DEVELOPMENT OF MCP BASED PHOTON DETECTORS FOR THE EUROPEAN XFEL

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Abstract

Radiation detectors based on micro channel plates (MCP) are planned for installation at the European XFEL. Main purpose of these detectors is searching a signature of lasing and further fine tuning of the FEL process. Detectors operate in a wide dynamic range from the level of spontaneous emission to the saturation level (between a few nJ and 25 mJ), and in a wide wavelength range from 0.05 nm to 0.4 nm for SASE1 and SASE2, and from 0.4 nm to 5 nm for SASE3. An essential feature of the detectors is high relative accuracy of measurements (below 1%), which is crucial for detection of a signature of amplification and characterization of statistical properties of the radiation. Photon pulse energies are measured with traditional MCP with anode, and photon beam image is measured by MCP imager with phosphor screen anode. The visualization of a single bunch in a train, or average image over the full train will be performed at a spatial resolution of 30 µm.

DESIGN OF THE DETECTOR

An important task of the photon beam diagnostics at the European XFEL is providing reliable tools for measurements aiming at the search for and fine tuning of the FEL creating SASE process (Self Amplified Spontaneous Emission). The problem of finding SASE amplification is crucial for the XFEL because of a large synchrotron radiation background. This requires a detector with a wide dynamic range, controllable tuning to the required wavelength range, and suppression of the unwanted radiation background. The JINR-XFEL collaboration proposes to design, manufacture, and install MCP-based photon detectors as a primary tool for the search for and fine tuning of the SASE process. Three MCP devices will be installed after each SASE undulator of the European XFEL (SASE1, SASE2, and SASE3).

Previously the JINR-DESY collaboration developed and installed four generations of MCP-based photon detectors at FLASH [1-4]. They have proven to be reliable devices for the search and fine tuning of the SASE process in the VUV wave range. The present proposal for the European XFEL is essentially based on our experience gained at FLASH.

Three different tasks can be fulfilled with the XFEL MCP-based photon detectors [5]: study of the initial stage of the SASE regime; measurement of the photon pulse energy; and measurement of the photon beam image. The MCP detector will resolve each individual pulse at a repetition rate of 4.5 MHz. The following wavelength ranges are to be covered by three MCP stations: 0.05-0.4 nm for MCP1 and MCP2, 0.4-5 nm for MCP3.

MCP detectors for SASE1 and SASE2 are installed after the first deflecting mirrors [6-7] (Fig.1). The first European XFEL diamond-like carbon coated mirror (C mirror) is 800 mm long with a variable incident angle of 1.1-3.6 mrad. The second offset C mirror is placed at a distance of 10.4 m from the first one, which provides the large incident photon angles of 10-30 mrad. The diamond attenuator and the CeYaG screen are installed in front of the first offset C mirror.

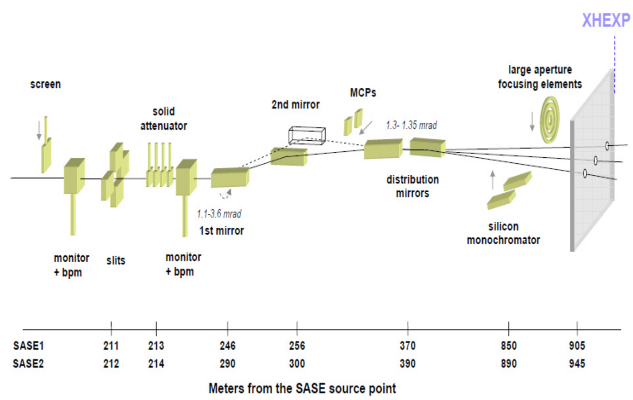

Figure 1: Shematic view of the SASE1&SASE2 mirrors and attenuators for the MCP.

The offset mirrors are here used as additional attenuators of the radiation intensity. The attenuation range of the mirrors combined with the diamond plate attenuators is about 10^3-10^4. The dynamic range of the MCP is 10^3-10^4. Thus, it is possible to monitor radiation intensities in the dynamic range of about seven orders of magnitude. One problem is that the offset C mirror considerably reduces the available horizontal space to 0.9-2.9 mm during the search of amplification. The search for the SASE regime by the MCP is realized when the first mirror is displaced from the beam axis in the horizontal direction to increase the acceptance of the setup. Finally, three MCP operation regimes are considered: 1) both mirrors removed at large horizontal acceptance to search for initial stages of SASE processes, 2) using only one mirror installed to provide the attenuation factor $R=1\text{-}3\cdot10^{-2}$ and small horizontal acceptance, and 3) using both mirrors to produce the total attenuation factor $R=1\text{-}10^{-5}$. To detect XFEL radiation in these three regimes with different positions of the C mirrors, the MCP should move in the horizontal direction over a distance of ±10 cm relative to the photon beam axis in the XFEL chamber. When both mirrors are removed, the photon beam passes through the axis of the MCP detector; when one mirror is installed it is deflected in the horizontal plane to the left relative to the central axis; and using two mirrors it is sent to the right.

MCP detector for SASE1&SASE2 consists of three MCPs equipped with the anode as a pulse energy monitor and one MCP detector for imaging the photon beam (Fig.2).

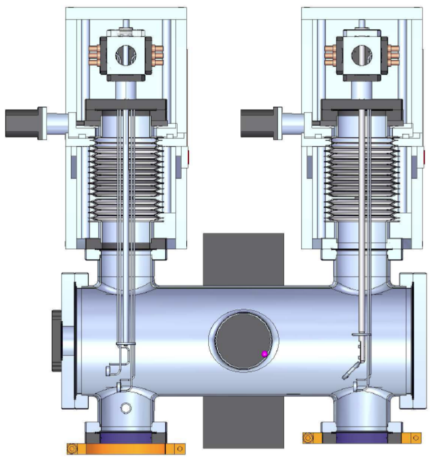

Figure 2: View of MCP detector for SASE1 and SASE2.

The first MCP detector port houses two F4655 Hamamatsu MCPs 18 mm in diameter (Fig.2), which are used for measuring the pulse energy and for searching for initial indication of SASE regime. The PM 100-250 3D vacuum manipulator displaces these MCPs in the horizontal direction at a distance of 250 mm. The range of vertical displacement is ±2.5 cm relative to the beam axis. It permits a considerable increase in the vertical size of the SASE regime search area in comparison with the MCP diameter. The vertical and horizontal displacements of the MCPs permit searching for the SASE regime in a rectangular area 20×6.4 cm. The linear motion of these MCPs in directions, horizontal and vertical, is executed by the stepper motors, and placed outside of the vacuum chamber, with the help of movable bellows.

The second detector port houses two MCPs: F4655 Hamamatsu for measurement of the pulse energies, and beam observation system (BOS) MCP (model BOS-40-IDA-CH/P-47) of 40 mm diameter with a phosphor screen. These MCPs are also displaced in the horizontal direction over a distance of 250 mm and in the vertical direction at a distance of ±2.5 cm relative to photon beam axis. BOS MCP is set by an angle of 45^0 with respect to photon beam and a viewport to provide best imaging on a CCD.

MCP detector for SASE3 will have an additional port with movable semitransparent mesh and wire targets for production of scattering FEL radiation similar to those used at FLASH [1-4].

The SASE1& SASE2 MCP is placed at a distance of L_2= 2.5 m from the middle of the second mirror. The distance between the middle points of the first and second mirrors is L_1=10.4 m.

When two mirrors are used, the horizontal position of the X-ray spot displacement in the MCP (Table 1) relative to the undulator axis is determined by the photon incident angles θ_1 and θ_2 on the first and second mirrors. The horizontal X-ray spot displacement is $\delta x=2L_1\theta_1-2L_2(\theta_2-\theta_1)$. When only the first mirror is used, the horizontal light spot displacement in the MCP is $\delta x=2(L_1+L_2)\,\theta_1$.

Table 1: Horizontal Position of the MCP Relative to the Photon Beam Axis

λ, nm	θ_1/θ_2, mrad	R	X, cm
0.4	3.6/31.5	10^{-3}	-6.75
0.4	3.6/8.72	1	+4.64
0.248	3.6/21.8	5×10^{-4}	-1.9
0.248	3.6/19.2	10^{-3}	-0.6
0.248	3.6/6.1	1	+5.95
0.177	3.6/13.7	10^{-3}	-2.15
0.177	3.6/4.3	1	+6.85
0.137	1.2/10.5	10^{-3}	-2.25
0.137	3.6/10.5	10^{-3}	+3.75
0.137	3.6/3.5	1	+7.25
0.1	3.6/7.7	3×10^{-5}	+5.1
0.1	2.6/7.7	10^{-3}	+2.65
0.1	2.6/2.4	1	+5.3
0.05	3.6/3.8	1.2×10^{-6}	+7.1
0.05	1.2/3.8	10^{-3}	+1.1
0.05	1.2/1.2	1	+2.4
0.1	3.6	3×10^{-2}	+9
0.05	3.6	1.2×10^{-3}	+9

The horizontal X-ray spot displacement for the two-mirror scheme (θ_1=3.6 mrad, θ_2=31.5 mrad) is 6.75 cm to the right relative to the photon beam axis at the wavelength of 0.4 nm. The X-ray spot displacement for the one-mirror scheme (θ_1=3.6 mrad) is 9 cm to the left relative to the beam axis at the wave- length of 0.05 nm (Table 1). The total MCP displacement is about 16 cm.

The system with two mirrors easily provides the attenuation factor $R=10^{-3}$ at all wavelengths in the range of 0.1-0.4 nm on the first undulator harmonic. The operation with one mirror permits implementation of the scheme for hard radiation at a wavelength of 0.05-0.1 nm and attenuation factor $R=10^{-2}$-10^{-3}.

ATTENUATION OF XFEL RADIATION

A C mirror in the SASE1 and SASE2 MCPs is used as an attenuator. Attenuation of the photon radiation signal is effected by a plane C mirror in combination with a diamond attenuator (Fig.1). The C mirror reflectivity (Fig.3) is reduced by the factor R when the incident angle is θ_R(mrad)=25.5×lg(R^{-1})×λ(nm).

The dependence of the reflectivity on the incident angle is shown in Fig. 3. At the wavelength of 0.1 nm the reflectivity is close to 100% at the incident angle of 0.15^0 (2.6 mrad). The maximum incident angle for the first mirror is 3.6 mrad (0.206^0). The attenuation of the reflectivity is reduced to 3×10^{-2} at this angle (Fig.3). The use of two mirrors for photon beam attenuation permits the intensity reduction more than 2.5×10^{-5}.

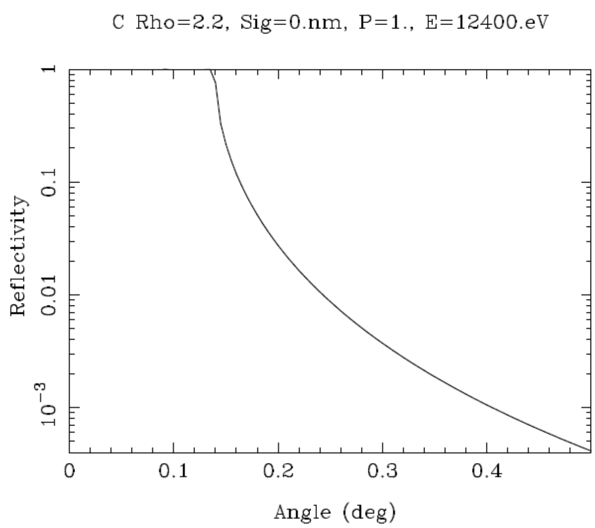

Figure 3: Dependence of the C mirror reflectivity on the incident photon angle.

At the FWHM photon beam diameter of 0.5 mm the FWHM spot size on the C mirror is about 20 cm. Diamond plates are used as the solid attenuator of FEL radiation (Fig. 1). Dependence of the photon transmission through a diamond plate 100 μm thick on the photon energy is shown in Fig.7. The attenuation coefficients at λ=0.4 nm are T=0.1 at 81 μm, $T=10^{-2}$ at 162 μm, and $T=10^{-3}$ at 243 μm.

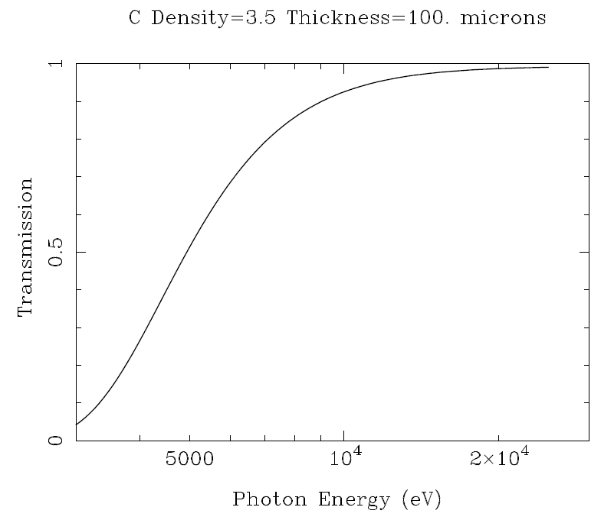

Figure 4: Dependence of the photon transmission through a diamond plate 100 μm thick on the photon energy.

At λ=0.1 nm the diamond plate permits the following attenuation coefficients T to be reached at the zero photon scattering angle depending on the plate thickness: T=0.1 at 0.5 cm and $T=10^{-2}$ at 1 cm. The attenuation coefficient in the plate is dictated by the photoeffect. The fraction of Compton- scattered photons is 27%, and the fraction of coherently scattered photons is 24 % at the attenuation of 10^{-1}. The solid attenuator can be effectively used at low photon energy of 3.1 keV; however, its application at high photon energy of 12.4 keV is restricted by a large number of scattered photons.

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