Main 5 kW Electron Beam Dump Engineering Specification

J. Langton  
Author  
1/4/08  
Signature  
Date

James Turner  
Linac IMT  
1-4-08  
Signature  
Date

Jose Chan  
Linac. Manager  
1/8/08  
Signature  
Date

Dave Schultz  
Electron Beam Systems Manager  
1/8/05  
Signature  
Date

Paul Emma  
Linac System Physicist  
1/4/08  
Signature  
Date

Darren Marsh  
Quality Assurance Manager  
1/7/08  
Signature  
Date

Change History Log

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</table>
TABLE OF CONTENTS:

1.0 SCOPE
2.0 SOURCE DOCUMENTS
3.0 GENERAL DESCRIPTION
4.0 MATERIAL PROPERTIES
5.0 BEAM PARAMETERS
6.0 ALTERNATING TEMPERATURE
7.0 STEADY STATE TEMPERATURE
8.0 PEAK DUMP TEMPERATURE
9.0 COOLING FLOW PROPERTIES / REQUIREMENTS

1.0 SCOPE:
This document defines the engineering requirements and analysis results for the LCLS main electron beam dump. The dump is located inside the E-pit in the EBD tunnel at the end of the electron beam line (LCLS Z = ~715.8 M).

2.0 SOURCE DOCUMENTS:
The following documents provide the basis for this document;
LCLS PRD 1.3-008 R3:
   Electron Dumpline Requirements
LCLS PRD 1.1-011 R3:
   Electron Beam Loss in LCLS
LCLS PRD 1.1-013 R0:
   Shielding Requirements for the Electron Beam Dump and Wall 1
LCLS PRD 1.3-024 R0:
   Electron Beam Power Absorbing Device Performance Requirements
Radiation Physics Note RP-07-17:
   Radiation Safety Evaluation for Engineering Implementation of the LCLS 5 kW Electron Dump and Shielding
Radiation Physics Note RP-07-18:
   Calculation of Energy Deposition and Instantaneous Temperature Rise to Design LCLS Electron Beam Dump and Stoppers

3.0 GENERAL DESCRIPTION:
The LSLS main electron beam dump is located at the end of the EBD tunnel inside the E-pit at LCLS Z = ~716.0 M. It is mounted from the down-beam end of a steel plug which is inserted into the front wall of the E-pit. Steel is stacked into the E-pit to create, in conjunction with the steel plug, an enclosure for the dump providing shielding as required by radiation physics simulations.
The main electron dump design is modeled after the SLAC-SLC Final Focus TD23 / ST4 dump block. The primary absorption medium is OFE copper, 10.19 inch thick (beam direction) by 6.0 inch wide-high. This mass is backed by a tungsten based “superdensalloy” block approximately 1.0 inch thick.

A copper plate / stainless steel tube heat transfer plate is brazed to one side of the copper mass. A burn-through-monitor backs the main E-dump.

The dump may, in fact, be fabricated from an actual SLC final focus TD23-ST4 beam stop block. The SLC final focus stoppers were bi-directional. There placement in SLC was such that they intercepted beam from both directions. They therefore had tungsten alloy clad on both end faces. If the LCLS main dump is fabricated from a reserve SLC unit, the forward face layer of tungsten will be machined such that the LCLS beam impacts OFE copper as the first absorption medium.


4.0 MATERIAL PROPERTIES:

Over 99% of the total incident beam energy is absorbed by the OFE copper medium of the dump. Copper properties are therefore of principal importance. The secondary tungsten medium is not considered with respect to the alternating and steady state temperature of the dump. The secondary tungsten medium was considered in the effective radiation dose to the surrounding environment.

4.1 COPPER PROPERTIES:

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<th>value</th>
<th>units</th>
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<td>Critical Energy</td>
<td>( \varepsilon )</td>
<td>18.8</td>
<td>(Mev)</td>
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<td>Density</td>
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<td>( X_0 )</td>
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<td>(g/cm^2)</td>
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<td></td>
<td>( X_0/\rho )</td>
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</table>

**Table 1**

5.0 BEAM PARAMETERS:

The LCLS main electron dump thermal analysis was performed using beam parameters as defined in the LCLS physics requirements document 1.3-024, “Electron Beam Dump Performance Requirements”.

With respect to the as-defined beam pulse-bunch parameters of 1.3-024, the beam was modeled as a train of single bunch, zero length instantaneous inputs of full charge (3 nC). Beam size is \( \sigma_x = 120 \) micron and \( \sigma_y = 20 \) micron. Beam energy is 17 Gev maximum. Maximum average beam power is 5.0 kilowatt.

6.0 ALTERNATING TEMPERATURE:

The alternating temperature of the dump is modeled as the instantaneous, adiabatic temperature rise of the absorption medium due to the energy input of a single “zero length” electron bunch with the above defined parameters. This is referred to as the “alternating temperature” since, after some discrete number of bunches, the dump must reach a steady state equilibrium condition. For this condition to be satisfied the dump temperature must decrease, between pulses, by the same amount as the adiabatic increase.

6.1 ALTERNATING TEMPERATURE AT THE DUMP FACE

The most critical parameter in determining the performance of the dump is the alternating temperature at the face of the dump. The face of the dump is defined as extending from the free
surface at the beam entrance location to a depth where the electromagnetic shower cascade begins to dominant the energy input to the dump medium. The transient thermal shock reflecting off the free face of the dump

In this region the energy input and derived temperature change (alternating) is a function of the material properties and beam bunch charge and size only.

The per bunch alternating temperature is [1]:

\[ D_t = \frac{(-de/dx)/c}{Co/Aspt} \]

Where:
- \(-de/dx\) = material energy loss
- \(Co\) = bunch charge
- \(Aspt\) = bunch spot area
- \(c\) = material specific heat

With \(Co\) taken as the maximum 3.0 nC (PRD 1.3-024) and evaluating \(Co/Aspt\) over the gaussian distribution of the bunch (\(\sigma_x = 20\) micron / \(\sigma_y = 120\) micron), the alternating temperature at the face of the dump is shown in figure 3.

![Figure 3](image)

**Figure 3**  
Alternating Temp at Beam Entrance Face LCLS Main Electron Dump

The peak temperature is approximately 75C. Which is well below the acceptable limit of 200C [2].
6.2 ALTERNATING TEMPERATURE THROUGH THE DUMP:

Within the dump absorption medium, where the effects of the shower cascade multiplicity and shower divergence dominate the energy deposition, Monte Carlo (EGS4) simulations were completed to precisely determine the overall energy deposition and derived alternating temperature.

Output from EGS4 was in the form of energy loss per unit energy - unit volume, \((\text{de}/\text{Eo})/\text{dV}\), per incident electron. Post processing of the data scaled for full bunch charge and energy. As with the alternating temperature at the dump face, the incident beam was assumed to be zero length and energy deposition adiabatic.

Energy scaling was over from 13.6 to 17 Gev. EGS4 simulations were done at 17 Gev. While shower divergence is a function of energy, the scaling range used was small and scaling to lower energy is conservative.

The worse case temperature raise was found the be a 14 Gev, 3.0 nC (5 kW) bunch. A 17 Gev, 2.45 nC (5 kW) bunch gives marginally lower peak temperatures.

The EGS4 radial mesh was refined until the peak temperature near the front of the dump converged with the peak temperature as determined from section 6.1 above. An extremely fine radial mesh near the central beam core was the result (~0.5 - 10 micron). The depth of the model dump went well below peak shower cascade / alternating temperature. Results were extrapolated beyond this depth for use in maximum steady state results.

Figure 4 shows the peak alternating temperature at the center \((R = 0.0)\) of the beam spot / dump.
7.0 **STEADY STATE TEMPERATURE:**

As with the alternating temperature through the dump (section 6.2) shower effects dominate the steady state temperature distribution. EGS4 Monte Carlo simulations were the source of the data for steady state analysis. The EGS4 output was actually identical to the alternating temperature output. Post processing converted the EGS4 (de/Eo/dV) energy loss output to volumetric thermal heat generation (watts/CM³) for input to ANSYS®.

The EGS4 mesh density was increased to a practical size for modeling in ANSYS (100 – 200 micron). The absorption medium depth of the simulation was extended to the full 17 radiation length thickness of the dump to insure maximum capture of the beam energy. Greater than 99% of the 5 kW beam was accounted for.

Figure 5 presents the steady state power deposition for a 14 Gev, 5 kW beam. Figure 6 presents the temperature profile through the depth of the dump at R=0.0 and R=1.0 cm. Figure 7 shows ANSYS results at a depth of 0.5 radiation lengths into the stopper. Figure 8 shows ANSYS results at a depth of 6.0 radiation lengths into the stopper (peak SS temp).

![Figure 5](image-url)

**Figure 5**
Figure 6

5 Kw Steady State Temperature
14 Gev, 3.0 nC (1.87E10 e-/pulse), 120 Hz, Tref = 30C

Figure 7

ANAVS

MIDAL SOLUN
STEP=1
SUB =1
TIME=1
TEMP  (AVG)
ESTD=0
SRI =30.009
SMO =36.047

steady state temp for 14 Gev, 3.0 nC, 5 Kw at 0.5 RL depth into stopper
8.0 PEAK DUMP TEMPERATURE:

The mean temperature of the dump is the steady state temperature as output from ANSYS plus some fraction of the alternating result. The worst case assumption for peak dump temperature is to assume the alternating temperature adds directly to the steady state temperature ($T_{\text{mean}} = T_{\text{ss}} + T_{\text{alt}}/2$). Using this assumption the peak temperature for the LCLS main electron dump is shown in figure 9.
The maximum temperature of the dump is less than 250°C. This is well below the 630°C peak temperature predicted for the SLC beam into the TD23-ST4 stopper block, of similar design [3].

9.0 COOLING FLOW PROPERTIES / REQUIREMENTS:

The dump flow parameters as presented in table 1. The total pressure drop for the circuit (~31 PSI) is for the cooling loop starting at its entrance into the shielding plug and exiting at the same location.
Table 2

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References: