CAMD’s 7.5 Tesla Wiggler – Assembly and Self-Shielding

M.L. Marceau-Day; Center for Advanced Microstructures and Devices, Louisiana State University, Baton Rouge, Louisiana 70806, U.S.A.

The Center for Advanced Microstructures and Devices at Louisiana State University houses 1.4 GEV 2nd generation Synchrotron Ring. Recently the facility received a 7.5 Tesla superconducting Wiggler. Although most Health Physicists never have observed how a wiggler is put together, we were given this opportunity upon receipt of the disassembled wiggler from the Budker Institute in Novosibirsk, Russia. Health Physicists spend a substantial amount of time modeling the output of such insertion devices, without consideration of the potential self-shielding aspects of the unit. The total weight of the device is 4200 kg, fully assembled. Assembly was difficult and constrained given a total long straight section of only 2.9 meters. The existing circular crane assembly in the facility is limited to 2 short tons.

Table 1 describes the characteristics of the wiggler. It has a peak field, on access, of 7.5 Tesla and processes 11 poles and 4 corrector poles within an overall length of 2.2 meters. It has a vertical beam aperture of 15 mm and a magnetic gap of 40 mm. The device is capable of producing a maximum beam power of 15 kW at 200 MeV.

Table 1: Multiple pole wiggler configuration and specifications

<table>
<thead>
<tr>
<th>MPW specifications</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak field on axis (Tesla)</td>
<td>7.5</td>
</tr>
<tr>
<td>Number of poles</td>
<td>11+4</td>
</tr>
<tr>
<td>Pole length (mm)</td>
<td>100</td>
</tr>
<tr>
<td>Overall MPW length (m)</td>
<td>2.2</td>
</tr>
<tr>
<td>Beam vertical aperture (mm)</td>
<td>15</td>
</tr>
<tr>
<td>Magnetic gap (mm)</td>
<td>40</td>
</tr>
<tr>
<td>Beam power at 200 mA (kW)</td>
<td>15</td>
</tr>
</tbody>
</table>

It became obvious during the reassembly of the wiggler on-site, that for the Health Physicist, this was a unique event. Generally, calculations and evaluations are made based on the physics of the device without consideration of any potential self-shielding. This wiggler will have a maximum energy output of 85 KEV at 0°. Although the self-shielding does not contribute substantially to radiation dose from gas Bremsstrahlung, it does contribute significantly to the overall shielding profile for the device. The half value layer of copper, iron and aluminum for 100 KEV photons are indicated in the top right-hand corner of Figure 2. The most significant of the materials present in the Wiggler include copper, that serves as a heat shield, with a half value layer at this energy of 1.8 mm, iron, represented by the steel housing with a half value layer of 2.6 mm and aluminum with a half value layer of 15.9 mm, which also acts as a heat sink at 15.9 mm in thickness. Each of these materials, contribute to the self-shielding aspects of the Wiggler.

Figure 1: Copper heat shield located within the Wiggler assembly.
Figure 1 shows the 1st of two copper heat sink shields in the wiggler. The upper left hand corner indicates the ½ value layers for various elements including Lead, Copper, Iron and Aluminum. The thickness of the copper heat sink [25.4 mm] represents approximately 14 one half value layers of radiation shielding against 100 KeV photons. The maximum energy of the X-rays produced by this 7.5 T wiggler is not anticipated to exceed 85 KeV, due to limitations of the ring energy. Thus, the ½ value layer calculation is indeed conservative, at 100 KeV maximal energy value. This means that a radiation dose of 100 μSv per hour would be reduced to 6 μSv per hour by this single heat shield.

Figure 2 shows the placement of both copper heat shields in the base of the wiggler assembly. The total thickness of this shield exceeds 50 mm of copper. Two such layers would reduce a 100 μSv per hour dose rate to 3 μSv per hour.

Figure 2: The installation of both copper heat shields (of 25.4 mm thickness each) within the bottom half of the wiggler housing.

The housing of the wiggler is a steel cylinder exceeding 50 mm in thickness. The ½ value layer for Iron [represented here as the steel housing] is 2.6 mm for 100 KeV photons. The greater than 50 mm thickness of steel represents approximately equivalent of 10 one half value layers of shielding. This would reduce the dose of 100 KeV photons from an initial dose rate of 100 μSv per hour to approximately 1 ηSv per hour.

Figure 3: The magnet core housing represents a further >50 mm of iron self-shielding.

The magnet housing itself [Figure 3] represents an additional 10 half value layers of iron which also contributes to the overall shielding in the wiggler. These two layers of iron [i.e. the housing and the magnet cavity] would reduce a 100 μSv per hour dose of 100 KeV photons to 0.5 η Sv / hour.
This evaluation of shielding does not include the weight of the magnets themselves which function as a radiation source term without consideration of any shielding effect. In this case it would be too difficult to model where the radiation from the magnet poles would contribute the radiation source term and where they might act as a shield. Therefore, the shielding contribution of the poles are not been considered in this paper, despite their substantial weight [and therefore shielding capacity of the poles].

The copper heat shields are further insulated from heat via a 25.4 mm thick aluminized blanket (Figure 4). The ½ value layer for aluminum is given as 15.9 mm for 100 KeV photons. This value therefore represents approximately one and a half ½ value layers of aluminum. However, since the precise make-up of the aluminum blanket is not completely defined, a value of ½ value layer was assumed for the shielding calculations. Thus the contribution of the aluminized layer would reduce a 100 μSv per hour to approximately 50 μSv per hour. There is an additional one half value layer of aluminum blanket is added to the outside of the copper shielding to circumscribe the entire wiggler magnet assembly.

*Figure 4: Aluminum blanket, as a heat sink with a thickness exceeding ½ value layer.*

This additional layer of aluminum would again reduce the dose by ½ reducing a hypothetical dose from 100 μSv per hour reduction to 25 μSv per hour. Thus, self-shielding by the wiggler components is significant and should be considered when designing or calculating the total dose produced by the wiggler.

Considerations of contributions to shielding should be weighed against the overall shielding requirements, including those that calculate the total dose due to gas Bremsstrahlung. The gas Bremsstrahlung dose, with the potential to reach energies on the order of storage ring operation [i.e. 1.4 GeV] must be addressed separately according to the method of Rindi and Tromba (1993)
Gas Bremsstrahlung Calculations were calculated by the method of Rindi and Tromba (1993)

\[
\frac{3.0 \times 10^4}{P \times X_0} \quad \frac{E^2}{0.511^2} \quad \frac{L \times I}{(L+1)}
\]

Rindi and Tromba, 1993

Where:

- \(X_0\) = radiation length of air @ \(10^{-9}\) torr = \(2.34 \times 10^{16}\)
- \(L\) = effective length in meters (8 meters)
- \(I\) = beam current in e/s
- \(E\) = electron beam energy in MeV [1300]

For the CAMD facility, the ring normally operates in the high \(10^{10}\) torr range. However, recent vacuum incursions, coupled with a truncated operating schedule of only 14 hours per day for 5 days per week will make the gas Bremsstrahlung dose the most significant radiation hazard during the early stages of commissioning. Initial calculations suggest a Bremsstrahlung gas dose on the order of 0.57 mSv/hour without any shielding implementation. The beam is equivalent to a 3 GeV bending magnet radiation, which was used to calculate. On this reduced re-commissioning schedule, the CAMD ring will take approximately 4 months to achieve even a minimal current of 100 mA, and perhaps 6 months before a routine current of 200 mA is achieved.

Figure 5 gives the comparison of power output from the current and new insertion device. The operation of the 7.5 Tesla will be controlled by keeping the output of the Wiggler circumscribed within a finely tuned phase space. Any excursions from the ideal orbit will immediately drop the RF cavities in the ring.

This modification will be incorporated into the existing personnel protection system at the CAMD facility and will, of course, require re-commissioning of the personnel access safety system. Other minor configuration changes, such as moving search and secure buttons will also be implemented. The power requirements for the operation of the ring with both insertion devices are such that, if either of the two RF cavities is lost, not a single electron will complete the entire orbit. Additional modifications will be placed into the beamline management system, in particular for the new micro-tomography beamline with the installation of a new Laue monochromator.

References:

Figure 5: Power Comparison between the 7 T wave-length shifter and the 7.5 T Wiggler at CAMD.