text{theo}}$/%	$\Delta\sigma_{s,\text{meas}}$/%
10	−3.4	−3.8
−10	3.6	3.5

A preliminary design of the RW was done in `RADIA` [5] in order to check if the requirements determined before are feasible, comp. Fig. 1. For a current density of $j = 18\,\text{A}\,\text{mm}^{-2}$, the on-axis field is estimated to be $B_y = 1.08$ T with a gradient of $\partial B_y/\partial x = 14.1\,\text{T}\,\text{m}^{-1}$ in the center of the vacuum chamber. This would be sufficient, but a final check for realization is to be made.

Another requirement for a stable operation is that the device needs to be transparent to the beam so that the beam does not get any kicks or large offsets when passing through. The device has a horizontal gradient and two options are investigated, how to achieve transparency:

The first one is adjusting the pole length of every pole in which the electrons experience a stronger field due to the gradient. The change in polelength would be in the order of 4 %. The second one is to alter the coil current in these poles in order to decrease the field. The change in current density would be in the order of 13 %. The second option guarantees more flexibility, whereas the first option is cheaper as no additional power supply is needed.

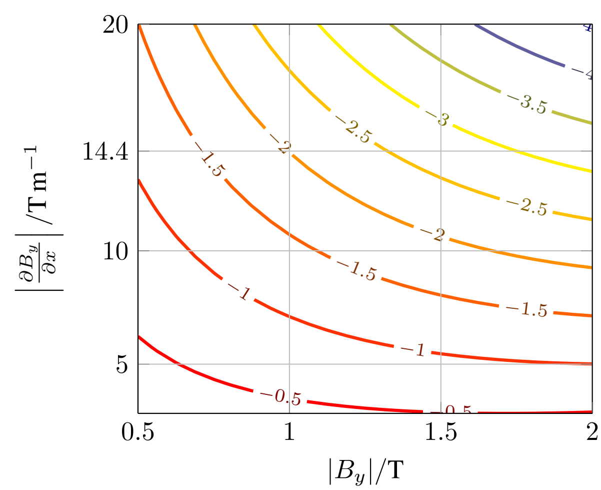

Figure 3: D in colors as a function of $|B_y|$ and $|\partial B_y/\partial x|$ for a fixed dispersion $\eta_x = 1.2$ m and "good field length" of 1.1 m.

POSSIBLE USE AS A SYNCHROTRON RADIATION SOURCE

With a field map generated by RADIA, the synchrotron radiation spectrum could be calculated with WAVE [7]. In Fig. 4 the spectrum is presented together with the spectrum of a dipole at the MLS. The spectrum was calculated as an undulator spectrum. For low photon energies, harmonics become visible and for high photon energies the spectrum looks like a wiggler spectrum, which is in agreement with the calculated undulator parameter of $K_{\mathrm{RW}} \approx 41$. The photon intensity is higher than the intensity of the single bend all over the spectral range. The critical photon energy is slightly shifted to lower energies, as the on-axis, maximum bending field $B_{y,\mathrm{max}} = 1.08\,\mathrm{T}$ is weaker for the wiggler than that of the regular bend at the MLS $B_{y,\mathrm{bend}} = 1.37\,\mathrm{T}$.

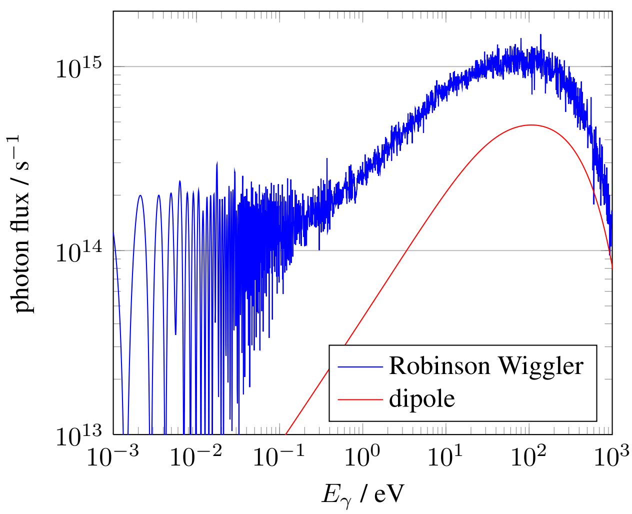

Figure 4: Synchrotron radiation spectrum of possible RW as developed in RADIA, calculated with WAVE [7], compared to MLS dipole. Radiation of RW through $6{\times}6\,\mathrm{cm}^2$ aperture in 10 m distance for 200 mA beam current, band width $\Delta E_\gamma / E_\gamma = 1\,\%$ and 630 MeV beam energy.

POTENTIAL GAIN IN LIFETIME

By installing the RW the lifetime τ at the MLS can be improved. It depends on the actual optics about which ratio the lifetime can be increased. By just installing the RW and keeping the optics as close to the current standard user optics as possible, and tuning the RW from $D = -0.055$ to $D = -1.75$, the properties presented in Table 2 could be achieved.

The emittance would reduce by a factor of two, while the energy spread would increase by a factor of three. The lifetime would then increase from 6 h to 12 h for 150 mA, which would be a lifetime improvement of 100 %, while keeping the beam size preserved.

Another option is to choose an optics with an increased horizontal emittance of around 200 nm rad as a starting optics. By properly tuning the Robinson Wiggler, the horizontal emittance can then be reduced back to 100 nm rad, which is the design emittance at the MLS. The lifetime gain for this option would be even higher than with the previous option and would be in the order of 160 %, although on the cost of an increased beam size due to the increased energy spread.

Table 2: Potential Lifetime Gain by Installing the Robinson Wiggler (Emittance and energy spread derived with MADX-PTC)

D	ε_x/nm rad	σ_δ	τ(150 mA)/h
−0.055	100	4.4×10^{-4}	6
−1.75	50	1.3×10^{-3}	12

CONCLUSION AND OUTLOOK

The idea of installing a Robinson Wiggler to the MLS is promising regarding the possible gain in lifetime as well as its use as a radiation source. Lifetime improvements in the order of 100 % seem achievable. Emittance and energy spread are tunable with this device, giving rise to new optics and operation options at the MLS.

Next steps will include the design of the final hardware layout as well as additional particle tracking with different codes to verify the final design.

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