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ENGINEERING CHALLENGES FOR THE NEH2.2 BEAMLINE AT LCLS-II*

F. O'Dowd†, D. Cocco, J. Defever , S. Guillet, C. Hardin, D. Morton, M. Owens, T. Osier, D. Rich, L. Zhang, G. Dakovski, SLAC National Laboratory, Menlo Park, USA

Abstract

SLAC National Accelerator Laboratory is developing LCLS-II, a superconducting linear accelerator based free electron laser capable of repetition rates up to 1MHz. The NEH2.2 Instrument at LCLS-II will use this combination of exceptionally high flux of monochromatic photons to achieve multidimensional and coherent X-ray experimental techniques that are possible only with X-ray lasers. The challenges, which emanate from delivering the beam from the sub-basement level to the basement of the Near Experimental Hall (NEH) along with the stringent requirements for providing a stable beam at the interaction points, necessitate unique engineering solutions.

With this paper we present the conceptual design for the NEH2.2 Instrument along with an overview of the R&D program required to validate design performance. Furthermore, it will show the design of the proposed Liquid Jet Endstation (LJE) and Resonant Inelastic X-Ray Scattering Endstation (RIXS) that will be installed on the beamline. After introducing the context and the layout of the beamline, this paper will focus on the main technical challenges and present the mechanical design solutions adopted for beam delivery and other strategic components.

INTRODUCTION

The LCLSII is a nextgeneration facility based on advanced superconducting accelerator technology (continuouswave RF) and tunable magnetic undulators. The Xray FreeElectron Laser (FEL) is being designed to deliver photons between 200eV and 5keV with an unprecedented flux, approximately 10^{18}ph/s (0.1mJ/pulse = 10^{12}ph/pulse), at repetition rates as high as 1MHz using a superconducting RF linac (SCRF) while still providing pulses at short wavelengths and high Xray pulse energy over the photon range of 1 to 25keV using the existing copper RF (CuRF) LCLS linac at 120Hz.

The unique LCLS-II capability opens the possibility to follow chemical dynamics with time resolved x-ray absorption and emission spectroscopy as well as time resolved inelastic X-ray scattering. LCLS-II will enable the full implementation of time-resolved resonant X-ray Raman spectroscopy (resonant inelastic X-ray Raman scattering, RIXS). RIXS uniquely provides information on both occupied and unoccupied valence states probed from core levels to achieve chemical specificity.

NEH2.2 BEAMLINE

The NEH2.2 beamline fulfils the need for high throughput spectroscopic and resonant scattering applications with the high repetition rate LCLS-II beam (see key requirements in Table 1). It will take advantage of the unprecedentedly high flux of narrow-band, nearly transform-limited femtosecond soft X-ray pulses to open new scientific opportunities for spectroscopic studies of elementary excitations. The major components include a beamline monochromator, bendable re-focusing optics, pump laser integration and two endstations: Resonant Inelastic X-ray Scattering (RIXS) Endstation and Liquid Jet Endstation (LJE).

Table 1: Key Requirements

Parameter	Range	Comment
Photon Energy	250-1600eV	Reject 3rd harmonic at O
Beamline Transmission	20%	Zero Order
Bandwidth Control	>50,000; 5-10,000	High resolution RIXS
Spot Size	2-1,000μm	Adjustable

X-ray Optical Layout

The layout of the beamline stretches from the Front End Enclosure (FEE) into the Near Experimental Hall (NEH) and ultimately to the upper level, as shown in Figure 1. The beam will be deflected vertically by the soft X-ray monochromator (through a combination of mirrors and a grating) and will rise at an angle of ~7º. A horizontally deflecting flat mirror directs the beam south by ~3º towards NEH 2.2, while the straight-through beam continues to NEH 2.1. The beamline exits the FEE high on the east wall and enters Hutch 1 (AMO), where the exit slit is mounted. The beam continues in Hutch 1, penetrates the ceiling and continues to the basement level of the NEH. The beam is then deflected back down by a combination of a flat and vertically re-focusing mirror, so it is again horizontal, and enters the RIXS Sample Chamber, Figure 2.

The beamline monochromator is projected to house four gratings ruled at different groove densities. Three of them are used to provide very high spectral resolution. The fourth one has a low groove density (50l/mm) and will provide transform limited beam with resolution between 5 and 10,000. The footprint of the beam on the grating is controlled using the elliptical bendable mirror upstream of the monochromator. For the very high resolution option, approximately 10^{15}ph/s, in first diffraction order, at resolving power (RP) up to 50,000 will be made available at the sample location in high repetition rate mode.

* fodowd@slac.stanford.edu

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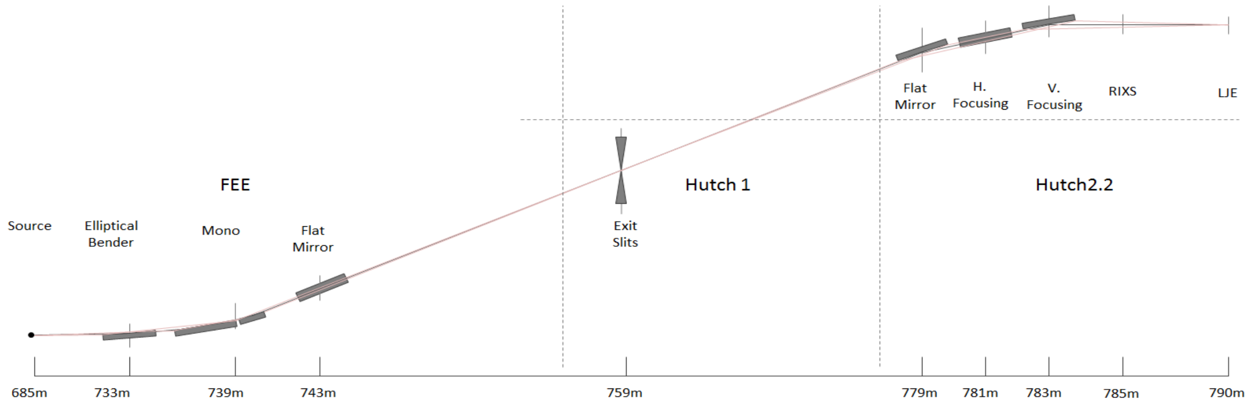

Figure 1: NEH2.2 Beamline Layout.

Liquid Jet Endstation

LJE is comprised of a sample chamber, designed with emphasis on soft X-ray spectroscopy experiments on liquid samples, and two X-ray emission spectrometers, the Varied Line Spacing (VLS) portable spectrometer and the Transition Edge Sensor (TES) spectrometer. The VLS is a grating-based spectrometer which disperses the beam and the spectrum is recorded by a 2D position-sensitive detector. Here resolving power >2,000 can be achieved. Alternatively the TES spectrometer allows for higher count rate at resolving power of ~1,000.

For typical liquid-based experiments, samples in solution are introduced via a jet, mounted on a manipulator. Adequate pumping must be provided to ensure no beamline contamination and proper detector operation. Key requirements for this endstation include ensuring spatial and temporal overlap of x-ray, pump laser and sample jet; sample positioning and stability; sample delivery and extraction and data acquisition rates.

RIXS Endstation

The RIXS spectrometer at LCLS-II will have a target resolving power (RP) of 50,000 and a combined (beamline + spectrometer) RP of better than 30,000 at 1keV. A unique aspect of the RIXS instrument enabled by LCLS-II is the capability of performing time-resolved measurements with high energy resolution (e.g., 100fs correspond to 18meV at the Fourier-transform limit) to study the dynamics of these collective excitations and photo-induced non-equilibrium states. Upon photo-excitation, one can readily probe the temporal evolution of elementary excitations.

For typical RIXS experiments, solid samples are mounted on in-vacuum diffractometer and cooled to low (down to few K) temperatures. The soft x-ray fluorescence is spectrally dispersed by a diffraction grating and the spectrum is recorded by a 2D position-sensitive detector. In order to accurately map out the momentum transfer-dependent excitations, the spectrometer (grating and detector) needs to rotate over a large angular range (40º-150º).

The spectrometer consists of a combination of horizontally collimating mirror and vertically displacing set of gratings, together with a multilayer polarization analyzer and 2D detector. The positioning of the detector in the focal plane along with its stability and that of the grating are key parameters in delivering performance. Sources of vibration in and around the RIXS endstation need to be minimized so as not to adversely affect measurements.

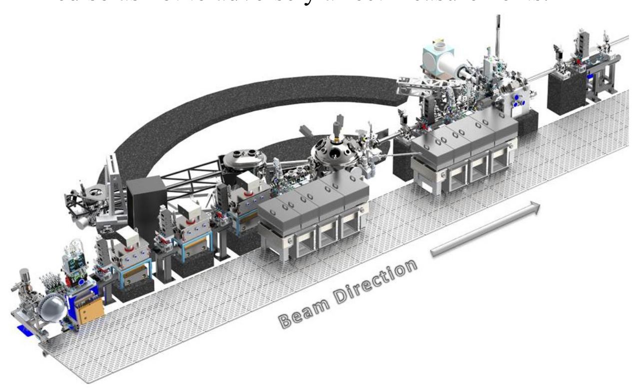

Figure 2: NEH2.2 Endstations.

CHALLENGES

The NEH consists of three floors: a ground floor, basement and sub-basement levels. The basement floor on which the NEH2.2 instrument will be installed is 36” thick reinforced concrete, which then reduces to 18” on the North end of the hutch and extends to the walkway beyond. Delivering stable beam, in both position and energy, while also maintaining overlap with the optical laser and sample delivery system provides significant challenges for the design of this instrument. This section will present some of the main challenges and proposed design solutions.

Building Structure

The layout of the optical system is a multifactorial optimization to meet scientific requirements through trade-offs between technical, resource and space constraints. Delivering beam from the FEE to an upper level of the NEH is not without significant challenges and risk. Foremost among those is maintaining the required spectral resolution. A concept solution is currently being developed which will use a photoemission spectrometer for diagnostic purposes. In this design, the exit slit will be used as a pick-off to send an offset beam to this diagnostic, allowing a non-destructive feedback on energy resolution, Figure 3.

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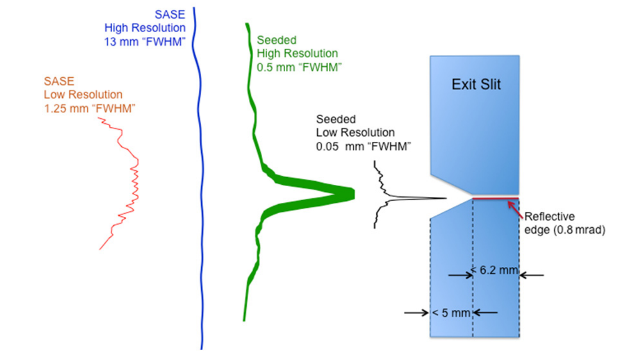

Figure 3: Relative dimension of the dispersed beam at the exit slit location.

Stability

The South and East sides of the building are fully underground, while the North and West are exposed to the elements. The induced heating by solar radiation on the building has led to noticeable bowing of the basement and sub-basement floors over a diurnal cycle. Thermal measurements of the NEH building show large variations in temperature over this cycle, which is manifested in relative variation in floor-to-ceiling heights and across individual slabs. Figure 4 shows hydrostatic levelling system (HLS) measurements on the floor of the NEH2.2 hutch.

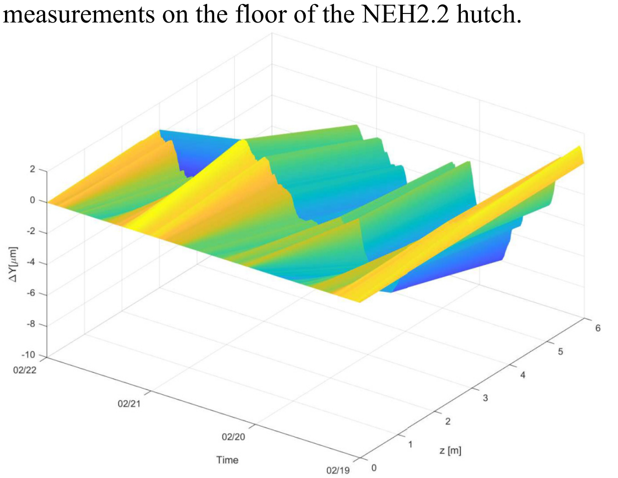

Figure 4 Hydrostatic Level Measurements of Hutch2.2.

A global solution to insulate the building was proposed. Initial analysis has shown that the variation can be reduced by a factor of 30 through insulation of the North and West faces as well as improved performance through shading of the exposed roof. Furthermore, where forced air ventilation was traditionally used, the new hutches will employ radiant panels to remove short term thermal oscillations and pressure fluctuations.

The FEE is a separate structure and measurements of this area show a diurnal change of approximately 10 μm (see Table 2). Comparing the building motion measurements with the and the outside temperature a clear correlation can be derived.

Table 2: Floor Deformation

Condition	West-East	North-South
Current	1.8 μm	12.63 μm
Roof Shading	1.2 μm	8.16 μm
Foam 20cm	0.07 μm	0.65 μm
Foam + Shading	0.06 μm	0.29 μm

Vibration

A series of measurements were taken in the location of the future NEH2.2 hutch to measure the vibration on the basement level. As shown in Figure 5 many external sources can induce vibration on the floor of the hutch.

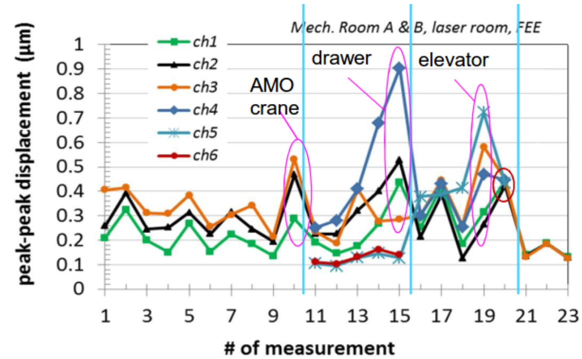

Figure 5 Vibration Measurements in NEH.

While it will be possible to restrict much of this noise, it is proposed to include an accelerometer in the hutch to identify and veto data above a given threshold level.

Cooling

The monochromator consists of a pre-focusing mirror, flat mirror and grating, providing a fixed exit angle. Up to 200W beam power will irradiate the monochromator. To preserve the beam quality, all the optics shall be water-cooled. Particularly challenging is the case of the flat mirror. During the scan, the beam position on the flat mirror will change with energy, inducing a significant temperature variation along its length. This temperature variation results in a aspherical thermal 'bump' around the beam footprint, impossible to correct entirely with a bender.

A scheme will be implemented with variable length cooling that will allow optimization of the mirror cooling to change with the changing footprint and location of the beam.

CONCLUSION

The NEH2.2 beamline is progressing through its preliminary design stage, with the LJE expected to be operational in June 2020 and RIXS June 2021.

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