DESIGNING THE FLASH II PHOTON DIAGNOSTIC BEAMLINE AND COMPONENTS

D. Meissner*, M. Brachmanski, M. Hesse, U. F. Jastrow, M. Kuhlmann, H. Mahn,
F. Marutzky, E. Plönjes, M. Röhling, H. Schulte-Schrepping, K. Tiedtke, R. Treusch
Deutsches Elektronen-Synchrotron DESY, 22607 Hamburg, Germany

Abstract

From 2013 to 2016 the free electron laser FLASH at DESY in Hamburg, Germany was upgraded with a second undulator line, photon diagnostic line, beam distribution and experimental hall connected to the same linear accelerator. This paper shows the layout of the photon diagnostic section and an overview of the civil engineering challenges. The mechanical design of selected components, e.g. vacuum components, diagnostic equipment and safety related components is presented.

INTRODUCTION

The x-Ray Free Electron Laser FLASH at DESY has been running as a user facility for XUV and soft x-ray photon experiments since 2005. In 2010 the upgrade project FLASH II was started to increase the number of user end stations by adding a second undulator line to the FLASH accelerator and operating both beamlines simultaneously and independently regarding wavelength [1, 2].

Two largely identical photon diagnostic sections had to be developed to provide beam parameters to accelerator operation and user experiments. The first section is located inside the accelerator tunnel starting at 10 m from the source where the beam is very small and intense, the second section is in the experimental hall and is fully accessible to users. Both provide data on beam intensity, position and wavelength. The complete layout is described in [2].

Since most of the components use various gases at different pressures main focus in designing the vacuum system was on differential pumping, especially the gas attenuator located between tunnel and hall where the beam crosses the PETRA III accelerator tunnel. Additional mechanical component development focused on absorbers and mirror chambers for beam steering and radiation protection.

GAS ATTENUATOR AND DIFFERENTIAL PUMPING

The straight section of 12 m between the end of the FLASH II tunnel and the beginning of the experimental hall is used as an intensity attenuator. For the purpose of reducing beam transmission for selected wavelengths this section can be flooded with gas up to a pressure of 0.5 mbar. Gases available are Xe, N_2, Kr and Ar [2].

To separate the beamline vacuum from the attenuator and minimize gas usage five-stage differential pumping stations with small and long apertures are used on both sides of the section. Pumping apertures are 16 mm diameter in the tunnel and 20 mm in the hall. The aperture lengths for stages 2 to 5 are 287 mm in the tunnel and range from 400 mm to 700 mm in the hall. Stage 1 which is closest to the attenuator features a 1 m (1.2 m in the hall) cantilevered tube that protrudes into the attenuator beam pipe and also into the radiation shielding wall of tunnel and hall (see Fig. 1).

Stages 2 to 5 use turbomolecular pumps with a volume flow rate of 300 mbar l s^{-1} and additionally ion getter pumps for UHV operation. Stage 1 uses a similar turbomolecular pump which can use cooling gas and can bypass the aperture through a DN100 pipe to allow for rapid pumping of the attenuator down to UHV. Table 1 shows the resulting pressures of the setup.

Table 1: Pressure at All Pumping Stages from Attenuator to Following Vacuum Chamber [3]

Stage	Diameter mm	Length cm	Pump type mbar l s^{-1}	Pressure[a] mbar
ATT	100	1300	300, TP[b]	5E-01
1.	16	100	300, TP	9E-03
2.	16	29	300, TP	8E-05
3.	16	28	300, TP	7E-07
4.	16	28	300, TP	7E-09
5.	16	29	300, TP	6E-11
6.[c]	25	7	55, Ion GP	3E-11

[a] Simulated prediction of pressure range
[b] with cooling gas option
[c] Aperture of following UHV section

Due to the long and narrow apertures special care must be taken for supports and alignment. All pumping sections are pre-assembled outside of the accelerator tunnel on granite girders with high precision manufactured steel grooves for alignment of the components. The girder itself sits on two sand-filled supports of thick walled steel tubes and a three-point kinematic mount. Since alignment is done only by adjusting the kinematic girder support the manufacturing tolerances of the girder and the pumping stages have to be very small. Precision steel tubing and special welding equipment were used to achieve the desired concentricity of all apertures. The cantilever tube of the first stage is suspended by three wires to compensate for bending due to its span. By adjusting the tension in the wires while measuring the resulting aperture with an alignment laser the aperture can be maximized.

* daniel.meissner@desy.de

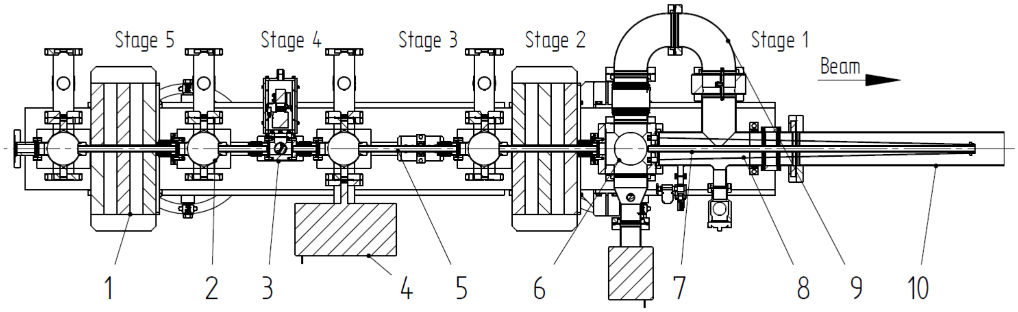

Figure 1: Attenuator Differential Pumping, vertical section. 1: Radiation Collimator, 2: Pumping Chamber, 3: Beam Position Monitor, 4: Ion Getter Pump, 5: Flow Constriction Tube, 6: Stage 1 Pumping Chamber and Support for Cantilever Tube (7), 8: Cantilever Tube Support and Adjusting Wires, 9: Bypass, 10: Attenuator Tube. Turbomolecular pumps not shown.

Each pumping section of stages 2 to 5 consist of a pumping chamber with flanges for turbomolecular pump, ion getter pump and vacuum gauges. The flow constricting tube with an additional bellow is precision welded to the chamber, measured and straightened if necessary.

The attenuator pipe itself connects the FLASH II tunnel and the experimental hall. The beamline has to cross 1.5 m of radiation shielding concrete at the end of the tunnel, 1 m of soil, crosses the PETRA III accelerator (3.5 m), another 6 m of soil until it reaches the wall of the experimental hall. The connection between FLASH II and PETRA III is core drilled with both hole endings not perpendicular to the wall. The hole is fitted with an outer steel tube, an inner steel tube supported in a concrete layer for better alignment and the beamline UHV pipe with aligning supports on either tunnel wall. The other core drilling section features a similar setup. Its slope was measured to pre-align sliding supports of the UHV pipe that rest on the reinforcement tubing. The UHV pipe is welded to one piece on site, outfitted with the pre-aligned sliding supports and installed. Concentricity of the DN100 UHV pipe to the beam axis is inside a few millimeters.

APERTURE AND BEAM DIAGNOSTIC UNIT

For FLASH II the aperture and beam diagnostic units from FLASH I was re-engineered to adjust them to the new requirements and fix long-known mechanical problems with the current design. Furthermore to minimize beamline space the units vacuum chamber should double as differential pumping station. Every chamber can be outfitted with turbomolecular pump, ion getter pump and vacuum gauges. To further minimize space part of the flow constriction tube is also integrated into the chamber wall. The unit features a 3-axis motor driven linear stage setup to adjust diagnostic components or apertures as well as retract them out of the beam. Beam adjustment travel range is ±10 mm and vertical travel range 125 mm from bottom position (paddle in alignment socket) to top position (fully retracted). The reproducibility of position is 0.1 mm [4].

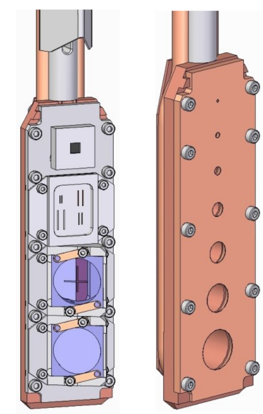
Figure 2: Diagnostic paddle (left) and aperture paddle (right).

Two separate compilations of components can be used alternatively depending on type of the unit. The diagnostic compilation is outfitted with a diode, double slit unit, fluorescent screen and diffusing screen. The aperture compilation has seven apertures from 1 mm to 14 mm in a copper plate. Figure 2 shows both setups. Both compilations can be mounted on the water cooled copper heat sink that sits at the end of the movable aluminum rod. This rod houses the cooling pipes, electric cables and translates the movement from the adjustment drive into the vacuum chamber through an edge welded bellow [4].

Since mechanical stability was one of the main concerns the chamber is milled from a stainless steel block. Its outside dimensions are 230 mm × 170 mm × 195 mm (LxWxH) with a cylindrical pumping chamber of ⌀158 mm × 120 mm. The support structures for the linear stages are precision manufactured from solid aluminum plates to reduce vibrations and deformations due to vacuum forces and bellow reaction forces (see Fig. 3). The total height of the unit including travel is 892 mm [4].

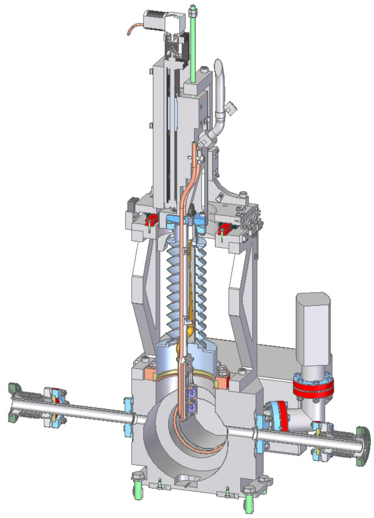

Figure 3: Cross section of aperture and diagnostic unit. Flow constriction tubes attached, diagnostic paddle in fully retracted position. Bellow not detailed.

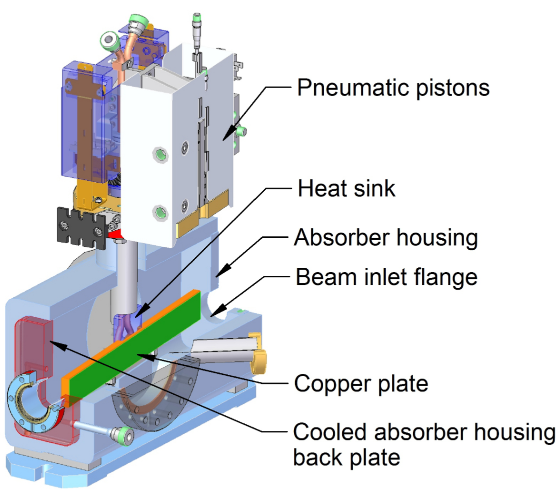

Figure 4: Mechanical concept, absorber housing cut open.

BEAM ABSORBERS

Both photon diagnostic sections feature retractable copper absorbers which were initially placed at 10 m and 45 m along the beamline to allow for machine operation while the photon beamlines are not in use. The thermal load from bunch trains of 3500 bunches with a repetition rate of 10 Hz is 3988 W /mm^2. The mechanical design is a water cooled copper plate at 6 ° that can be retracted upwards by pneumatic pistons. The absorber consists of an EDM[1] machined housing with 40 mm aperture in the open position. For security reasons and to absorb scattered radiation the back plate of the absorber housing is also made of copper and can be cooled externally. Figure 4 shows the mechanical concept with cut-open housing [2, 5].

[1] Electrical discharge machining

FEA calculations at the given values showed peak temperatures in the copper plate of 1041 °C and so variations of geometry and cooling options were considered but none showed significant improvement. Because of the peak temperature the beamline layout, as well as machine operating conditions, had to be changed. The first absorber was moved to 18 m from the source and bunches were limited to 800 per bunch train. This reduced the mean beam power from 1120 W to 256 W and the resulting temperature dropped to 102 °C (see Fig. 5) [5].

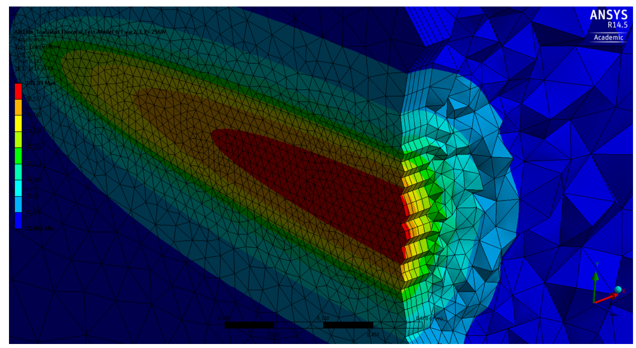

Figure 5: Final FEA result, peak temperature of 102 °C in red in the middle.

CONCLUSION AND OUTLOOK

Manufacturing and installation of all components described went as planned and without problems. The tunnel beamline was commissioned for UHV in August 2013 and received first beam in January 2014. The attenuator and experimental hall saw first light in 2014 and commissioning of the machine started. First user experiments took place in April 2016 on beamline FL24. It is planned to extend FLASH further by adding the FLASH III undulator beamline which will have an identical diagnostic setup in the same tunnel and hall.

REFERENCES

[1] B. Faatz *et al.*, "Simultaneous operation of two soft x-ray free-electron lasers driven by one linear accelerator", *New Journal of Physics*, Volume 18, June 2016.

[2] E. Plönjes *et al.*, "FLASH2 Beamline And Photon Diagnostic Concepts", in *Proc. FEL2013*, New York, NY, USA, Aug. 2013, paper WEPSO50, pp. 614-617.

[3] U. F. Jastrow, "Differential Pumping Stage for Flash2 - Part 7", Presentation at Flash2 Beamlines and Photon Diagnostic Meeting, unpublished.

[4] H. Hahn, "Diagnose-/Apertur-Druckstufe für FLASH II", Poster at KITE - DESY Engineering and Innovation Day 2014, unpublished.

[5] F. Marutzky, "Absorber für FLASH II", Poster at KITE - DESY Engineering and Innovation Day 2014, unpublished.