X-ray split and delay system for soft x-rays at LCLS

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Abstract

We describe the development of a mirror based x-ray split and delay system (XRSD) for soft x-rays at the Linac Coherent Light Source (LCLS) free electron laser at the SLAC National Accelerator Laboratory. The XRSD will add x-ray pump/x-ray probe capability to the AMO and SXR soft X-ray beamlines, allowing experiments expected to have an impact on basic energy sciences research in areas such as atomic and molecular science, chemical physics, nanoscience, ultrafast science, and imaging.

The AMO and SXR beamline characteristics have been evolving in the last 3 years. An up to date information on the beam specifications can be found at the following link:

https://portal.slac.stanford.edu/sites/lcls_public/instruments/Pages/default.aspx

1. General description

The XRSD divides the LCLS x-ray pulse into two portions, delays one of them by a user-selected time of 0 to 100 femtoseconds (±0.1 fs), then recombines them at a sample focal point for x-ray pump/x-ray probe experiments.

Typical FEL pulse widths at LCLS can be quoted as under 10 fs to over 100 fs. The shortest pulse is expected to be shorter than 10 fs, but this has not yet been measured directly.

Two mirrors located immediately downstream of the AMO/SXR Kirkpatrick-Baez focusing mirrors will split the FEL wave front. The downstream edge of the first mirror will intercept and deflect a portion of the beam towards the focal point. That portion of the beam which passes over the trailing edge of the first mirror will follow a longer path and be deflected by the second mirror positioned in line after the first one. A variation of the vertical position and pitch angle of the second mirror will provide for both a variation in delay between the two portions of the beam and an overlap of the deflected beams at the focal point.(Fig.1, 2)

Variation of beam footprint ratio on each mirror can provide the user with positive or negative delays.
2. Main specifications

| Specification                  | Value                        |
|-------------------------------|------------------------------|
| Energy range                  | 500 to 1800 eV               |
| Delay range                   | 0 to ±100 fs                 |
| Working distance              | 1.2 m                        |
| Resulting KB focal length     | 2.2 m                        |
| Pump probe ratio              | 0 to ±100%                   |
| Mirror pitch resolution       | 0.25 µrad                    |
| Mirror position repetability  | 10 nm                        |
| Mirror motion range           | Rough ±10mm, precise ±30microns |
| Vacuum level                  | $10^{-10}$ torr              |
The following challenges and technical features are addressed in the design of the instrument.
- First mirror’s beam cutting edge quality
- Vacuum quality versus mirrors motion systems
- High resolution mirror positioning
- Slit system

3. **Mirror 1, beam cutting edge**

To obtain a clean division of the x-ray beam into two separate arms of the XRSD the first mirror being used to split the beam must be polished with a $< 2$ nm rms figure error and $< 0.4$ nm rms roughness all the way to a well defined cutting edge of the mirror.

Particular attention was given to obtain a very sharp cutting edge to divide the beam. Carl Zeiss group is manufacturing the mirrors for this instrument. The sharp edge is obtained by lapping a chamfer in the last step of the overall manufacturing and polishing process. Cutting the chamfer after the optical surface has been completely polished is the safest way to obtain the required figure specifications all the way to the edge of the mirror.

Mirror dimensions are
M1: L 150mm x W 25mm x H 70mm
M2: L 400mm x W 25mm x H 80mm

Mirrors are made of silicon with no coating, enabling working energies of 500 to 1800 ev

4. **Vacuum constrains**

Contamination of the mirrors optical surface due to carbon deposits has shown to be a major concern on previous Xx-ray optics at the LCLS. To alleviate these concerns a vacuum in the $10^{-10}$ torr range is required. The XRSD design is providing a vacuum environment that minimizes in vacuum motion and measurement devices to a strict minimum in order to achieve this requirement. Mirrors will be supported on vacuum feed through pedestals that transfert all the motion and control devices to the out of vacuum space (Fig.3)
5. High resolution mirror positioning

The relative pitch angles between the mirrors must be precise to better than 0.25 microradian to maintain pulse overlap at the FEL focus.

The combined mirror motion for vertical and pitch positioning is controlled by a set of two out of vacuum differential interferometers. Motions are obtained through a combination of stepper-motor linear stages and piezo actuators. The overlap of the two beams in the interaction region is verified through additional diagnostics in the experimental chamber. (Fig.4)
6. **Differential interferometers**

Renishaw RLD10-X3DI differential interferometers were chosen for their compact size and compatibility with other linear encoders used in the XRSD system. The standard use of these interferometers is in the measurement of the relative displacement of parallel surfaces. In the XRSD design the use of retroreflectors will provide for the angular offset of the mirror’s lever arms. Renishaw’s RLE system is a unique, advanced homodyne laser interferometer system specifically designed for position feedback applications. Each RLE system consists of an RLU laser unit and two RLD10 detector heads. The system provides the user with sub-nanometre resolution capability.

**Slit system**

A set of two horizontal slits is installed upstream of the mirrors to mask either pump or probe portions of the beam. These slits are mainly used as a diagnostics device to verify the spatial overlap of the two portions of the beam by extinguishing either one of them.

**System delivery**

The XRSD is expected to be ready for user experiments early 2013. It will first be installed on the LCLS-AMO beamline downstream of the KB mirror system. It will allow the use of different types of end station configuration.

**References**

[1] Brendan Murphy – *ICPEAC 2011* – “Split and Delay System for Soft X-ray Pump/Soft X-ray Probe Experiments at the LCLS Free Electron Laser”

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