PHOTON DIAGNOSTICS AND PHOTON BEAMLINES INSTALLATIONS AT THE EUROPEAN XFEL

Jan Grünert, Andreas Koch, Naresh Kujala, Wolfgang Freund, Marc Planas,
Florian Dietrich, Jens Buck, Jia Liu, Harald Sinn, Martin Dommach, Serguei Molodtsov,
European XFEL GmbH, Albert-Einstein-Ring 19, 22761 Hamburg, Germany

Abstract

The European X-ray Free-Electron-Laser (XFEL.EU) is a new a 4th generation light facility which will deliver radiation with femtosecond and sub-Ångström resolution at MHz repetition rates, and is currently under construction in the Hamburg metropolitan area in Germany. Special diagnostics [1,2] for spontaneous radiation analysis is required to tune towards the lasing condition. Once lasing is achieved, diagnostic imagers [3], online monitors [4], and the photon beam transport system [5] need to cope with extreme radiation intensities. In 2015 the installation of machine equipment in the photon area of the facility is in full swing. This contribution presents the progress on final assemblies of photon diagnostics, the installation status of these devices as well as of the beam transport system, and recent design developments for diagnostic spectrometers and temporal diagnostics.

CONTENTS

This paper starts with a brief overview of the photon part of the European XFEL facility, outlines the photon diagnostics devices, details on the current status of the assembly of final devices. It continues with the status of the installations of photon diagnostics and beam transport system in the tunnels. Some recent design developments for advanced diagnostics are presented and finally, a schedule outlook is given.

INTRODUCTION

General Facility Layout

The general layout of the photon part of the European XFEL facility is shown in Fig.1 and is described in more detail elsewhere, e.g. in [5]. There are three undulators, of which the two called SASE1 and SASE2 provide hard X-ray FEL radiation up to 24keV in the fundamental, while SASE3 caters the soft X-ray domain below 3keV (SASE means self-amplified spontaneous emission). The photon diagnostics and beam transport system is located in all photon tunnels indicated in orange, called XTD1 through XTD10. The tunnels lead to the experimental hall XHEXP1, where in the startup phase there will be six experimental endstations. As an example for the beam transport and diagnostics layout, Fig. 2 shows the elements in the SASE1 beamline inside the tunnels XTD2 and XTD9 as well as shaft building XS3.

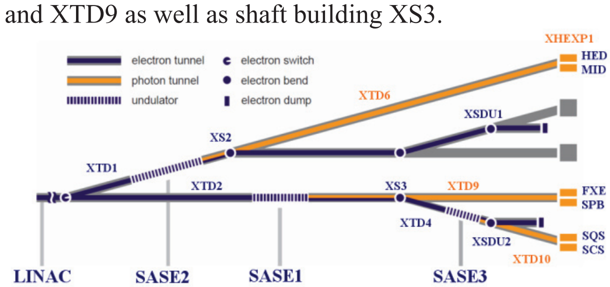

Figure 1: General facility layout, photon part

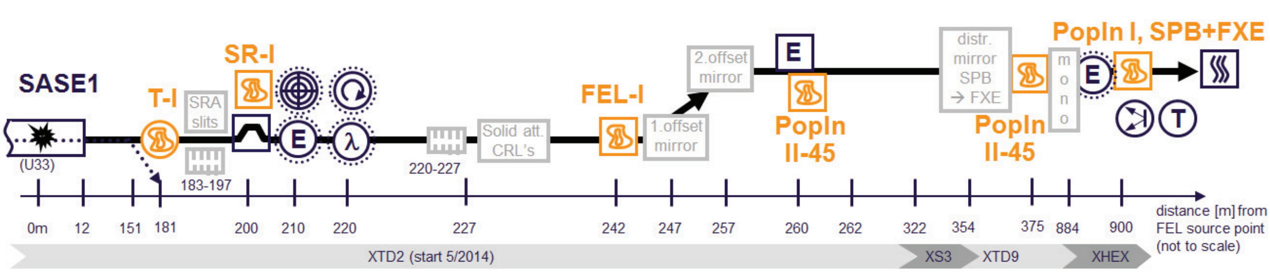

Figure 2: SASE1 beamline as an example for beam transport and diagnostics layout. Elements in the SASE1 beamline inside the tunnels XTD2 and XTD9 as well as shaft building XS3 are shown. Beam transport and optics elements are in grey, diagnostic imagers in orange, other diagnostics in black. From source to experimental hall, there are the transmissive imager (T-I), the synchrotron radiation absorber (SRA), the K-Monochromator with its spontaneous radiation imager (SR-I), the gas based online systems X-ray Gas Monitor (XGM) and PhotoElectron Spectrometer (PES) surrounded by differential pumping systems, the solid attenuators and Compound Refractive Lenses (CRLs), the FEL imager (FEL-I), the two offset mirrors, the MCP-based detector (denoted “E” here), a pop-in monitor type II-45°, the distribution mirror to switch between SPB and FXE endstation, another pop-in monitor type II-45°, a crystal monochromator, another XGM with its differential pumping, plus advanced diagnostics for timing and wavefront in the experimental endstation. Not shown is the HiREX spectrometer which was now added to the layout just upstream of the distribution mirror.

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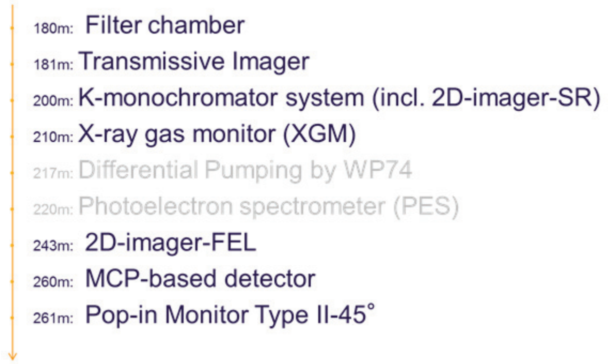

Figure 3: Sequence of diagnostics devices in the first equipped tunnel XTD2.

The sequence of diagnostics devices in the first equipped tunnel XTD2 (SASE1) is illustrated in more detail in Fig. 3. The device positions are given as a distance to the (theoretical) radiation source point in the third last undulator segment.

Timeline of Photon Diagnostics

2014

- Final assembly of first UHV-chambers: Imagers, K-mono, XGM (SASE1), PES (SASE3)
- Tunnel installation of first support structures (XTD2): Concrete pedestals and grouted steel pillars

2015

- Final assembly and tunnel installation of systems for SASE1 and SASE3
- Detailed design and production of the HiReX spectrometer, the modified PES for hard X-rays, and the Exit Slit and SR-imager-2D
- DAQ&Control System preparation, cabling, technical commissioning

2016

- Installation of remaining systems in SASE3
- Production/assembly/installation of SASE2 systems.

Status of Photon Diagnostics (WP74) in 2015

Several devices are built in-house at WP74: the 2D-imager-FELs, the K-Monochromators, the photo electron spectrometer PES, and the differential pumping stations. Pop-in monitors were and HiREX spectrometer as well as the 2D-imager-SR is in commercial production (after design by European XFEL), XGM and transmissive imager are produced and provided by DESY groups, the MCP-based detectors are provided by JINR at Dubna, Russia. The following devices are currently in the design and prototyping stage: Exit Slit Imager and Timing Diagnostics.

Diagnostics installations started in 2014 with the construction of concrete bases and installation of steel support pillars in tunnel XTD2. In 2015, the installation of the vacuum systems started with imagers and the K-monochromator for SASE1.

Perspectives until Fall 2015

The remaining diagnostics vacuum chambers destined for XTD2 will be installed, and also in XTD9 as soon as the tunnel conditions allow it in terms of humidity, cleanliness and infrastructure. Continuously pumped systems like the XGM require at least electrical power and pressurized air to be available, ideally also network for online device protection and monitoring.

Most SASE3 / XTD10 devices will be produced, the detailed designs for the HiREX and Exit Slit Imager will be finalized, the first 2D-imager-SR will be produced, and more diagnostics activities occur in the domain of temporal diagnostics.

Of all mentioned diagnostics devices, most are already required or used during the initial beam commissioning with spontaneous radiation before First Lasing, except systems that are only sensitive to XFEL radiation like the gas based systems which are crucial as soon as First Lasing is achieved.

PHOTON DIAGNOSTICS DEVICES

A detailed description of all photon diagnostics devices is given in [1] and in the Conceptual and Technical Design Documents, e.g. [2-4]. Here, we'll focus on the achieved status for the SASE1 devices and give some details about their implementation.

For all devices, before installation in the tunnel, particular emphasis was put on vacuum tests (RGA spectra) for conformity to the stringent beam transport UHV requirements and on checking all control items like motors and encoders for their correct performance. Also, all device-local patch panels were installed, wired and checked.

Transmissive Imager

This most upstream diagnostics device serves as a first monitor during initial commissioning. We use a slightly modified imager from the electron beam system, there called a standard „OTR-C“ imager, and modified only the target arm to record photons instead of electrons. This modified scintillator holder was designed, produced and delivered to the DESY group that provides this imager.

K-Monochromator System

This system consists logically of a filter chamber, the actual K-monochromator (a two crystal, 2-bounce or 4-bounce monochromator for spontaneous radiation), and one imager for spontaneous radiation.

The filter chamber can be used for energy calibration of the K-mono by insertion of thin metal foils such as aluminum, chromium, copper, nickel, or molybdenium. The filter chamber holds up to 5 filter foils. Its alignment base plates were now designed and produced, all assembled and tests completed, RFI.

The K-mono device for SASE1 was designed, produced, assembled, tested and installed in XTD2, more details about this device see [2] (Fig. 4). Now the next two devices are under clean room assembly.

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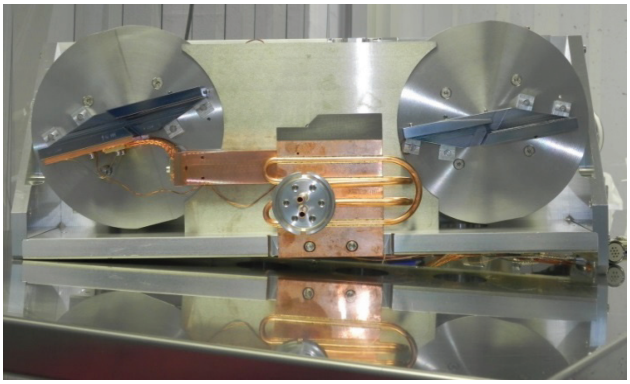

Figure 4: In-vacuum parts of the K-mono. Two Huber goniometers carry each a channel-cut silicon crystal, and the upstream crystal is water cooled.

The 2D-Imager-SR was fully designed down to workshop drawings in-house including its particular optical setup for optimum light collection of the faint spontaneous radiation of single undulator segments at large distances (Fig. 5). Its design contains YAG:Ce and Gd_2O_2S:Pr scintillators and a mirror on a manipulator in a UHV chamber, out-of-vacuum tandem lens optics (Leica Summilux 1.4/50 and Schneider Cinelux Ultra 2/110, f/0.95), a motorized iris, and a low noise camera (Photonic Science sCMOS, 16 bit, noise 0.92 e^- rms). This imager is in production at a commercial workshop and will be assembled at European XFEL in fall 2015.

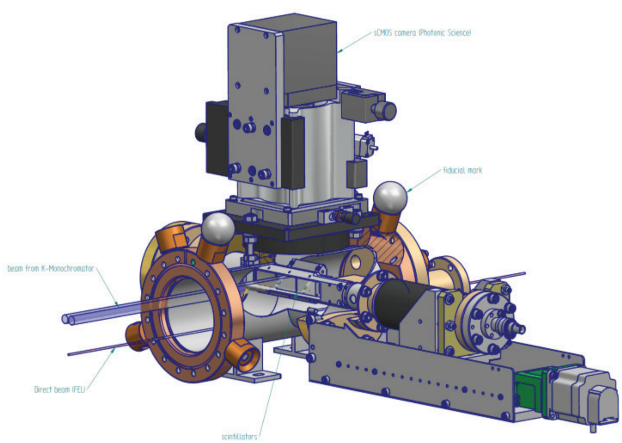

Figure 5: 2D-Imager-SR design sketch. The device can image the beam from the K-mono (indicated by the upper two larger diameter spontaneous radiation beams), or the direct beam when the K-Mono is not inserted (lower thin beam, typically FEL radiation), depending on its vertical positioning. The scintillators are inserted horizontally.

Pop-in Monitors

There are four types of these alignment monitors, details in [3]. The vacuum and motion parts of these monitors were designed in detail, produced and assembled by the company JJ X-ray, Denmark. Final assembly of the scintillators and mirrors is done at European XFEL as well as final vacuum and motor checks, see Fig. 6. The first such monitor was installed in XTD2 in April 2015, and more devices are continuously prepared for installation. In total, the facility will have 14 pop-in monitors.

Figure 6: Pop-in monitor type II-45° during final assembly.

MCP-based Detector

Each SASE beamline includes one monitor for SASE search and optimization, based on multi-channel plates (MCPs). This is a contribution by JINR, Dubna, Russia. All three systems were produced and vacuum tested. They each contain several integrating MCPs and one imaging MCP which is observed from outside the vacuum by an optical setup, in which a camera/lens combination sits on a motorized rail for focusing adjustment. The MCPs were checked without beam: signals were recorded during illumination with a UV light source and secondly by observing rare signal events caused by ions from the ion pump, see Fig. 7.

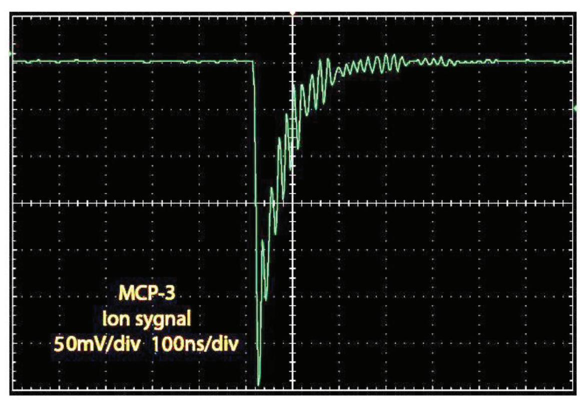

Figure 7: MCP-based detector signals

X-Ray Gas Monitor (XGM)

There are six XGMs in the facility to monitor online the beam position and intensity of the FEL radiation during beam delivery to the experiments. Each XGM consists of four vacuum chambers on a common girder, see Fig. 8, and can record fast shot-to-shot beam position and intensity as well as absolutely calibrated intensity. The latter is recorded slower but the shot-to-shot intensity is internally cross-referenced. Distribution of the XGMs: there is one XGM per beamline in the direct beam from

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the undulator, upstream of offset mirrors. Additionally there is an XGM near the end of the photon tunnels in the SPB and HED branch and a last XGM in the SCS hutch. This system is contributed by the Tiedtke group (DESY), who have so far produced four devices and calibrated them with synchrotron radiation at the PTB, Berlin. Two more XGMs will be ready for installation beginning 2016.

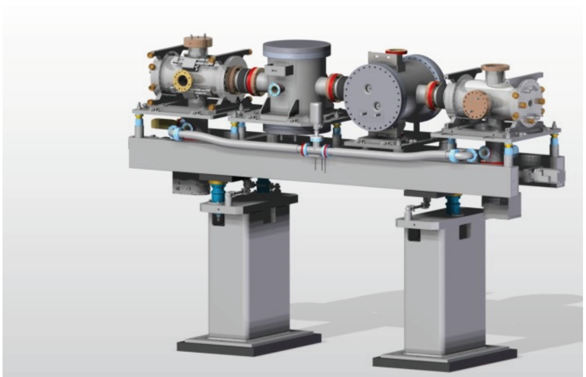

Figure 8: XGM model as built.

Photoelectron Spectrometer (PES)

This device [4] is for shot-to-shot spectrum and polarization monitoring. The detailed design for the SASE3 device was completed as well as for the fully motorized support. The SASE3 device was fully assembled and very successfully tested with X-ray FEL beam at AMO/LCLS which will be reported elsewhere.

This device was used in a scientific beamtime (PI Helml), a scientific in-house beamtime (PI Coffee), and for the commissioning of the DELTA undulator, see the presentation by J.Viefhaus in this conference. The SASE1 device requires development of modifications for hard X-ray application and will be therefor installed in a later installation phase. Hard X-ray High Resolution Single Shot Spectrometer (HiREX)

Hard X-ray High Resolution Single Shot Spectrometer (HiREX)

The HiREX, see Fig.9, will deliver high-resolution spectra during online beam operation, enabled by a transmissive grating of which the first order diffracted beam is sent on a bent crystal that disperses the spectrum on a flat linear detector. Various fixed bending radii and crystal reflections are planned to cover the hard X-ray range between 3 and 25keV, see Fig.10. The design documents explaining the physics and simulation results were completed [6] as well as the Technical Specifications Document for public tendering of the production, awarded in June. The detailed technical design is due in fall 2015 and one device will be installed in XTD9 in July 2016 for use in the SASE1 beamline.

Advanced Diagnostics

Prototype chambers are under construction for temporal diagnostics, mainly for two methods: spectral encoding for arrival time monitoring, and THz-streaking of rare gases for pulse duration monitoring.

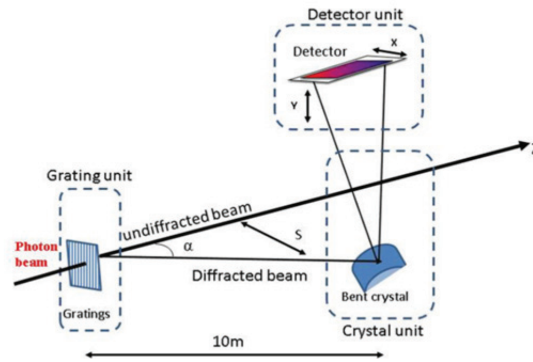

Figure 9: Schematic view of the HiREX setup.

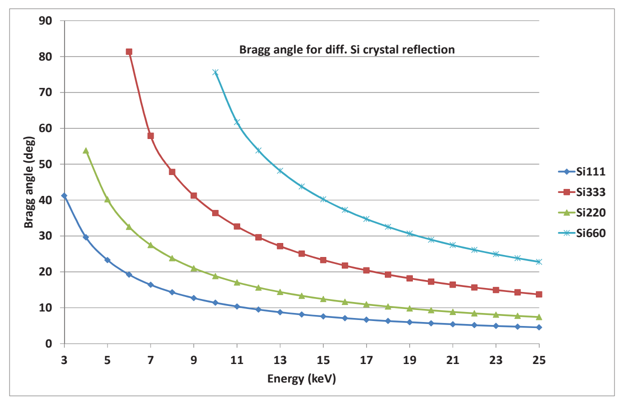

Figure 10: Bragg angles for the planned crystal reflections of the HiREX spectrometer in the hard X-ray range.

BEAM TRANSPORT INSTALLATIONS

The installation of the photon beam transport system started in 2014 when 140m of beamline in XTD2 became accessible for installation. The installations continued in 2015 with tunnel XTD9 where a huge length of 1050m had to be equipped, the larger part of this separated into two branch vacuum lines, leading to the SPB/SFX and the FXE instruments. Sections of 18m long vacuum pipes were mounted by joining three 6m pieces by orbital welding in the tunnel under clean room conditions. The remaining 20m of SASE1 beam transport in the connecting shaft building XS3 will be mounted last.

Large and heavy objects were mounted in the beamline, such as the supporting granites for the offset mirror chamber, see Fig. 11. Also, beam shaping devices like the compound refractive lenses (CRL) and the SRA were installed in XTD2. Not part of beam transport but inherently required for the operation, electronic racks were placed throughout the SASE1 tunnel area and started to get filled with control crates for the four Beckhoff loops controlling vacuum systems, motion control and encoders, equipment protection system (EPS) and backup loop.

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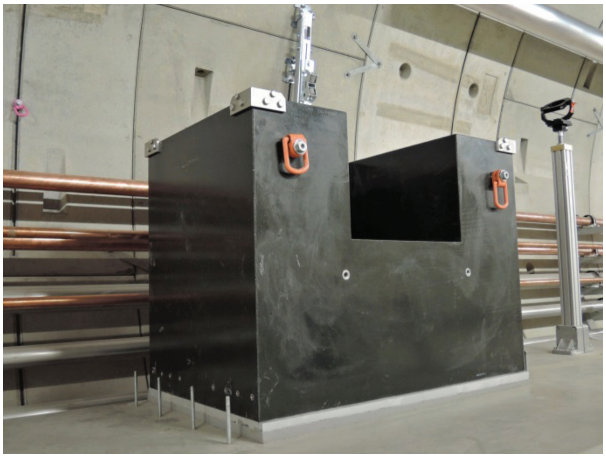

Figure 11: Support granite for the mirror chamber, installed on top of a concrete base.

The beam transport system now covers the entire SASE1 tunnel area, see Fig. 12 for a view of the many XTD9 support holders before installation of the vacuum pipes.

Figure 12: View into SASE1 tunnel XTD9.

SCHEDULE OUTLOOK

In 2015, the SASE1 vacuum and electrical installations will be finished, and the SASE3 installation starts including the mirror chamber and soft X-ray monochromator. The SASE3 detailed beam transport design was completed. The control system in SASE1 will be commissioned.

In 2016, more SASE1 installations are scheduled, including the hard X-ray monochromators, and the HiReX and PES spectrometers. SASE2 devices will be installed and SASE1 beam commissioning will start.

Finally, in 2017 the facility is ready for First Lasing and First Users!

CONLUSION

The final assembly and installation of the photon diagnostics and beam transport system for the European XFEL facility is on track for receiving beam end of 2016.

ACKNOWLEDGMENT

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Also, we are grateful for the support to diagnostics implementation by other workpackages and groups in European XFEL such as WP73, the science groups, and the electronics groups CAS, AE, and ITDM.

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