**Stabilization, Alignment and Support Requirements for Gun, Solenoid and Linac Structure**

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**Brief Summary:** These specifications describe the tolerances for alignment of the gun, the gun solenoid, the laser injection mirror and linac section L0a. It describes vibration tolerances for the same components.

**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>Nov. 7, 2005</td>
<td>All</td>
<td>Initial Version</td>
</tr>
</tbody>
</table>
The RF gun electrical axis is the reference axis for the beam dynamics. All tolerances are given with respect to that reference axis, but in some cases where another axis is more relevant. As the reference axis for the alignment team [1] is the geometric axis of the beamline, determining the RF gun electrical axis with respect to the geometric axis of the beamline is critical.

We distinguish between slow and fast motions
- “slow” is defined as drift of components over periods of time from 1 s to longer.
- “fast” corresponds to vibrations with frequencies ranging from 1 to 120 Hz

The “slow” motion can be handled by good alignment combined with feedback system which compensate for drifts due to thermal effects and due to diurnal ground motion effects. The maximum tolerable drift of components is imposed by emittance requirements. The drift of a component should not induce an increase by more than 1-2 % of either the slice emittance and/or the projected emittance.

The ”fast” motion is difficult to control as no feedback system can correct for it. The vibrations generate kicks which in turn produce orbit offsets in the undulator. The limit criteria for orbit excursion , as stated in [2], is that the orbit offset should not be larger than 10% of the rms beam size in the undulator. Vibration tolerances given here have to be taken as guidelines. Modeling of the high frequency motion of the components is very intricate and is not worth the effort. Accelerometers will be installed on those components to check if the vibrations tolerances are met. If not, damping systems will have to be added. Measurements of the vibrations, should be done with water pumps on.

I- Summary

We summarize the tolerances for the slow motion drift (<1Hz) in table1 and for vibrations (between 1Hz and 120 Hz ) in table 2.

An rms amplitude is given for the transverse motion of a component with respect to the reference axis described in column 2 of the table.

<table>
<thead>
<tr>
<th>Component</th>
<th>Reference</th>
<th>rms amplitude</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser pointing</td>
<td>RF gun electrical axis</td>
<td>200 µm</td>
<td>imposes laser stabilization system to give &lt; 150 µm rms in incidence plane</td>
</tr>
<tr>
<td>Laser injection mirror</td>
<td>RF gun electrical axis</td>
<td>100 µm, 200 µrad</td>
<td></td>
</tr>
<tr>
<td>Vacuum chamber</td>
<td>Geometric beamline axis</td>
<td>1.5 mm</td>
<td></td>
</tr>
<tr>
<td>Solenoid</td>
<td>RF gun electrical axis</td>
<td>250 µm, 250 µrad</td>
<td></td>
</tr>
<tr>
<td>Linac Section L0a,L0b</td>
<td>Geometric beamline axis</td>
<td>250 µm, 250 µrad</td>
<td></td>
</tr>
</tbody>
</table>

Table 1- Maximum slow motion drifts tolerable

Alignment should be done at least to half those rms amplitude values, leaving room for drifts.
Component | Reference | rms amplitude | Comments
---|---|---|---
Laser pointing | RF gun electrical axis | 10 µm | 
Laser injection mirror | RF gun electrical axis | 2.5 µm, 5 µrad | in incidence plane
RF gun | Geometric beamline axis | 100 nm | 
Solenoid | Geometric beamline axis | 100 nm | 
Linac Section L0a,L0b | Geometric beamline axis | 500 nm | 

Table 2- Maximum vibration amplitudes tolerable

II - Slow drift

The relative position of the solenoid (SOL1) magnetic axis, the linac sections, the vacuum chamber of the GTL (Gun-To-Linac) region and the injection laser mirror with respect to the RF gun electrical axis is critical for achieving an emittance meeting the LCLS Injector specifications. The following results were derived from PARMELA simulations, for the 1-nC nominal tuning of the LCLS injector for which a maximum 1.2 mm-mrad projected emittance is required once all types of errors (electromagnetic, alignment, drive laser profile) have been taken into account.

**Laser steering on cathode**

If the pointing of the drive laser beam to the RF gun electrical axis exceeds 200 µm rms, non-linear RF effects start deteriorating the slice emittance. A 1 mm laser pointing error generates a 20% slice emittance increase at the gun exit. A 200 µm laser pointing error produces about 2-10% slice emittance increase at the gun exit.

The laser stabilization system will use a reference on the virtual cathode and not the RF gun center. The virtual cathode centered will be determined experimentally with the electron beam. The relative position between the RF gun electrical center and the virtual cathode should not vary by more than 150 µm rms. The laser stabilization system must then bring back the laser beam within 150 µm rms of the virtual cathode reference. The pointing requirement to RF electrical center of 200 µm rms will then be met.

**Injection mirror (AM00) and RF gun**

The relative position between the RF gun electrical center and the virtual cathode should not vary by more than 150 µm rms in the incidence plane. Both the RF gun and the injection mirror should have common support with the virtual cathode. The maximum rms relative motions are then
- 100 µm for the RF gun with respect to virtual cathode
- 100 µm, 200 µrad for the injection mirror with respect to virtual cathode.
Solenoid w.r.t gun
The relative position of the solenoid (SOL1) with respect to the electrical center of the RF gun needs to be less than 250 µm in position and 250 µrad in angle.

These values were deduced from the following facts
- for a mis-positioning larger than [500 µm, 500 µrad], the emittance growth becomes irreversible; the non-linearities in the focusing of the solenoid produce similar effects as those described for the case of the RF gun
- for a mis-positioning within the specified limits [250µm, 250µrad], the best trajectory in the Gun-To-Linac region already has an excursion of 0.5 mm with respect to the beamline axis. This is tolerable but should not be exceeded to meet the transverse wakefield impedance budget.

Vacuum Chamber w.r.t gun
The vacuum chamber components should not be misaligned transversally by more than 1mm rms, with respect to the RF gun electrical axis.

The Earth magnetic field (0.4 G) will produce a \( \Delta y'/\Delta z = 2\text{mrad/m} \) kick in the Gun-to-Linac region. After the SOL1 correcting coils are set up to optimum values, the beam offset with respect to the geometrical axis will be at best no larger than 0.5 mm.
The GTL vacuum components meet the transverse wakefield budget for transverse offsets no larger than 1.5 mm.

Linac section
Alignment should be better than 250 µm and 250 µrad for the linac section with respect to the geometrical axis.
The beam steering into L0a should be within 150µm in position and 120 µrad in angle with respect to the electrical axis of L0a. GTL steerer magnets will compensate for offsets of 250 µm in position and 250 µrad in angle.

III - Vibrations
Vibration tolerances are defined for the frequency band of 1 to 120 Hz and those vibrations are referred to as “fast vibrations”. A justification for the vibration tolerance budget has been given in “Quadrupole Magnet Vibration Tolerances” [2]. Vibrations cannot be compensated for by feedback systems. The perturbation in orbit introduced by the vibration of a component propagates down the LCLS accelerator. The tolerance has been defined such that all vibration sources combined should not introduce an orbit displacement larger than 10% of the rms beam size in the undulator [2].

Laser Pointing stability
The laser pointing stability with respect to RF gun electrical axis for frequencies ranging between 1 Hz and 120 Hz should not exceed 10 μm of the laser radius on the cathode. This value includes all the possible sources of vibration along the laser transport and steering line and of the RF gun. Those vibration tolerances distribute as follows:
- injection mirror (AM00 with respect to the RF gun electrical axis): 2.5 μm, and 5 μrad angle
- RF gun fast vibrations should have an amplitude smaller than 100 nm with respect to the beamline geometric axis for reasons described in the RF Gun vibration paragraph
- laser beam transported to the injection mirror should not vibrate by more than 10 μm, 20 μrad in the incidence plane
This latter tolerance corresponds to the centroid of the laser beam. The source of oscillation of the centroid of the laser beam can be either due variation in the transverse uniformity or displacement of the edges of the transverse disk.

Measurements to estimate the amplitude of those different contributions have to be carried out at the early stage of commissioning. Spaces to position appropriately the accelerometers have to be incorporated in the mechanical design of the RF gun and the injection mirror chamber. Room to implement damping systems, if it is found to be necessary, has to be reserved too.

Solenoid
The vibration of the solenoid should be smaller than 100 nm as described in [2]. The calculation is summarized here below where $A$ is the normalized trajectory amplitude.

$$A = x' \sqrt{\frac{\beta}{\varepsilon}}$$
and
$$x' = \frac{1}{f} \Delta x$$

With $\beta = 15$ m, $\varepsilon = \varepsilon_n / \gamma$ with $\varepsilon_n$ the normalized emittance after emittance compensation $f=0.12$ m for the solenoid $A$ is taken as 0.1/√N where $N$ is the number of components (about 150) contributing to orbit jitter in the undulator. From this computation, $\Delta x < 68$ nm. The 100-nm level is acceptable. The solenoid will be considered as a larger weight component in the overall vibration budget.

RF Gun
The defocusing kick at the exit of the gun will generate an orbit change in the undulator if the beam (centroid) exits the gun off-axis. In particular, due to the earth magnetic field the beam offset at the gun exit is 70 μm if the beam left the cathode on axis. The focal length of the RF gun exit kick is of the order of $f = 0.10$ m and the betatron function is also $\beta = 15$ m. Those numbers are similar to those used for the solenoid.
Accordingly, the vibration of the RF gun should produce a transverse motion smaller than 100nm w.r.t the geometric axis of the beamline.

### Linac Structure

The vibrations of the linac structures need to be less than 500 nm. Indeed, the focal length of the kicks produced at the extremities of L0a are 0.5m for the entrance kick and 6.4 m for the exit kick. The betatron functions and energy are summarized in the table here below.

<table>
<thead>
<tr>
<th></th>
<th>$\beta$ [m]</th>
<th>$\gamma$</th>
<th>$\epsilon$</th>
<th>$\Delta x$</th>
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</thead>
<tbody>
<tr>
<td>Entrance L0a</td>
<td>2</td>
<td>12</td>
<td>$8.3 \times 10^{-8}$</td>
<td>780 nm</td>
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<tr>
<td>Exit L0a</td>
<td>30</td>
<td>128</td>
<td>$7.8 \times 10^{-9}$</td>
<td>792 nm</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>f</th>
<th>$\beta$ [m]</th>
<th>$\gamma$</th>
<th>$\epsilon$</th>
<th>$\Delta x$</th>
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<tr>
<td>Entrance L0a</td>
<td>0.5</td>
<td>2</td>
<td>12</td>
<td>$8.3 \times 10^{-8}$</td>
<td>780 nm</td>
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<tr>
<td>Exit L0a</td>
<td>6.4</td>
<td>30</td>
<td>128</td>
<td>$7.8 \times 10^{-9}$</td>
<td>792 nm</td>
</tr>
</tbody>
</table>

### References

[2] [http://www-ssrl.slac.stanford.edu/lcls/prd/1.1-008-r0.pdf](http://www-ssrl.slac.stanford.edu/lcls/prd/1.1-008-r0.pdf)