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 $\sigma_\delta$, and by that the bunch length $\sigma_s$ 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.

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

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

with

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

where $\rho$ is the bending radius, $\eta_x$ 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 $\varepsilon_x$ and $\sigma_\delta$ on the value of $D$ is shown in Fig. 2. Currently, the MLS is operated at $D = -0.055$.
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 MAD-X-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 $\sigma_\delta$ and horizontal emittance $\varepsilon_x$.](image)

**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

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

where $\Delta x$ is the horizontal displacement of the beam inside the quadrupole of length $l_{\text{quad}}$ and strength $k$. The experiment was carried out in the standard user operation optics at the MLS. The beam was displaced by approximately $\pm 10$ 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 $\partial B_y / \partial x = 14.4$ T m$^{-1}$ would be required to achieve $D = -2$.

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 $j = 18$ A mm$^{-2}$, the on-axis field is estimated to be $B_y = 1.08$ T with a gradient of $\partial B_y / \partial x = 14.1$ T 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.](image)

<table>
<thead>
<tr>
<th>$\Delta x$ / mm</th>
<th>$\Delta \sigma_{x,\text{theo}}$/%</th>
<th>$\Delta \sigma_{x,\text{meas}}$/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>-3.4</td>
<td>-3.8</td>
</tr>
<tr>
<td>-10</td>
<td>3.6</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Table 1: Expected and Measured Changes in Bunch Length via Off Centered Orbit
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 \( K_{RW} \approx 41 \). 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 \( B_{y,max} = 1.08 \text{T} \) is weaker for the wiggler than that of the regular bend at the MLS \( B_{y,\text{bend}} = 1.37 \text{T} \).

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

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

<table>
<thead>
<tr>
<th>( D )</th>
<th>( \varepsilon_x/\text{nm rad} )</th>
<th>( \sigma_\delta \times 10^{-3} )</th>
<th>( \tau (150 \text{mA})/\text{h} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.055</td>
<td>100</td>
<td>4.4</td>
<td>6</td>
</tr>
<tr>
<td>-1.75</td>
<td>50</td>
<td>1.3</td>
<td>12</td>
</tr>
</tbody>
</table>

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.

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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REFERENCES