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| PHYSICS REQUIREMENT DOCUMENT (PRD) | Doc. No. SP-391-000-26 R0 | LUSI SUB-SYSTEM CXI |
| Physics Requirements for the CXI Particle Injector System | | |
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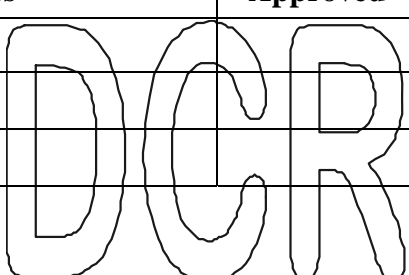
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1. Overview

The CXI particle injector system will consist of a differential pumping system that will include an aerodynamic focusing lens system capable of transferring an aerosol from atmospheric pressure to the vacuum of the CXI Sample Chambers (PRD# SP-391-000-20 and PRD# SP-391-001-41) and delivering the aerosol particles to the interaction region with the LCLS beam.

Also included in the Particle Injector System are aerosol generation devices as well as aerosol diagnostics devices to be used on the aerosol at atmospheric pressure.

The Particle Injector System will also include diagnostics for the particle beam inside and outside the vacuum of the CXI Sample Chambers (PRD# SP-391-001-41 and PRD# SP-391-000-20).

The differential pumping interface, the aerodynamic lens and their mounting mechanism are referred to as the particle injector while other devices, such as aerosol generators, aerosol diagnostics and in-vacuum particle beam diagnostics are part of the CXI Particle Injector System but not the particle injector itself.

The coordinate system is defined in Mechanical Design Standards Supplement DS-391-000-36.

2. Performance Requirements

- 2.1. The particle injector shall be capable of delivering particles in the size range 10-1000nm. Two or more aerodynamic lens stacks may be required to provide optimum focusing for a specific size range, i.e. 10-250nm vs. 250-1000nm.
- 2.2. The design goal of the particle injector shall be to produce a focus of 250 μm or less for all sizes in the range specified in Requirement 2.1.
- 2.3. It shall be a design goal to have greater than 50% transmission of the particles to vacuum through the differential pumping interface.

3. Size Requirement

- 3.1. The particle injector shall interface to the CXI Sample Chambers through a 6" CF flange.
- 3.2. A cylindrical volume with diameter of 4" starting 2" above the interaction region shall be reserved for the particle injector and shall be clear of obstructions in the CXI sample chambers.
- 3.3. The 4" cylindrical volume in the 2" directly above and below the interaction region in the CXI sample chambers shall be as free of components as possible to allow the Particle Injector nozzle to approach the LCLS beam as described in Requirement 4.5.

4. Particle Injector Positioning Requirements

- 4.1. The particle beam shall travel in the $-Y$ direction. The injection shall be from above the interaction region with the particles travelling down.
- 4.2. The axis of the Particle Injector shall be aligned to the Y-axis to within ± 1 degree in pitch and yaw. This shall be achieved with machining tolerances.
- 4.3. It shall be possible to position the particle beam in the X and Z directions over a range of at least 10 mm with the center of travel centered on the designed interaction region in the sample chamber to within 0.5 mm.

| Motion | Nom. Position | Range | Resolution | Repeatability | Stability |
|--------|---------------|-------------------------------------|------------------|------------------|-------------------------------------|
| X | 0 mm | $-5 \text{ mm} < x < 5 \text{ mm}$ | 10 μm | 10 μm | 1 μm (10 μm) |
| Z | 0 mm | $-5 \text{ mm} < y < 5 \text{ mm}$ | 10 μm | 10 μm | 1 μm (10 μm) |
| Y | 0 mm | $0 \text{ mm} < x < 150 \text{ mm}$ | 10 μm | 10 μm | 1 μm (10 μm) |

Table 1: Positioning resolution, stability and repeatability requirements for the particle injector. The stability requirement is for short term (a few minutes) and the number in parentheses is for long-term (12 hours). Both stability numbers refer to stability with respect to the focal spot of the LCLS beam inside the CXI Sample Chambers.

- 4.4. The particle injector shall have the motorized motions listed in Table 1.
- 4.5. It shall also be possible to bring the exit nozzle of the particle injector into the interaction region inside the Sample Chambers. This will allow for a rough alignment of the injector with the LCLS beam. Some of the components inside the Sample Chambers will have to be move for this to occur.
- 4.6. The particle injector shall be reentrant into the CXI Sample Chambers with the Y position motorized as described in Table 1.

5. Aerosol Generator and Diagnostics Positioning Requirements

- 5.1. The distance between the aerosol generators, as well as the aerosol diagnostics, and the inlet of the differential pumping interface (the particle injector) shall be minimized to reduce the loss of particles in the aerosol transport tubing. This will likely require a platform around the Sample Chamber at a height near the top of the chamber to support all the aerosol generators and aerosol diagnostics devices.
- 5.2. The design goal shall be to have the aerosol generators located less than 30 cm from the inlet of the particle injector.

6. Vacuum Requirements

- 6.1. The particle beam focus described in Requirement 2.2 shall be achieved with an aerodynamic lens focusing system and a differential pumping interface.
- 6.2. There shall be 3 stages in the differential pumping interface.
- 6.3. The first stage shall allow for a pressure range of 1 to 30 Torr.
- 6.4. The second stage shall allow for a pressure range of 001 to 1 Torr.
- 6.5. The third stage shall allow for a pressure range of 10^{-5} to 10^{-3} Torr.
- 6.6. There shall be the possibility of remotely adjusting the pressure in each stage to achieve focusing of particles of the desired size.

7. Electrical Requirements

- 7.1. The electronic components associated with the charge detectors are very low noise devices and all rack mounted electronics for the charge detectors shall be mounted away from high noise electronics inside the racks. Preferably, they should be shielded from all possible electronic interference in the racks.

8. Aerosol Generation Requirements

- 8.1. The Particle Injector System shall allow for the aerosolization of a variety of samples including particles in solution and powders.
- 8.2. The aerosol generation system shall be compatible with organic and inorganic samples, as well as amorphous and nano-crystalline samples.
- 8.3. The aerosol generation system shall be compatible with particles in the size range of 10-1000nm.

- 8.4.** It shall be possible to neutralize the aerosol particles after the creation of the aerosol. This will be achieved using an ionized bath gas produced with a radioactive source, typically Po210.
- 8.5.** It shall be possible, with future upgrades, to select particles based on their chemical composition and size before they are aerosolized.

9. Aerosol Diagnostics Requirements

- 9.1.** It shall be possible to select particles within a narrow size range from the aerosol suspension in the size range 10-1000nm.
- 9.2.** There shall be a diagnostic device capable of measuring the size distribution of the aerosol in the size range 10-1000nm.
- 9.3.** There shall be a diagnostic device capable of measuring the aerosol concentration at atmospheric pressure.
- 9.4.** It shall be possible to sample the aerosol onto a suitable substrate for offline characterization.

10. Particle Transfer to Vacuum Requirements

- 10.1.** All aerosol transfer lines shall be kept as short as possible by positioning the aerosol generation devices and the aerosol diagnostic devices as close as possible to the particle injector inlet.
- 10.2.** It shall be possible to remove the moisture from the aerosol suspension before it enters the differential pumping interface.

11. Particle Beam Diagnostics Requirements

Charge Detectors

Devices known as Charge Detectors will be used inside the CXI Sample Chambers to detect single charged particles as they fly through the Charge Detector. The charge detector is a device capable of measuring the image charge produced on a conductor by a charged particle flying past it. It will be used to determine the transmission of the particle injector and for alignment of the particle beam. Two Charge Detectors will be used inside the CXI Sample Chambers. The first one will be attached directly to the Particle Injector (right after the injector exit nozzle) while the second will be mounted inside the sample chamber, completely detached from the injector. The following are the requirements for the Charge Detectors.

- 11.1.** The Charge Detectors shall be capable of detecting particles with as few as 500 electron charges.
- 11.2.** The Charge Detectors shall measure the charge of the particles with an accuracy of 100 electrons.
- 11.3.** The Charge Detectors shall measure the velocity of the particles with an accuracy of 10 m/s.
- 11.4.** The first Charge Detector and its associated in-vacuum electronics shall be attached directly to the exit nozzle of the Particle Injector.
- 11.5.** The first Charge Detector and its in-vacuum electronics shall be designed in a way that allows the entire assembly to pass through the 6" CF flange for the particle injector. This will allow the entire injector and Charge Detector assembly to be removed without disassembly.
- 11.6.** The signal cable(s) or wire(s) feedthroughs of the first Charge Detector shall be included in the particle injector assembly so that no wire or cable needs to be disconnected in order to remove the particle injector and the first Charge Detector assembly.
- 11.7.** The positioning requirements for the second Charge Detector are found in the PRDs for the 1 micron and 0.1 micron sample chambers ((PRD# SP-391-001-41 and PRD# SP-391-000-20 respectively).

Particle Beam Viewer

A particle beam viewer shall also be implemented to characterize the beam profile and position. The following requirements apply to this particle beam viewer.

- 11.8.** A low power unfocused laser beam with a roughly 1 cm diameter shall counter-propagate with the particle beam. This means this laser beam shall travel in the +Y direction.
- 11.9.** The light scattered by this laser beam shall be focused onto a CCD located outside the sample chamber. The sample viewer described in the CXI Sample Chamber PRDs (SP 391-000-20 and SP 391-000-141) would be ideal for viewing the particle beam on the LCLS axis.
- 11.10.** A second achromatic lens and CCD shall view the particle beam perpendicular to both the particle beam and the LCLS beam. This requires a port on the Sample Chamber that would be located either in the +X or -X direction.

12. Maintenance Requirements

Past experience with an existing similar particle injector indicates that clogging could be an issue. In order to minimize down time, some requirements exist to allow rapid replacement of some devices and for cleaning without breaking vacuum. This section outlines these requirements.

- 12.1.** There shall be a valve at the entrance of the aerodynamic lens stack which when closed shall allow for the first differential pumping stage to be removed without breaking vacuum.
- 12.2.** Two identical copies of the first pumping stage shall exist so that one can be used while a second one is being cleaned or unclogged.
- 12.3.** It shall be a design goal to include a valve at the exit of the aerodynamic lens stack which when closed shall allow for the lens stack to be removed without breaking vacuum.

13. Controls Requirements

- 13.1.** Some commercial devices for aerosol generation and diagnostics at atmospheric pressure will be required. All of these devices shall be fully controlled remotely via the instrument control system. No manual knobs or controls are to be allowed. If the commercial devices contain manual controls, they shall be modified accordingly for remote control.
- 13.2.** Every axis of motion of the particle injector shall be motorized and controlled remotely via the instrument control system.
- 13.3.** The position of every actuator shall be recorded in the scientific metadata for every LCLS pulse for which scientific data is recorded.
- 13.4.** It shall be possible to record every parameter of the aerosol generation and diagnostics devices in the scientific metadata for every LCLS pulse for which scientific data is recorded.
- 13.5.** The users of the instrument shall select from a list of parameters which ones they wish to record in the metadata for a given run.
- 13.6.** Every controlled parameter included in the list that can be saved shall also be displayed on the control station at the request of the users with a refresh rate of 1 Hz.
- 13.7.** The pressure in each differential pumping stage shall be monitored and controlled remotely via the instrument control system.
- 13.8.** It shall be possible to scan any parameter controlled by the instrument control system and record the signal at each point of the scan for any “detector” including but not limited to the following: charge detector rate counters (see Section 14) , Ion TOF hit rate counter (see PRD SP-391-000-30), Faraday cup current.

14. Data Acquisition Requirements

The particle injector itself has no data acquisition requirements. However the charge detectors do have requirements related to data acquisition.

- 14.1.** The image charge pulse on the charge detector pickup tube shall be amplified, differentiated, digitized and recorded with a time resolution of 100 ns.
- 14.2.** There shall be a trigger level set on the digitized signal, set on the rising edge of the differentiated pulse to trigger the recording of the pulse.
- 14.3.** Each pulse shall be recorded with 2000 samples per pulse.
- 14.4.** The digitized waveforms shall be displayed on the instrument console at a rate of 5 Hz when desired by the users.
- 14.5.** The average waveform shall be updated at a rate of 5 Hz and reset at the discretion of the users.
- 14.6.** It shall be possible to record each individual pulse coming from single particles passing through the charge detector or to record an average trace over multiple particles, with this number set by the users via the instrument control system.
- 14.7.** There shall be a charge detector rate counter which shall measure the number of detected particles (number of the times the trigger is activated) every second. This counter shall reset every second.
- 14.8.** The charge detector rate shall be displayed on the instrument control console at a rate of 1 Hz.
- 14.9.** The charge detector rate shall be recorded in the experimental metadata if desired by the users.
- 14.10.** The pulse height of each pulse and the time between the 2 peaks of the differentiated pulse shall be calculated for each triggered pulse.
- 14.11.** The pulse height and time duration shall be displayed at a rate of 5 Hz, along with the displayed waveform discussed in Requirement 14.4.
- 14.12.** The average pulse height and time duration shall be displayed at a rate of 5 Hz and reset when desired by the users.
- 14.13.** The average pulse height and duration shall be recorded in the instrument metadata if desired by the users.

15. Interface Requirements

- 15.1.** The particle injector shall interface with the sample chamber through a 6" CF flange located above the interaction region.
- 15.2.** The electronic connections and feedthroughs of the first charge detector shall be fully included in the particle injector assembly.
- 15.3.** The second charge detector electronics and feedthroughs shall be fully included within the design of the sample chambers without any interferences or collisions allowed.

16. Safety Requirements

- 16.1.** No mechanical or electrical safety requirements beyond the standard electrical and mechanical safety requirements.
- 16.2.** There will be safety issues related to the use of a Po210 source to neutralize the aerosol. This source will be fully enclosed within an environment in the aerosol generation

instrument that requires a special tool for access. Hazards will exist when removing or replacing the source. All the necessary safety steps related to the use of such a radioactive source shall be followed, including but not limited to

- Wearing gloves when handling the source
- Only removing the source when necessary
- Replace the source annually, or earlier
- Use a proper enclosed storage when the source is not in use
- Corrosive materials can degrade the integrity of the unit. Do not use chemicals that corrode 303, 304, or 316 stainless steel, copper, silver, braze or epoxy
- Only GERT trained personnel shall be allowed to handle the source

16.3. The aerosol generation equipment used with the Particle Injector will create an atmospheric suspension of nanomaterial that could be smaller than 100 nm. Some safety hazards are associated with inhalation, dermal contact and ingestion of such nanomaterials. The users of the system shall

- Follow the guidelines of the SLAC Nanomaterial Safety Plan
- Attempt to work with lowest risk level of nanomaterials at all times:
 - Low-risk level (green) – bound or fixed nanostructures
 - Solid materials with imbedded nanostructures
 - Solid nanomaterials with nanostructures fixed to the material’s surface
 - Medium-risk level (yellow)
 - Nanoparticles suspended in liquids
 - High-risk level (red)
 - Dry, dispersible nanoparticles, nanoparticle agglomerates/ aggregates
 - Nanomaterials determined to be high risk based on safety assessment (see Section 3.1.3, “Safety Assessment”)
- All work with high-risk level nanomaterials shall be reviewed and approved by the Nanomaterials Safety Committee
- All work with medium risk level nanomaterials shall be performed with quantities <100ml
- Avoid handling nanomaterials in the open air in a free particle state. Whenever possible, handle and store dispersible nanomaterials, whether suspended in liquids or in a dry particle form in closed (tightly sealed) containers.
- Clean up dry engineered nanomaterials with wet wiping
- Transfer nanomaterial samples between workstations in closed labeled containers (microcentrifuge tubes)
- Read the Nanomaterial Safety Plan of the ES&H manual (exhibit, Chapter 40)
- Complete ES&H course on Nanomaterials Orientation and Laboratory Safety Training