IMPLEMENTATION PHASE OF THE EUROPEAN XFEL PHOTON DIAGNOSTICS

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Abstract

The European XFEL facility with 3 undulators and initially 6 experimental end-stations requires an extensive set of photon beam diagnostics for commissioning and user operation, capable of handling the extreme brilliance and its inherent damage potential, and the high intra bunch train repetition rate of 4.5 MHz, potentially causing additional damage by high heat loads and making shot-to-shot diagnostics very demanding [1].

After extensive design [2-5] and prototype studies, in 2014 the installation of the photon beam devices starts with the equipment in the first photon tunnel XTD2 which is where the SASE1 hard X-ray undulator is located. This contribution reports on the device construction progress by focusing on the XTD2 tunnel devices and their implementation into the tunnel environment.

OVERVIEW

The photon part of the European XFEL facility is here defined as starting from the undulators, followed by the photon transport system leading into the experimental hall with the experimental endstations. The photon transport system contains beam transporting and shaping X-ray optics as well as X-ray photon diagnostics and is located in the photon tunnels XTD1 through XTD10. The hard X-ray undulator SASE1 is located in tunnel XTD2 which is also the first tunnel in the installation sequence to be equipped with the machine. As an example of the photon diagnostics devices in the overall facility, in this article we will describe the devices in XTD2 and their current implementation.

After definition of the overall diagnostics layout [1], long design phases of the individual devices, prototyping and production, most devices for XTD2 are ready for installation. Their implementation into the tunnel is prepared, which means that their design was accommodated to the space restrictions at their particular tunnel position, possible collisions were checked, infrastructure interfaces defined, and where required special infrastructure such as the rare-gas supply was designed.

Implementation

A particular feature of the XTD1 and XTD2 tunnels and an example of the tunnel implementation difficulties is that here the photon beamline is at a different and varying height – up to 2.65 m above the tunnel floor, whereas in all other tunnels there is a standard beamline height of 1.4 m. These two tunnels containing the undulators SASE2 and SASE1 respectively have downward slopes towards their ends in order to allow for transport paths crossing underneath the photon and electron beamlines when approaching the shaft buildings which are the branching points of tunnels and connect the incoming tunnel to the subsequent two outgoing tunnels. Due to this feature it was decided to build concrete platforms for the devices bringing the floor up so that the devices and their mounts can be built for the standard beamline height, avoiding special versions of the devices which are present in all tunnels. One such platform can be seen in Fig. 7.

Installation Sequence

The sequence of tunnel installations of infrastructure and also photon transport and diagnostics was fixed in the same order as the future commissioning sequence: first SASE1, then SASE3, and finally SASE2 will be installed. SASE1 is the hard X-ray beamline with a directly linear transport of the electron beam into the undulator - in SASE2 the electrons need to pass a bend before entering into the undulator which is an additional complication. Once electrons are transported through SASE1 they necessarily pass through the soft X-ray undulator SASE3 on their way to one of the two available main dumps, which is why the SASE3 area is installed next after SASE1.

DEVICES

This proceedings paper focuses on the photon diagnostics devices in XTD2 which is a representative subset of all diagnostics. In this conference the temporal diagnostics will be presented in another contribution (MOP014), as well as more details on the undulator commissioning spectrometer (MOP009) and details about the imagers (MOP013).

The photon diagnostics devices in XTD2 are all downstream of the separation point where the electron beam is separated from the photon beam. The first device, pushed as far as spatially possible towards the source, towards this separation, is a filter chamber and the transmissive imager. The space is very limited since the electron beamline is still very close, branching off at only a small angle.

The **Filter chamber**, see Fig. 1, is the most upstream photon diagnostics component and allows for initial spectroscopy by selecting and inserting X-ray filters, using characteristic K-lines of metals, and it contains absorbers for synchrotron radiation during undulator commissioning.

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ISBN 978-3-95450-133-5

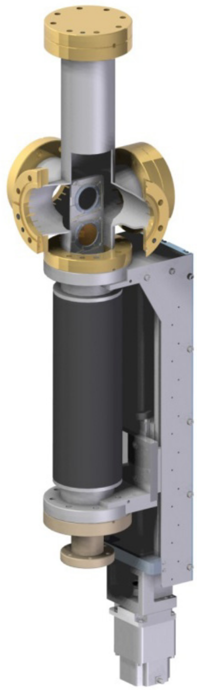

Figure 1: Filter chamber.

The **Transmissive Imager** will deliver the most upstream photon beam image, with the largest possible unobstructed view on the undulator radiation before any X-ray optics. With light transmitted to a second, downstream imager one can determine undulator beam pointing. It‘s an OTR screen from the electron beam diagnostics work-package converted for X-ray use.

Next in line is the **undulator commissioning spectrometer** or **K-monochromator** which is used during commissioning for tuning the gaps and phases of individual undulator segments. It can operate in 2-bounce or 4-bounce mode and requires either photodiodes or the 2D-imager-SR downstream for detection. It rests on a fully motorized support structure and can be completely retracted from the beam [4], see Figs. 6,7 and poster MOP009.

After a set of differential pumps, the X-ray beam enters the **X-ray Gas Monitor (XGM)**, see Fig. 2, which non-destructively delivers absolutely calibrated per-pulse intensity and also x/y-beam position data, using photoemission in rare gases. It consists of four UHV chambers on a common girder, resting on two steel pillars. Each chamber is equipped with a split electrode and can therefore deliver beam position in one transverse direction. Two chambers per direction are needed because one measures an absolute intensity calibrated at a synchrotron, but is averaging over many photon pulses, while the other chamber contains a very sensitive large area custom built electron multiplier which delivers a relative intensity value for every shot in the pulse trains, even at harder X-ray energies beyond 20 keV where rare gas cross sections become challenging small. The XGM is a contribution by DESY, and it‘s implemented together with WP74. To provide the support up to the girder, WP74 performed FE-analysis of possible vibrations and determined that good stability could be obtained with two separated hollow steel pillars with rectangular shape, which rest on the ground on manually adjustable threaded rods and are then fixed to the floor by grouting.

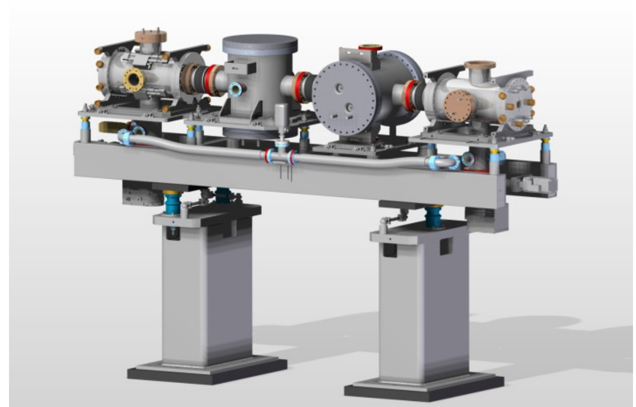

Figure 2: X-ray gas monitor.

The next monitoring device is the **Photoelectron Spectrometer (PES)**, see Fig. 3, which delivers non-destructively the FEL spectrum and polarization on a shot-to-shot basis. It requires high-speed DAQ electronics, an elaborate frame motion, magnetic field compensation, and rare gas supply. This device [2] is developed together with the P04 team at PETRA3.

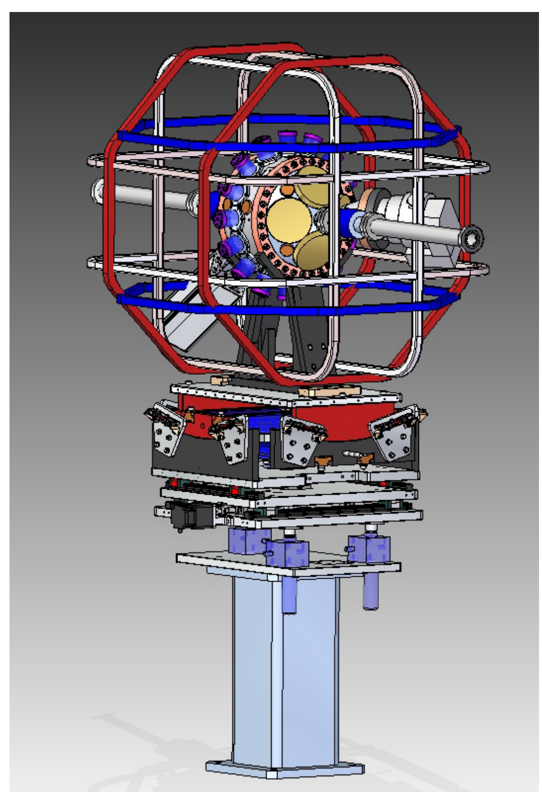

Figure 3: Photoelectron spectrometer.

ISBN 978-3-95450-133-5

Differential Pumping Units are inserted in the photon transport between the XGM and PES to separate the gas environments of these two devices. Changing pressure or type of gas in one device will therefore not affect the operation and accuracy of the other, which is especially important to guarantee the absolute calibration of the XGM intensity data.

The **2D-imager-FEL** (Fig. 4) is the main device to determine the FEL beam shape and important for commissioning and FEL optimization [3]. Several scintillators and a photodiode can be inserted into the beam. In combination with the transmissive imager, it allows to determine the beam pointing.

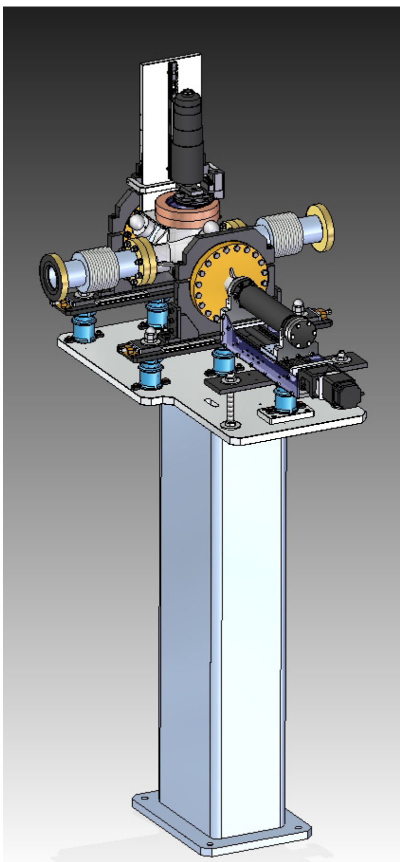

Figure 4: 2D-imager-FEL.

After passing across the two offset mirrors, the beam arrives at the **MCP-based detector** (Fig. 5) which records X-ray intensities from the spontaneous level (~nJ) all the way up to FEL in saturation (~mJ), in order to establish lasing at the critical intensity threshold and to study and optimize the gain curve. Built-in redundancy by installing three MCPs in the device ensures commissioning reliability. This contribution by JINR / Dubna has a long history at FLASH, and was tested at DORISIII with hard X-ray synchrotron radiation [5]. It has a basic aluminium frame since the position accuracy requirements are low compared to the devices that were placed on grouted steel pillars.

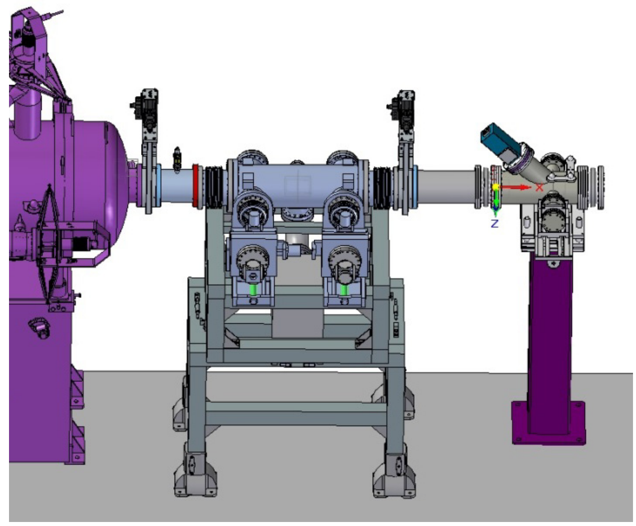

Figure 5: MCP-based detector (center) and Pop-in monitor type II-45° (right). On the left, the chamber of the second offset mirror can be seen, which is very close in order to minimize the required transverse motion of the MCPs for different photon energies and their corresponding mirror angle settings.

The X-rays arrive finally at the last diagnostics device in XTD2, the **Pop-in Monitor.** This Imaging Station is required to find and adjust the FEL beam downstream of X-ray optics in general and here in particular for the two offset mirrors. The Pop-in monitors currently come in four types (here it's a type II-45°) to cover different field of view ranges depending on their location in the beamline.

Table 1 lists the complete sequence of photon diagnostics devices in XTD2 along with their positions in tunnel coordinates.

Table 1: Sequence of Photon Diagnostics Devices in XTD2 (positions are given as distances from the FEL origin in the undulator)

Position [m]	Device name
180.3 m	Filter chamber
181.3 m	Transmissive Imager
200.3 m	K-monochromator system, incl. 2D-imager-SR
209.7 m	X-ray gas monitor (XGM)
216.6 m	Differential Pumping by WP74
220.0 m	Photoelectron spectrometer (PES)
242.5 m	2D-imager-FEL
259.6 m	MCP detector
261.1 m	Pop-in Monitor Type II-45°

ISBN 978-3-95450-133-5

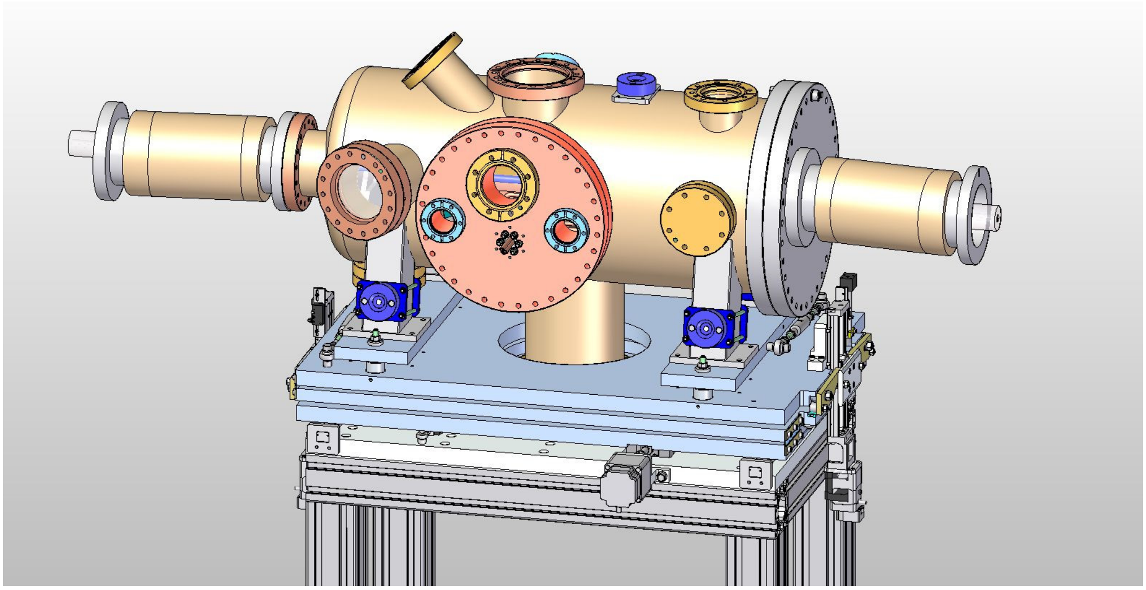

Figure 6: K-monochromator.

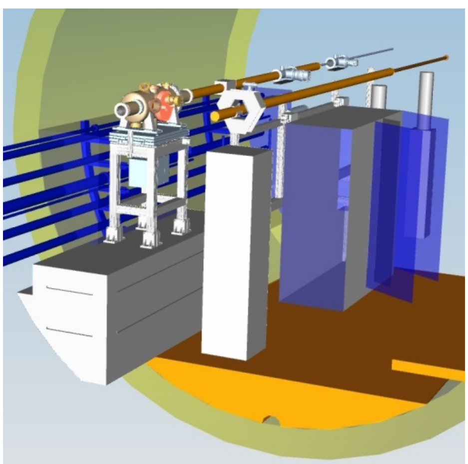

Figure 7: K-monochromator on concrete pedestal.

CONCLUSION

The X-ray photon diagnostics devices were designed and produced for the tunnel XTD2, and their implementation in terms of collision checks, infrastructure planning etc. has progressed to a point that they are ready for installation. Most devices will be reproduced for the SASE2 beamline and with modifications for the soft X-ray beamline SASE3. Additional devices not described here are located in downstream photon tunnels and in the experiemental hall, most notably all diagnostics of temporal pulse properties.

ACKNOWLEDGMENT

Most of the photon diagnostics devices were developed and produced in collaboration with external institutes, which we wish to acknowledge here: the MCP-based detectors were developed and prototypes tested together with E. Syresin group at the Joint Institute for Nuclear Reasearch (JINR), Dubna, Russia, who also provided the final devices. The X-ray gas monitors are a development of the FLASH photon diagnostics team of K. Tiedke at DESY, Hamburg, Germany. The undulator commissioning spectrometer was built within WP74 with support by A. Erko and J. Rehanek from Helmholtz-Zentrum Berlin (HZB), Berlin, Germany, who also contributed to the design of the hard X-ray high-resolution single-shot spectrometer. C. David group at Paul-Scherrer-Institute (PSI), Villigen, Switzerland, worked with us on the single-shot spectrometer and on wavefront sensing with grating interferometers. The development of an online photoelectron spectrometer is a close collaboration with the PETRA3-P04 team of J. Viefhaus at DESY. The work on diamond detectors is a collaboration with M. Pomorski at Commissariat à l'Energie Atomique (CEA), Saclay, France.

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ISBN 978-3-95450-133-5