## Physics Requirement for the Gun Solenoid (SOL1)

**Cecile Limborg**  
Author  
*Signature*  
*Feb 13-06*

**Eric Bong**  
Injector/Linac WBS Manager  
*Signature*  
*2/14/06*

**Dave Schultz**  
E-Beam Systems Manager  
*Signature*  
*2/16/06*

**Paul Emma**  
Accelerator Physics Team Leader  
*Signature*  
*2/15/06*

**Darren Marsh**  
Quality Assurance Manager  
*Signature*  
*2/16/06*

**John Galayda**  
Project Director  
*Signature*  
*2/17/06*

### Brief Summary:
The requirements for the Gun solenoid (SOL1) are described. This magnet is the fundamental component for emittance compensation.

### Change History Log

<table>
<thead>
<tr>
<th>Rev Number</th>
<th>Revision Date</th>
<th>Sections Affected</th>
<th>Description of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>000</td>
<td>Feb 01-2006</td>
<td>All</td>
<td>Initial Version</td>
</tr>
</tbody>
</table>

---

Check the LCLS Project website to verify that this is the correct version prior to use.
Gun Solenoid (SOL1) Physics requirements

Functionality
The gun solenoid is the fundamental component for emittance compensation. Its appropriate design will allow the LCLS injector to achieve a 1mm-mrad projected emittance for a 1nC bunch charge. The principle of emittance compensation was first described in [1]. Briefly, the gun solenoid provides linear focusing forces to the beam which has undergone and is undergoing defocusing forces from strong space charge effects present at low energy. The solenoid compensates only for the linear part of the space charge force. It needs to act as early as possible in the beam acceleration so that minimal non-linear effects have time to develop.

Simulations (PARMELA) have shown that for our LCLS injector based on the S-Band gun, it would be advantageous to position the solenoid as close as possible to the cathode. However, no longitudinal magnetic field should be present on the cathode. Accordingly, a separate bucking coil is required to cancel the field on the cathode. The bucking coil parameters are described in [2].

Great care has to be paid to the field quality. In particular the tolerance on the quadrupole component is critical. The vibration stability of the solenoid is also critical and has been justified in [3]. Last but not least the regulation of the field to better than $10^{-4}$ is also critical to reach the working point of low emittance and to maintain it. These tolerances are given in Table 1.

Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focal length Nominal/Minimum</td>
<td>0.126/0.083</td>
<td>m</td>
</tr>
<tr>
<td>Effective Length of magnet (1)</td>
<td>0.1947</td>
<td>m</td>
</tr>
<tr>
<td>Full Width Half Max of field</td>
<td>0.1934</td>
<td>m</td>
</tr>
<tr>
<td>Nominal/Maximum Integrated field $\int B_z ; dz$ (1)</td>
<td>0.49/0.61</td>
<td>kG-m</td>
</tr>
<tr>
<td>Nominal/Maximum on-axis field (1)</td>
<td>2.55/3.15</td>
<td>kG-m</td>
</tr>
<tr>
<td>Accuracy of absolute field at nominal setting</td>
<td>0.25</td>
<td>%</td>
</tr>
<tr>
<td>Precision of set-point</td>
<td>&lt;5.10^{-5}</td>
<td></td>
</tr>
<tr>
<td>Relative rms fast field stability (2)</td>
<td>0.01</td>
<td>%</td>
</tr>
<tr>
<td>Relative rms field variation over 24 hours</td>
<td>&lt;0.01</td>
<td>%</td>
</tr>
<tr>
<td>Maximum Integrated Dipole component(3)</td>
<td>0.5</td>
<td>G.m</td>
</tr>
<tr>
<td>Maximum Integrated Quadrupole component(3)</td>
<td>2</td>
<td>G</td>
</tr>
<tr>
<td>Maximum Integrated Sextupole component</td>
<td>10</td>
<td>G.m^{-1}</td>
</tr>
<tr>
<td>Transverse rms vibration tolerance (2)</td>
<td>&lt;0.1</td>
<td>μm</td>
</tr>
<tr>
<td>Alignment tolerance transverse position x,y</td>
<td>250</td>
<td>μm</td>
</tr>
<tr>
<td>Alignment tolerance longitudinal position z</td>
<td>&lt;1</td>
<td>mm</td>
</tr>
<tr>
<td>Alignment tolerance in angle (pitch, yaw)</td>
<td>250</td>
<td>μrad</td>
</tr>
</tbody>
</table>

Table 1:
(1) for a 19.5 cm effective length field as presented in figure1
(2) for frequencies > 1Hz specified in [4,5]
(3) at all operating points
This magnet does not require solenoid trim coils or a bipolar power supply, but does require integrated dipole steering coils in the two transverse directions (as described below).

\[
\frac{1}{f} = \int \left( \frac{e}{2\gamma(z)mc} \right)^2 B_z^2(z)dz
\]  

The peak rise/fall time of the field of the magnet should exceed the normalized value \(d(B_z/\max(B_z))/dz\) of 14 m\(^{-1}\) since the location and slope of the rising field is critical. The magnet to be built should have the maximum of the rising slope at less than 10cm from the cathode.

Emittance computations were done using a simulated magnet having a \(\sim 19.5\)-cm effective length. This magnet map, shown in figure 1, gives a satisfactory solution. This magnet map corresponds to measurements of the GTF solenoid map. Its parameters are listed in Table 1. Figure 1 also shows that the optimal longitudinal location has been chosen to have the center of the magnet at 19.6 cm from the cathode (at position = 0 in the figure) for that simulated magnet. Numerical computations performed with PARMELA show that the emittance starts degrading if this magnet is positioned further downstream.

A map has also been computed using RADIA which gives a slightly slower slope but a residual field on the cathode of 65 Gauss for a 3.15kG peak field. For that reason, plans to incorporate a separate bucking coil were included [2].

The two maps (GTF measured, LCLS computed) have been represented on the same plots in figure 2. It was calculated that the GTF map would only be satisfactory on the LCLS if its center was located at 19.6 cm from the cathode. Otherwise, the LCLS emittance requirements would not be met.

Dipole coil correctors
Two dipole orthogonal correctors should be included in the bore of the magnet for trajectory correction. The dipole component tolerances are therefore less critical since they can be corrected with these separately powered steering coils.

![Field profile and derivative](image)

Figure 2a and 2b show the measured GTF field (blue) and the map computed with RADIA (red). The measured GTF curve has been centered at 19.6 cm.

**Magnetic Measurements**

A measurement plan will have to be written which will describe the two following tasks:

1. **in the magnet laboratory**
   Measurements will be performed with rotating coil to determine the amplitude and phase of dipole, quadrupole and sextupole components. If the measurement shows that the multipole terms exceed the specifications, the magnet will have to be corrected, for instance by shimming with iron pieces.
   The necessity of such a correction has been justified for beam dynamics in [3].

2. **with vacuum chamber and valve**
The solenoid field map should be measured in the presence of the vacuum chamber and gun-exit valve to verify that no significant quadrupole component is generated from the non-unity relative permeability and asymmetric structure.

References
http://www-ssrl.slac.stanford.edu/lcls/prd/1.2-005-r0.pdf
http://www-ssrl.slac.stanford.edu/lcls/prd/1.1-008-r0.pdf