LCLS2 undulator beam dump vacuum chamber protection from beam mis-steering

LCLS-II-TN-19-05

4/8/19
(Updated on 3/6/20)
Y. Ding, J. Welch
SLAC
Abstract:

In this note we discuss tracking results related to mis-steered beam at the undulator dump area. Based on these results, we propose to insert a thin mask in the beamline just upstream of the dump. It would serve to prevent the possibility of mis-steered beam hitting the dump vacuum chamber without first generating radiation that can be easily detected and used to trip off the beam before any damage occurs. The mask could consist of a modified Conflat flange gasket. The beam would pass through it and generate enough radiation to be easily detected using a PBLM (Santana-Leitner 2019).

1 Introduction

In an LCLS-II Memorandum (Welch 2018), possible damage of the dump vacuum chamber by a mis-steered high-power electron beam has been discussed. This vacuum chamber is an aluminum tube that is welded to the dump and extends through the dump shielding. Damage to the vacuum chamber would necessitate replacing the dump. The MPS and BCS systems are already designed to protect this vacuum chamber from beam strikes by methods including BPM response, feedback system, beam loss monitors, etc., as discussed in the Memo. After discussion in several meetings, it was suggested that adding a thin mask and a radiation detector to each of the undulator beamlines could provide additional protection for the dump vacuum chambers. A special thin mask is not necessary for the BSY dump, since a bellows flange with a diameter of 3.402 inches right before the BSY dump already serves this purpose (Welch 2018). In this note, we focus on the undulator electron beam dump.

2 Undulator dump particle tracking simulations

LCLS2 has two undulator beamlines that provide FEL beams for users: one for hard x-rays and one for soft x-rays. In the dump area the design of the two beamlines is very similar, and we pick the hard x-ray undulator dump as an example for this study.

We start with an arbitrary (unlimited size and divergence) transverse phase space distribution before the XTCAV structure. The XTCAV structure, which exists in the hard x-ray line, is about 2-m long and has a 10-mm inside diameter. It provides effective collimation of the electron beam and defines the maximum initial transverse phase space distribution incident to the dump beamline. In the soft line, there will be a similar XTCAV structure. With a well-defined transverse phase space distribution at the exit of the XTCAV, we track the beam to the beam dump, including the varying apertures of the vacuum chamber, BPMs, and any other smaller structures such as the protection collimator PCPM1L. Note the BPMQD and BPMDD have a rectangular aperture (1.604 in x 3.75 in) and they are rotated by 90 degree, with BPMQD having a smaller aperture in x while the BPMDD having a smaller aperture in y. Figure 1, adapted from (Welch 2018), shows the beamline chamber near the dump including magnets and BPMs. The inside diameter of the dump vacuum
chamber is 95.25 mm. The dashed lines show the beam stay clear (BSC) requirement, and the three red lines are examples of the traced rays. Ray-1 shows the possibility of hitting the dump vacuum chamber but is only possible in the horizontal plane. Ray-2 and Ray-3 are possible extreme rays that only can happen in the vertical plane (Ray-3 is from a much stronger BPMDQD quad setting).

We consider two possible locations for adding a mask, labeled “a” or “b” in Figure 1. In the Elegant tracking, the mask is treated as an opaque collimator (1mm thickness) and we optimize the aperture size of the mask to make sure that no simulated particle will hit on the wall of the dump vacuum chamber (the light blue part before the dump core in Figure 1). Without considering any alignment errors, the required thin mask aperture radius size is not larger than 32 mm at location “a”, or 37 mm at location “b”. This insures that any track that would have hit the vacuum chamber would have hit something upstream first. We summarize the parameters in Table 1 and discuss the details in the following.

![Figure 1: Elevation view of mis-steering rays near Undulator Dump. The vertical scale is 100 times larger than the horizontal scale [1]. The “a” and “b” are two potential positions to add a mask.](image)

### Table 1: Thin mask and BSC parameters for the two locations.

<table>
<thead>
<tr>
<th>Location</th>
<th>Z location relative to BPMDD</th>
<th>BSC, (mm) [X_half, Y_half]</th>
<th>Required circular mask aperture radius (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>1.35 m upstream of BPMDD</td>
<td>[24.0 21.7]</td>
<td>32</td>
</tr>
<tr>
<td>b*</td>
<td>0.37 m downstream of BPMDD</td>
<td>[27.7 17.7]</td>
<td>37</td>
</tr>
</tbody>
</table>

*: b location is at the deferred RFBDD location in MAD deck.

It is easy to understand that for a location closer to the dump, less collimation (larger aperture) is required to intercept the mis-steered beam. At either location a or b, the mask aperture size is larger than the BSC requirement (see Table 1). This is good for operation and also gives some alignment tolerance for the thin
mask and the dump. Location b has a bigger tolerance: \(37 - 27.7 = 9.3\) mm.

In Figure 2 we show a few simulated beam transverse distributions to illustrate the function of the thin mask at the “b” location. The electron beam energy is 4 GeV. A worst case scenario was assumed by combining the following errors and settings together: -3\% dump bending magnets BYD strength, -1 mrad kick from horizontal correctors XCD3 and XCDD, +1 mrad kick from vertical correctors YCD3 and YCDD, and 20\% increases of quadrupoles QDMP1 and QDMP2 strength. We can see the XTCAV structure defines a round beam with 10 mm diameter, and BPMQD helps filter out particles having large horizontal offset. The proposed thin mask further truncates particles in the horizontal dimension. After several iterations varying the mask inside diameter, we found that when the mask inside diameter is not bigger than 74 mm, there will be no particle loss on dump vacuum chamber (the last two pictures show the beam at the beginning and the end of the aluminum chamber that we are trying to protect).

![Figure 2: Tracking examples of the beam transverse distribution along the beamline before the undulator dump. The rectangular or circular red shape represents the mask inner diameter at that location. This setup uses a circular mask (radius 37 mm) at the proposed location “b”.](image)

### 3 Summary

We discussed adding a thin mask near the dump to protect the final vacuum chamber from mis-steered beam. At either of the two proposed locations, it could work and the required aperture size is larger than the beam
stay-clear requirement, as shown in Table 1. Considering the alignment tolerance, the actual thin mask aperture size should be smaller than that listed in the Table 1. For example, if the relative alignment error between the thin mask and the dump core is 3 mm, then the required thin mask aperture radius at location “b” would be 34 mm.

In these tracking studies, we assumed the BYD bending magnets will be set to the beam energy within ±3%, and the quadrupoles QDMP1 and QDMP2 will be at the nominal strength within ±20%. The maximum corrector kick is limited by the power supplies to about 1 mrad with 4 GeV beam, as we used in the studies. If the beam energy is lowered to 2 GeV, at location “b”, the mask inner diameter needs to be 1 mm smaller in order to provide the same protection for the final vacuum chamber. The Z location of the proposed mask is not sensitive, tolerance can be at the 5 cm level.

Also note that although we used the XTCAV structure to define a phase space distribution in our tracking, we verified that even without the XTCAV structure, the conclusions are still valid. Starting from an unlimited phase space distribution after the XTCAV, the large divergence particles will be truncated by the small aperture devices downstream (mostly by PCPM1L here, 1.125-inch diameter). Finally, the upstream undulator chamber also limits the transverse phase space, so an unlimited phase space before XTCAV is really a conservative assumption.

4 Works Cited


5 Update on 3/6/2020: verify the solution with reversing the polarities of QUE1/2 and QUE1B/2B

To achieve the best resolution of the XTCAV measurement, undulator dump area will adopt matching solutions according to beam energy and undulator gap, which are optimized by Y. Nosochkov. The QDMP1 and QDMP2 (also the QDMP1B/2B in the soft x-ray line) are all kept at the same K values in the solutions, which will allow the interlock of the quads to the BYD dipoles. On the other hand, both solutions in the hard and soft line would prefer a reverse of the polarities of the QUE1/2 (and QUE1B/2B in the soft line) comparing to the original MAD deck. The QUE1/2 quads are located upstream of the BYD bending magnets, one before the XTCAV and one after the XTCAV. One question coming up is that if the polarity reverses of QUE1/2 (and QUE1B/2B) would affect our conclusion.

In the standard setup for these simulations, we started with an unlimited phase space distribution before XTCAV, and used XTCAV as a long aperture to collimate the beam before tracking further downstream. As we discussed in the last paragraph of Section 3, even we don’t use the XTCAV aperture, the conclusion is
still valid. In this case, switching the polarities of quads before BYD should make no changes of the requirement for the mask aperture size. To confirm this, we did further tracking with changing the polarity and strength of QUE2, and verified our conclusions. We still start with an unlimited phase space before the XTCAV. Since the QUE1 is upstream of the XTCAV, we do not need to consider it.

We first show the X and Y half aperture of the beam pipe in this area in Figure 3 (this is an extension of the apertures as shown in Figure 1). The QUE2 is right after the XTCAV. During the tracking, we changed the QUE2 strength by a factor 4, and/or reversed polarity as well. Those changes mainly make small differences on the particle loss at BYD chamber and PCPM1L collimator, but no particle loss has been observed at the last 2-m long aluminum chamber in any case. We adopted the mask radius size of 37 mm at the “b” location as in Table-1 in our simulations.

The pipe Aperture (including BPMs, BYD)

![Graph](image)

**Figure 3:** The beam pipe half aperture in the dump area (HXR line).

In the following Figure 4, we show the simulated beam images after the mask, before and after the aluminum chamber, based on the same worst combined configuration as discussed in Section 2: -3% dump bending magnets BYD strength, -1 mrad kick from horizontal correctors XCD3 and XCDD, +1 mrad kick vertical correctors YCD3 and YCDD, and 20% increases of quadrupoles QDMP1 and QDMP2 strength. The QUE2 strength was increased by a factor 4 with polarity reversed. We see with this worst scenario, the chosen mask aperture (37 mm radius) does the perfect collimation, which helps avoid particle loss on the aluminum vacuum pipe right before the dump face.

We conclude that, as expected, the solution of the added mask aperture (37 mm radius) at location “b” is still valid with reversing of the QUE1/2 (or QUE1B/2B) polarity.
Figure 4: Tracking results after the mask collimator, before and after the ~2-m long aluminum chamber. The red circular represents the pipe size. In this extreme case with QUE2 polarity switched, there is no particle loss on this Al chamber.