AMO Diagnostics

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Brief Summary:

Specifications for the suite of diagnostics instruments that will be built as a part of the LCLS Atomic Physics experimental equipment are detailed. The diagnostics are intended to provide pulse-by-pulse information on the properties of the LCLS beam in the AMO interaction region including photon energy, bandwidth, position and size of the focus and pulse energy.

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>11/23/2007</td>
<td>All</td>
<td>Initial Version</td>
</tr>
</tbody>
</table>
1. Introduction:

A suite of diagnostics is being developed along with the high field physics experimental instrument at the LCLS to provide feedback on the alignment and performance of the instrumentation as well as to monitor the FEL beam on a shot-by-shot basis. Beam-based alignment tools are required to verify the correct placement of the instrumentation relative to the LCLS FEL beam. While care will be exercised in positioning and aligning the instrumentation in the hutch before LCLS beam is available, only the position of the interaction region in the FEL beam is relevant to the performance of the instrument. During an experimental run, after the experiment has been aligned to the beam, pulse-by-pulse measurement of the FEL beam characteristic properties will be important for analysis of the data. In the scenario where the LCLS operates stably with shot-to-shot variations of ~10%, it will be sufficient to just measure the average properties of the beam. In the more likely scenario where the position, intensity, and perhaps even photon energy and bandwidth of the pulses from the LCLS vary dramatically, shot-by-shot diagnostics become more important for a clear understanding of the physics. Plans to measure the photon energy and bandwidth, position, and intensity of each pulse are presented in the remaining sections of this document.

2. Alignment:

2.1. Alignment Laser:

A visible alignment laser that is collinear with the LCLS photon beam will be introduced into the photon beam path in the AMO experiment line in hutch 2 using a retractable mirror.

![Alignment Laser](image)

Figure 1: Example of a commercial alignment laser system from H.W. Fairway International.

2.1.1. The laser, which would be used in the absence of the LCLS beam to align the experimental apparatus to the FEL beam axis, will be permanently affixed to the beamline just downstream of the hutch wall.

2.1.2. The retractable mirror should return to the same location upon insertion with a positional repeatability of 250 μm and an angular repeatability of 100 μrad to ensure a 1mm alignment tolerance.

2.1.3. The laser should be mounted on a kinematic mount to allow initial alignment with the LCLS beam. The mount should be lockable to maintain the position of the laser between uses.
2.1.4. Insertion of the mirror should be interlocked to the upstream valve being closed to prevent illumination of the back of the mirror by the LCLS beam.

2.1.5. Focusing optics may be required on the laser to provide a spot of <1mm at the point of interest (the volume downstream of the focusing optics).

3. Beam Viewing Paddles:

Insertable beam viewing paddles will be located along the beamline and throughout the instrumentation to allow viewing of the beam with video cameras on a real time basis. The beam viewing paddles will be used to verify the position of the beam in the experimental apparatus and to ensure the beam passes cleanly through restrictions such as differential pumping apertures.

3.1. The beam will illuminate an ~1” diameter YAG crystal mounted on a linear translation manipulator used to insert it into the beam.

3.2. The scintillating crystal can be held at a 45° angle relative to the beam and viewed along an axis perpendicular to the FEL beam.

3.3. The bottom of the holder should be open, i.e. with no metal surrounding the crystal, to allow insertion into the beam without consideration for a pulse hitting the holder.

3.4. A pneumatic translator that can quickly insert and retract the scintillator is preferred.

3.5. Position sensing switches should be incorporated into the translators to monitor the position of the crystal.

3.6. The video image of the beam can be integrated to the 30Hz rate of an inexpensive camera since it is the average position of the beam that is of interest.

3.7. Appropriate lenses and apertures need to be selected to ensure the visibility of the beam.

3.8. Beam viewing paddles will be located before and after each beam restriction:
   - Before the focusing optics
   - Between the optics and the experimental chamber
   - After the experimental chamber
- After the differential pumping aperture in the diagnostics chamber
- After the diagnostics chamber

4. **Pulse Diagnostics:**

4.1. Single shot beam viewing screens:

Two beam viewing screens equipped with video cameras that are capable of capturing images at the repetition rate of the LCLS (120 Hz) will be used to measure the position and size of the beam in the far field behind the interaction region. A semitransparent screen in the forward location will let ~50% of the beam pass through to a second screen a further distance beyond the first screen.

![Figure 3: Image of a SiN window.](image)

4.1.1. Both screens should be fully retractable from the beam.
4.1.2. The upstream screen can be made from a thin SiN window coated with the appropriate thickness of a scintillator such as YAG.

![Graph](image)

**Figure 4:** Transmission of SiN and YAG over the energy range of the soft x-ray branch of the LCLS.

4.1.3. Owing to the small size of SiN windows, ~5mm in diameter maximum, the first screen should be mounted on an XY manipulator to allow it to be centered on the FEL beam.

4.1.4. The upstream screen should be oriented in normal incidence to maximize the clear aperture of the window and minimize the thickness of material traversed by the beam and imaged at an acute angle by the CCD camera.

4.1.5. The second screen can be a thick crystal that fully attenuates the beam.

4.1.6. Images should be captured and processed on a shot-by-shot basis.

4.1.7. If uniform intensity patterns are observed, determination of the position and width of the spot will be sufficient.

4.1.8. If interference fringes are observed, the image should be processed to determine the focus of the beam.

4.1.9. Ideally both the position and size of the focus can be determined from the images on the two screens.

4.2. Pulse energy monitor:

The fluence or energy of each pulse is an important parameter to be determined for each LCLS pulse. Together with the size of the beam in the interaction region, the pulse energy determines the power density the sample was exposed to. This is a critical value to be determined for each shot in order to understand the physics taking place in the interaction region.

A pair of transparent gas detectors are being installed in the Front End Enclosure (FEE) of the LCLS on either side of the attenuator system. These gas detectors, which measure the pulse energy using gas fluorescence measurements, will provide an on-line measure of the pulse energy.
leaving the diagnostics section. There are many apertures and five optics between the FEE and the AMO experiment, however. Each of the optics will have a wavelength (and possibly time) dependent reflectivity. Apertures may also occlude part of the beam to a varying degree if insufficient clear aperture is provided, or alignment is not quite perfect, etc. It is therefore desirable to measure the pulse energy in the experiment. Since the AMO targets are mostly transparent, it is appropriate to measure the pulse energy after the experiment. A pulse energy monitor similar to the thermal sensor system being developed by the LLNL XTOD group will be installed in the diagnostics suite. The thermal sensor can be used either as a primary monitor of the beam intensity in the experimental chamber, or as a calibration of the transmission losses in the beamline between the experiment and the gas detector. With this calibration, the gas detector could be used to monitor the pulse energy.

The thermal energy sensor consists of several parts:

4.2.1. The sensor consists of a 0.5mm thick silicon substrate with a NdSrMnO GMR temperature sensor plated on the back that provides a sensitive measure of temperature rises in the Si substrate.

4.2.2. A temperature controlled heat sink that is weakly coupled to the sensor to provide a stable thermal bath.

4.2.3. A pulsed laser system to calibrate the response of the temperature sensor.

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**Figure 5:** Operating principle of the thermal sensor developed by LLNL XTOD group (figure from LLNL presentation of thermal sensor).
4.3. Magnetic Bottle Electron Spectrometer:

Detailed specifications of the magnetic bottle electron spectrometer are provided in a separate ESD, but the diagnostic capabilities of the instrument will be outlined briefly here. Magnetic bottle electron spectrometers are high collection efficiency spectrometers that use magnetic fields to guide electrons with a wide range of trajectories towards the detector without significantly compromising the temporal resolution of the TOF spectrum. Using a gas with well known binding and Auger energies, measurement of single shot electron spectra will permit the photon energy and bandwidth to be measured directly. Variations in the pulse intensity, which might give rise to changes in the plasma potential, which will shift the kinetic energies of the electrons observed. By measuring a wide range of kinetic energies simultaneously, however, including Auger electrons, it should be possible to correct for these variations.

The magnetic bottle spectrometer will also serve as an experimental instrument for the LCLS AMO program and will be useful for studying two-color non-linear phenomena in atoms and molecules. Sidebands to the main photoelectron peak can be created when two photon beams are present in the interaction region at the time of ionization. Using fundamental (or doubled or tripled) Ti:Sapphire laser radiation, for example, we should be able to observe side bands on the photoelectron and Auger lines of simple atoms, such as Ne with a single LCLS shot. Comparing the relative intensities of sideband peaks it is possible to quantify the temporal overlap of the x-ray and IR beams, as has been shown recently at FLASH.

![Image of sidebands in photoionization of Xe](image_url)

**Figure 6:** Example of laser+FEL sidebands observed in the photoionization of Xe with 32nm light (from the FLASH report).

5. Diagnostics Chamber:
The diagnostics outlined above will be mounted on a chamber and stand that is separate from the high field physics instrument. This serves two purposes, both allowing the diagnostics chamber to be used independently of the high field physics chamber, for example with other AMO experiments brought into the LCLS, and also allowing it to be moved to other hutches should the opportunity arise. The chamber and stand have similar requirements to those outlined in the high field physics chamber/stand ESD. The following differences are notable, however.

5.1. Magnetic shielding will only be present around the magnetic bottle spectrometer, the rest of the chamber volume will not be shielded.

5.2. The vacuum requirements for the diagnostics chamber are not as stringent as those for the main experimental chamber, a base pressure in the $10^{-8}$ range versus the $10^{-10}$ Torr range, and as such, only a turbo molecular pump is expected to be used to pump the chamber.

5.3. A higher level of differential pumping will be required between the diagnostics and high field physics chambers. A two stage differential pumping system with 4-5 orders of magnitude pressure differential will be used to isolate the two chambers. Two small turbo pumps are therefore required, one for each stage of the differential pumping.

5.4. The differential pumping will be dynamically aligned to the chamber axis when the chamber is at atmospheric pressure using a system of alignment struts. Once the differential pumping is coaxial with the chamber central axis, the differential pumping system will be locked into place and the entire chamber aligned to the beam as a single unit.

5.5. The chamber will terminate in a fixed beam stop made of a material such as B4C that can tolerate the full intensity of the beam at normal incidence. Additional collimators fabricated from materials that can tolerate illumination by the FEL beam will be located along the chamber to ensure that the beam cannot illuminate metal surfaces directly.

5.6. The stand supporting the entire suite of diagnostics will be similar to that used by the high field physics experiment, with similar alignment and stability tolerances.

5.7. The beam viewing screens and pulse energy monitor will be mounted on a long tube extending downstream from the body of the diagnostics chamber.

6. Gas Jet

Initially an effusive gas jet will be used to introduce gas into the interaction region of the magnetic bottle spectrometer. While the design will accommodate a skimmed molecular beam from below, this apparatus is not included in the current scope of the instrument. Rather a thin needle will be used to feed gas directly into the interaction region.

6.1. The needle will be mounted on an XYZ stage with stepper motors controlling the motion of the needle.

6.2. The X and Y stages require ±10 mm range with 10 μm resolution. The Z stage requires a 100 mm stroke with 100 μm resolution.

6.3. A video camera should be mounted to view the needle in the interaction region during alignment to ensure it is not hit by the FEL beam.

6.4. The needle should be made of a non-magnetic electrically conductive material and should be electrically grounded.

6.5. A pneumatic shut-off valve will be located on the gas line immediately outside the vacuum wall interface and interlocked to the chamber pressure.

6.6. Gas will be supplied to the needle from a pressure regulating valve that is supplied by a gas bottle with manually adjustable regulator.
6.7. A dry pump should be located on the gas line to pump it out when not in use.

7. **Beam Shutter:**

Although not currently in the scope of the AMO instrument project, a single pulse shutter will be useful when diagnosing problems with the instrumentation. The AMO instrument, when operational, will be the exclusive user of the beam. The optics and configuration of the instrumentation do not allow beam sharing between different experiments on the soft x-ray branch. The LCLS accelerator groups are confident that the LCLS can be operated at lower frequencies, i.e. 60 Hz or 30Hz, for experiments that require a lower repetition rate, but the machine will become less stable as the pulse frequency is decreased. It is unlikely that the machine can be run in single pulse mode with pulses on demand with much reproducibility. To select just one pulse, therefore, it would be best to have a pulse shutter.

![Image of shutter produced by Azsol GmbH showing one of the solenoid magnets used to acutuate the shutter.](image)

**Figure 7:** Picture of shutter produced by Azsol GmbH showing one of the solenoid magnets used to actuate the shutter.

A device that would be a suitable pulse shutter is being produced by Azsol, GmbH in Switzerland. The shutter is comprised of a teeter-totter like paddle with solonoidal magnets below either end of the paddle. The paddle can be moved from a position in the beam, to a position out of the beam in approximately 3 msec, fast enough to allow a single pulse to pass through, while subsequently closing before the next pulse. A UHV version of the shutter is being prepared and initial tests show that it is working as expected. One modification would be required – the paddle would need to be coated with a material that can be illuminated by the FEL beam without damage.

7.1. The shutter should be mounted in a location upstream of the focusing optics where the FEL beam has the largest beam waist.

7.2. The shutter should be attached to a mount that allows it to be positioned in or out of the beam with sufficient clearance that it will not interfere with the beam when it is not in use.
8. Controls and Data Acquisition:

The diagnostics section will require a variety of controls including positioning motors, vacuum control and timing operations. Additionally, data acquisition needs for the beam screens, pulse energy monitor and magnetic bottle electron spectrometer need to be considered.

8.1. Controls:

8.1.1. The position of the chamber in the beam will need to be controlled using the stand. Rotations around specific points, such as the front of the differential pumping entrance, should be possible.

8.1.2. Position (proximity?) sensors on the bellows protection mechanism must be used to prevent damage of the bellows due it being extended beyond its range of tolerable motion.

8.1.3. The gas needle should be alignable while watching both its position with a video camera and while measuring a signal from the sample as a function of position.

8.1.4. The upstream beam viewing screen will need to be positioned properly in the beam to allow the attenuated beam to pass through the central aperture of the SiN window.

8.1.5. The pulse energy monitor will also need to be positioned properly in the beam and withdrawn from the beam into the calibration position where its response can be calibrated with a laser.

8.1.6. The pulse energy calibration laser should be remotely operable so that the calibration can be done while the hutch is secured in operational mode.

8.1.7. The pulse tube cooler for the pulse energy monitor should be monitored by the control system, along with the temperature of the sensor.

8.1.8. The vacuum system should be controlled and interlocked as appropriate to allow single button pump down and venting operations as well as fail safe operation to prevent damage to the machine.

8.1.9. Voltages for electrostatic elements in the magnetic spectrometer should be settable by the user within predefined limits using the control system and interlocked to the vacuum conditions of the chamber.

8.2. Data Acquisition:

8.2.1. Waveforms from the magnetic bottle spectrometer detector should be acquired and stored on a pulse-by-pulse basis for later binning/analysis.

8.2.2. The pulse energy monitor is also read using a waveform measurement. The resistivity of the GMR sensor, which is sensitive to the temperature of the Si substrate, is read for a period of time following an FEL and converted to deposited energy. Occasionally it will be useful to store the waveform, i.e. for diagnostic testing, but usually it will be sufficient to simply convert the measurement to a pulse energy in real time.

8.2.3. Images from the beam screens should be acquired at 120Hz, coincident with the LCLS pulses. The images should be processed according to algorithms that are to be determined, and ideally the position and size of the beam stored in the data set. Occasionally it will be necessary to save a full image for subsequent analysis.