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CXLS INVERSE COMPTON SCATTERING INTERACTION POINT CHAMBER*

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Abstract

The Inverse Compton Scattering Interaction Point (ICS-IP) vacuum chamber provides a UHV environment where the electron and IR laser beams are overlapped in space and time to generate hard x-rays between 4 and 20 keV. The chamber has over two dozen motorized stages that position YAG screens with ~10 nm precision utilizing the EPICS framework for instrumentation interface. Using agile programming methods, MATLAB GUIs were created to control all the motors inside the chamber. Each YAG screen has a linear array of laser drilled holes ranging from microns to millimeters (depending on the diameter of the beam being measured), which are imaged by cameras mounted on top of the chamber. An IR lens focuses a ~30 mm collimated laser beam to ~10 µm with a ~210 mm focal length. The lens is secured to a 3-axis stage assembly to enable precise beam axis positioning. Beam pointing to the interaction point (IP) is adjusted using a motorized IR mirror. The focused IR laser pulse is convolved with an electron bunch at the IP to generate x-ray pulses at 1 kHz. A Montel x-ray optic, mounted on a six degree of freedom Nano-positioner, receives and collimates each divergent x-ray pulse coming from the IP. When freely diverging x-rays are desired, the Montel x-ray optic is retracted from the beam path. We present the systems integration of the chamber, diagnostics elements, and control software and comment on its performance during commissioning.

INTRODUCTION

The Compact X-Ray Free Electron Laser (CXFEL) Laboratory is part of the Biodesign Institute at Arizona State University (ASU). The facility is located in the basement of Biodesign C on the ASU Tempe Campus. The building was designed to host two compact x-ray beamlines, the Compact X-Ray Light Source (CXLS) and the CXFEL. The CXLS beamline will generate non-coherent hard x-rays between 4 and 20 keV, whereas the CXFEL beamline will be able to generate either hard or soft x-rays that are fully-coherent. The CXLS beamline build began in 2019 and x-rays were generated for the first time in February of 2023. The CXLS beamline is in commissioning, with first experiments expected in late 2024. CXFEL construction is ongoing with funding from an NSF RI-2 Midscale Research Infrastructure Award [1].

What separates the CXFEL Laboratory beamlines from traditional XFELs are their compact size and low-cost relative to current large XFELs operating across the globe. The accelerator beamlines for the CXLS and the CXFEL are each approximately 10 m long, in comparison to the multi-km length of existing XFELs. The innovation that allows the CXFEL beamlines to be much more compact, and therefore much less expensive, is the use of inverse Compton scattering (ICS) to generate x-rays. ICS utilizes an optical undulator to generate x-rays, while traditional XFELs require a long linear array of undulator magnets that can be over 170 m long to produce x-rays. The CXLS beamline uses a high-power IR laser beam as the optical undulator to generate x-rays. The laser produces 1030 nm, 100 mJ pulses at the same 1 kHz repetition rate as the accelerator [2]. The Inverse Compton Scattering Interaction Point (ICS-IP) vacuum chamber provides a UHV environment where ICS can occur. The ICS-IP vacuum chamber is the nexus of the CXLS beamline, as it contains the location where the electon beam interacts with the IR laser beam to produce hard x-rays that can be used in experiments. The mechanical design and integration, controls development testing, and ICS-IP chamber commissioning are presented.

MECHANICAL INTEGRATION

Description of Systems

The ICS-IP chamber is comprised of five primary systems that are necessary to control, capture, and diagnose the properties of the different beams inside the chamber. The first system involves the transportation and diagnostics of the electron beam. YAG screens having a predetermined array of laser drilled holes are used as a beam diagnostic. If a beam is smaller than the hole, and is centered in the hole then nothing will be seen. If, however, a beam is only slightly smaller than the hole and is off of center then the beam will intercept the YAG and the intercepted region will glow green. The "holey" YAG arrays are used at the following positions: e-beam chamber entrance, e-beam interaction point (IP), e-beam chamber exit, x-ray free divergent beam path, and x-ray entrance to the Montel optic, and Montel collimated x-ray path. The scintillation of the YAG allows it to be imaged by cameras [3].

The second system essential to operating the ICS-IP chamber is the laser system. The laser system consists of an optical train comprised of two sets of IR lenses and IR mirrors. The in and out coupling lenses are attached to motorized stage stacks that allow the lenses to be precisely positioned in X, Y, and Z. Furthermore, the IR mirrors are secured in custom frames that utilize Picomotor actuators, which enable precise control of the tip and tilt angles of the mirror. The mirror and lens assemblies collectively provide

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precise control of the IR beam trajectory and the spot size at the IP, which is necessary for ICS x-ray generation.

The third system enables the capture and collimation of the x-rays produced at the IP. A six degree of freedom Nano positioner with a linear stage mounted on top of it is located downstream of the IP. A Montel collimating x-ray optic is secured to the linear stage. The Montel optic enables the capture and collimation of x-rays coming from the IP, but it can also be retracted from the beam path using the linear stage. This results in a freely diverging x-ray beamline that can be used for x-ray phase contrast imaging experiments. Downstream of the Montel optic are two controllable stage stacks that are used to position holey YAG screens that intercept the collimated x-rays leaving the Montel optic or the freely diverging x-rays originating from the IP. Figure 1 below shows a CAD representation of the components and beams inside the ICS-IP chamber and examples of the holey YAG screens.

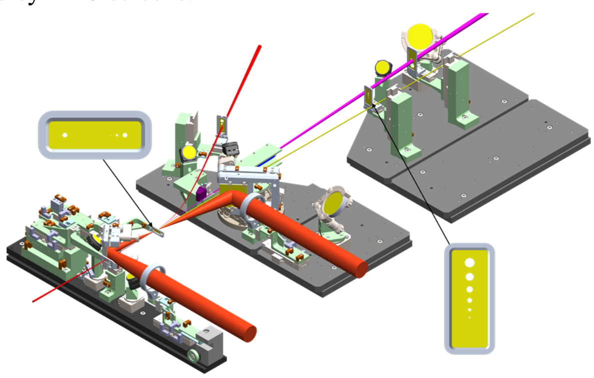

Figure 1: ICS-IP chamber internal assembly and YAGs.

The fourth key system for diagnosing the beam dynamics in the ICS-IP chamber is the camera imaging system. There are seven cameras mounted on top of the IP chamber. These cameras point straight down at mirrors that are strategically positioned on either a static mount or a rotation stage to look at the programmable holey YAG screens. There are LEDs positioned proximal to each of the screens to enable viewing of the YAG screens in the closed chamber. In addition, programmable focus lens controllers are integrated into three of the lenses, which enable remote control of the camera focus.

The last critical system for the ICS-IP chamber is the vacuum system. There are three Pfeiffer turbopumps mounted on the sides of the chamber that create a UHV environment inside the chamber that is ~10^{-8} torr. Figure 2 shows a CAD representation of the exterior of the ICS-IP chamber and how the cameras, turbopumps, and UHV feedthroughs are secured to the chamber.

Chamber Design & Installation

The ICS-IP vacuum chamber was designed by the by the CXFEL team and fabricated by Kurt J. Lesker. Detailed dimensional drawings for every panel of the chamber were provided to Kurt J. Lesker with a suggested welding sequence of the panels. The acceptable tolerances were discussed and agreed upon with the manufacturer. All of the individual vacuum chamber panels were made with 316 stainless steel and the tunnel section was made with 316LN stainless steel. The tunnel is encompassed by a large dipole magnet; therefore, 316LN stainless steel was selected for its nonmagnetic properties to minimize any perturbations to the magnetic field created by the dipole magnet. The chamber was designed with removable lids and flange ports to allow for easy installation of the internal components. Figure 3 shows the lids and flange ports that can be removed and installed on the chamber.

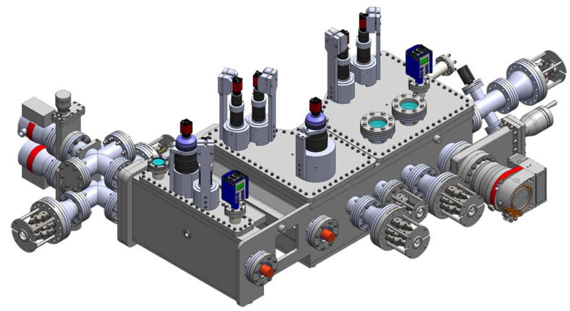

Figure 2: External representation of the ICS-IP chamber.

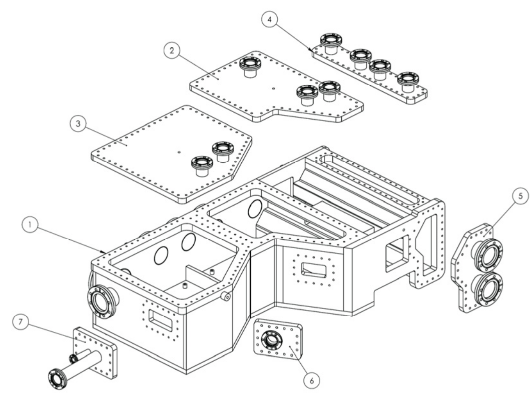

Figure 3: ICS-IP chamber lids.

The chamber was inspected and quality control checks were performed upon receival to ensure tolerance specifications had been met. Before integrating the chamber into the beamline, three motherboards were secured inside the chamber. The motherboards are secured to standoffs that are welded to the chamber to ensure no motherboard warpage during UHV operation. Each motherboard has cone-groove-flat kinematic mounts that allow daughterboards containing all the internal components to be precisely and repeatedly registered into the chamber. The chamber is mounted on top of a frame that enables it to be precisely positioned in all six degrees of freedom when placed on the beamline granite girders.

Subsystem Build & Integration

An open-frame test setup was designed and built inside a clean room hood to enable full system functional testing before final installation inside the ICS-IP chamber. Build-kits were prepared for each subsystem stage stack, which allowed the detailed assembly plan to be easily executed. The stage stacks were installed onto the daughterboards and all the mirrors were adjusted to look at the intended location on each of the holey YAG screens. All of the

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motors, LEDs, and cameras were tested in this open-frame setup before final installation into the chamber. Once the full set of system readiness tests were completed, the daughterboards were loaded into the chamber and secured to the motherboards. The UHV cables for all twenty-six motors, the hexapod, and five LEDs, were routed to their respective vacuum feedthrough ports and then the airside cables were routed from the UHV feedthroughs to their controllers to complete the wiring connections. After a final set of tests were performed with the chamber fully-loaded, the chamber lids were installed, and it was pumped down to UHV.

CONTROLS DEVELOPMENT

EPICS Integration

All of the stages, LEDs, and cameras were integrated into the CXFEL Labs EPICS architecture. EPICS is a distributed control platform that allows devices to be remotely controlled from any Linux workstation that is connected to our private VLAN. Open-source motor-record repositories on GitHub were leveraged to minimize the software development effort. Once the open-source file structure was integrated, the substitution and start-up files for our input output controllers (IOCs) were tailored to our devices. The substitution file defines the process variable names, and it is used to specify several motor parameters like the travel direction, speed, and limits for each motor, while the start-up file contains key information like the IP address of the controller. The IOC sends commands directly to the controller and gets readbacks of the positions or any errors that were logged on the controller.

MATLAB Graphical User Interfaces

Graphical user interfaces (GUI's) were developed using MATLAB App Designer with an agile software development approach, which is an iterative, incremental, and adaptive process that incorporates feedback from stakeholders early and often. A master dashboard GUI (see Fig. 4) was created that allows users to launch controls GUIs for each of the subsystem stage stacks.

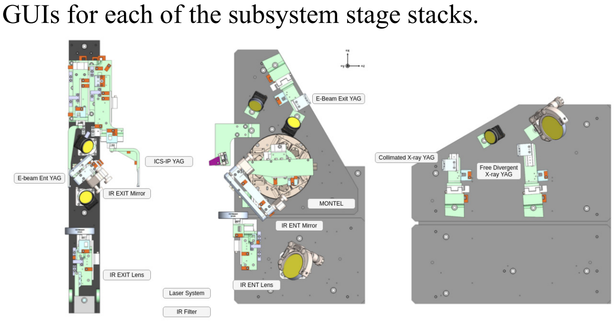

Figure 4: ICS-IP master controls dashboard.

A subsystem GUI is launched by pressing its individual button on the master panel. Each subsystem GUI has a dedicated panel for each motor axis that is part of the stack (see Fig. 5). The panels enable the user to make absolute and relative moves for each of the axes. The user can also complete moves to customizable, preset positions. There are also live position readbacks and an emergency stop button. Moreover, there are buttons for executing coordinated motions like the homing routine or for retracting/inserting a YAG screen.

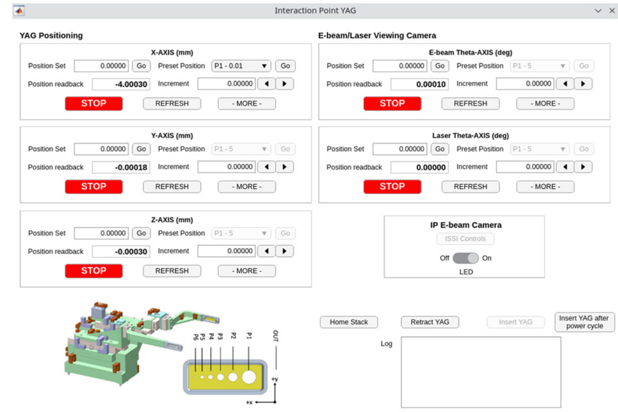

Figure 5: IP YAG controls GUI.

COMISSIONING

The ICS-IP chamber enables beamline scientists to get information about the electron beam dynamics inside the chamber, overlap the laser and electron beams, and it helps them track the trajectory of the x-rays generated. The IP YAG screen has a linear array of holes ranging from microns to millimeters, which are useful for finding the size of the electron beam at the interaction point. Furthermore, the IP YAG is used to get the electron beam and the IR laser beam overlapped at the interaction point in both space and time, which is essential for x-ray generation. In addition, there is a bare SMA wire positioned across the center of one of the 1 mm holes in the holey YAG array, which can be used to determine the timing of the IR laser pulses. The YAG screen at the entrance of the Montel optic has been used to intercept x-rays created at the IP. Current commissioning work addresses the alignment of the Montel optic to collimate the x-rays for transport into the adjacent experimental hutch for experiments.

CONCLUSION

The ICS-IP vacuum chamber provides a UHV environment where the electron beam and laser beam interact to generate x-rays that will be used in experiments. Chamber subsystems provide diagnostics for the electron, laser, and x-ray beams. The chamber body was designed with tight-tolerances in order to interface with beamline magnets. An open-frame test setup was designed and constructed to enable rigorous sub-system testing before final installation in the chamber. An agile software approach was used to integrate all the devices inside the IP chamber into our EPICS architecture. User friendly, intuitive GUIs were created using MATLAB App Designer that enable full control of the chamber from inside the controls room. The ICS-IP chamber has been fully commissioned as a subsystem and is now routinely used in the commissioning work of higher-level downstream systems.

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REFERENCES

[1] W. Graves, “The CXFEL project at Arizona State University”, presented at the IPAC'24, Nashville, TN, USA, May 2024, paper MOPG14, this conference.

[2] W.S. Graves *et al.,* “Compact x-ray source based on burst mode inverse Compton scattering at 100 kHz”, *Phys. Rev. ST Accel. Beams*, vol. 17, p. 120701, Dec. 2014. doi:10.1103/PhysRevSTAB.17.120701

[3] C. Behrens *et al.,* “Few-femtosecond time-resolved measurements of X-ray free-electron lasers”, *Nat. Commun.*, vol. 5, p. 3762, Apr. 2014. doi:10.1038/ncomms4762