Physics Requirements for the XTOD Attenuator System

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Brief Summary: This document provides general physics requirements for the XTOD Attenuator System, a system designed to attenuate the fundamental of the LCLS FEL x-ray beam, for any output photon energy in its range, by a factor of up to $10^3$.

Change History Log

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<tr>
<th>Rev Number</th>
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<tr>
<td>000</td>
<td>2006/2/27</td>
<td>All</td>
<td>Initial Version</td>
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<tr>
<td>001</td>
<td>2006/7/18</td>
<td>Sections 2 and 3</td>
<td>Maximum attenuation revised to $10^3$. Clarification regarding &quot;accuracy&quot;. Add requirement for remote repositioning.</td>
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PRD 1.5-003-r1
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1. Introduction

The XTOD Attenuator System will be located near the upstream end of the Front End Enclosure (FEE). Its purpose is to provide a wide range of stable attenuation for the full photon energy range available from the LCLS FEL. In so doing, the attenuator will permit both initial experiments and first-time diagnostics to operate with pulse intensities near levels familiar from other facilities and sources, but gradually increase these intensities as techniques and technologies mature. The system will likely combine both a gas attenuator sub-system and a solid attenuator sub-system. The use, range and crossover between these two will be best determined through the fulfillment of the other requirements listed below.

The actual attenuation provided by the system must be experimentally determined, as a function of photon energy; it may not be possible to predict the attenuation to a high degree of accuracy from tabulated theoretical absorption coefficients. This is due to the inherent uncertainty in some of the calculations required for a gas attenuator, and to the presence of unknown quantities of impurities in solid attenuator materials.

The system may also be required to transmit the full transverse extent of the projected radiation field from the undulator for some diagnostic systems located downstream of the attenuator. If needed, this “fully-open” mode will probably require that all solid attenuator materials be retractable from the beam, and the small differential pumping apertures in the gas attenuator may either have to be retractable, or present an acceptably-small x-ray attenuation factor to the downstream diagnostic systems.

Additional requirements regarding beam-scatter limitation and coherence preservation are noted.

Finally, this system will likely require a sophisticated control system, to permit all the flexibility of the system to be fully employed by remote control, while retaining full fault sensing and automated shutdown/recovery.

2. Fundamental Requirements

2.1. From PRD 1.5-001, LCLS X-Ray Transport and Diagnostics:

2.1.1. “The system attenuators must be able to reduce the FEL beam intensity by up to 4 orders of magnitude at any energy within the design range.”

2.1.1.1. The maximum attenuation stated here is now considered excessive, in light of anticipated LCLS experiments. Instead, a maximum attenuation of $10^3$ shall be required.

2.1.1.2. This statement is interpreted to apply only to the fundamental of the FEL radiation, as the intensity of the harmonic photon flux is insufficient to pose a power/damage concern.
2.1.1.3. It is also interpreted that an attenuation of up to the maximum magnitude is to be provided for every output FEL photon energy available from the present LCLS design, 826.5 eV to 8265 eV.

2.1.2. “The attenuator system must provide stable, reproducible (to within 1%) attenuation for repeated FEL shots.” This requirement was developed before its full implications on the gas attenuator sub-system were appreciated. Instead, at present, the long-term stability and the reproducibility of any given attenuation setting shall be determined based on the anticipated temperature stability of the Front End Enclosure and the accuracy and stability of available, off-the-shelf pressure-measuring systems. (See UCRL-TR-217793 by D.D. Ryutov, et al.)

2.2. The long-term stability and the reproducibility of any given attenuation setting shall be within 1.5% for an attenuation factor of 10, and within 4% for an attenuation factor of $10^3$. These values are based upon a Front End Enclosure temperature stability of ±1 °C (PRD 1.9-001-r1) and a pressure measuring system with a combined accuracy and stability of 0.1%.

2.3. The attenuation accuracy of the Attenuator System is not specified here. The attenuation obtained for any given in setting of the Attenuator, at any given FEL photon energy, must be experimentally measured using other systems, e.g. the Gas Detectors. The accuracy of that measurement, then, depends upon measuring instrument. In this document, only stability and reproducibility requirements for the Attenuator are specified.

2.4. The attenuator design shall adhere to all elements of PRD 1.5-002, XTOD Mechanical-Vacuum Systems.

2.5. The Attenuator design shall provide at least 3 steps for every decade of attenuation, up to $10^3$. To facilitate detector response characterization, up to 8-steps-per-decade may be desirable.

2.6. The design should make optimum use of z-space, i.e. the length along the FEL path, since the space available in the Front End Enclosure (FEE) is limited and precious.

3. **Optical Aspects**

3.1. Aperture requirements:

3.1.1. When “in-operation”, the system should permit un-obstructed passage of the full transverse extent ($5\sigma$) of the FEL photon beam, i.e. the only materials intercepted should be the attenuation materials.

3.1.2. If required, when “fully open”, the system should permit passage of the full transverse extent of the projected radiation field from the undulator, limited only by components upstream of the Front End Enclosure, and possibly by apertures in the gas attenuator sub-system,
which must be designed to present an acceptable level of x-ray attenuation to all downstream diagnostic systems.

3.2. The uniformity of attenuation over the transverse dimension of the FEL beam shall be better than 1%, for any photon energy, up to an attenuation of $10^3$.

3.3. Select attenuation materials and surface finish, where appropriate, to limit the effect of scattered radiation, consistent with requirements of anticipated LCLS experiments.

3.4. Select attenuation materials and surface finish, where appropriate, to limit degradation of FEL beam transverse coherence, consistent with requirements of anticipated LCLS experiments.

3.5. Means must be provided to remotely reposition the aperture centers of the Attenuator to any transverse location within at least ±3 mm of the survey-defined FEL beam axis. This is necessary due to the small diameters of these apertures, which are required in the gas attenuator subsystem differential pumping stages.

4. Controls

4.1. Changes in attenuation level should be accomplished with reasonable dispatch.

4.1.1. New attenuation settings of the solid attenuator should only require some seconds to accomplish.

4.1.2. New attenuation settings of the gas attenuator will generally require the response of its full pumping system. However, when the response can be accelerated safely, reasonable efforts to exploit this should be made. For a decrease in attenuation, the gas pressure will likely require a few minutes for the full pumping system to reach a new set-point and stabilize. However, for an attenuation increase, efforts should be made to decrease the response time to the new, higher pressure setting, through the gas-feed control system.

4.2. Fully-remote-controlled operation of the attenuator is required. This includes operations such as selecting an attenuator gas and its pressure and admitting it into the system, aligning the gas attenuator subsystem apertures to the FEL beam axis and inserting or retracting solid attenuator blocks. In addition, if necessary, switching the system back and forth between an “in-operation” mode, where gas and/or solid attenuation is applied to the FEL beam, to a “fully-open” mode, where a maximum aperture is produced, must be possible. These operations may require sophisticated sequencing logic for safe start-up and shut-down of multiple turbo-pumped systems, deployment of aperture-equipped valves, and multi-point monitoring of run
conditions, with pre-determined fault-response actions to component failures, to prevent system contamination and limit equipment damage.