AN ELECTRON BEAM DETECTOR FOR THE FLASH II BEAM DUMP

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Abstract

After the generation of the laser light, a dipole deflects the highly energetic electron beam of FLASH (Free Electron Laser Hamburg) into a dump. A detector is developed to monitor the position, dimensions and profile of the electron beam. Scintillation light is emitted due to the electrons hitting a luminescent screen located in front of the dump aperture. This light is guided by an optical system external to the vacuum to a CCD camera for optical analysis of the generated image.

In this paper the layouts of two different optical systems are presented, both of which will be redundantly installed at FLASH II. The conventional lens-mirror-arrangement consists of three single collecting lenses, two mirrors and a zoom lens. The second optical system is based on radiation-hard optical fibres. It can be shown that the resolving capacity of both optical systems is better than 0,5 line pairs per millimetre. Furthermore a test setup to investigate the impact of radiation on the optical qualities of the bundle by installing it into a "radioactive hot spot" at the bunch compressor in the FLASH accelerator is presented.

INTRODUCTION

The Free Electron Laser Hamburg (FLASH) is a linear accelerator producing brilliant laser light from 4 to 60 nm wavelengths, providing unique experimental opportunities to investigate the atomic structure and the properties of materials, nanoparticles, viruses, and cells. After the generation of the laser light in the undulator sections the electrons are separated from the FEL beam. While the laser light is guided to the experimental sites in the experimental hall, a dipole deflects the electrons downwards at an angle of 27° to dispose of them into a dump (see Fig. 1).

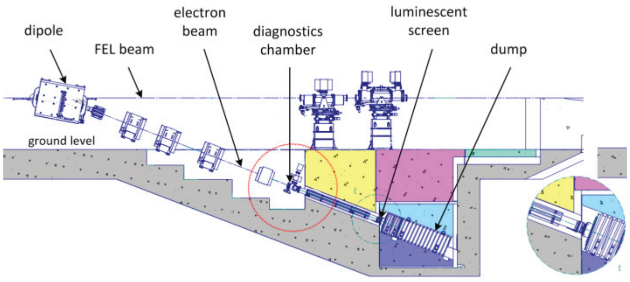

Figure 1: Beam dump section at FLASH II (schematic).

Owing to the high power, the beam is easily able to damage beam line components in the case of misdirection, which could in the worst case cause a total breakdown of the linac. Therefore, a detector is required at the dump to enable control of the shape and the position of the beam. The detector will be continuously monitored by the accelerator control room to immediately detect any beam electro-optic failures. During the operation of FLASH II the beam is expected in the middle of the beam pipe. Beam misdirection towards the pipe wall will first lead to an alarm signal, and if the beam is out of the detector's visible range, FLASH will be shut down immediately to avoid potential damage.

Due to the inaccessibility of the beam pipe terminus external coupling is not permitted in this area. The detector must also be able to operate and survive in a highly radioactive environment. Therefore a luminescent screen is installed at the FLASH II dump aperture. Based on the results of experiments made at the Mainz Microtron MAMI in 2009, where the luminescence yield of different screen materials under electron bombardment was studied [1], an Al_2O_3:Cr (Chromox) ceramic with a thickness of 1 mm is used as screen material. The screen has a diameter of 100 mm, and the optical system has to be able to detect the beam spot over the entire screen surface. The required resolving capacity is 0,5 line pairs per millimetre.

OPTICAL SYSTEM

As the beam dump is covered with massive concrete blocks to shield the radiation, the installation of optical components is only possible at diagnostics chamber, installed at a distance of approximately 2 metres from the screen. The entire optical system can be seen in Fig. 2. The emitted light is first reflected by a vacuum mirror through a window, perpendicular to the electron beam. The light has to be transmitted to a CCD camera, one of the components which have to be well protected from radiation. Therefore the camera is placed about one and a half meters away from the beam line, shielded by the concrete, at ground level. It is furthermore put into a camera box which consists of radiation shielding materials.

For guiding the light to the camera two different techniques will be applied redundantly. A conventional lens-mirror-system, consisting of two mirrors and four lenses, will be installed next to a system using radiation-hard optical fibres. The switching between the two systems will be possible within a short period of time. As can be seen in Fig. 2, the lower lenses and also parts of the fibre optic bundle are also protected against neutrons coming from the dump by Tetraboroxid-plates which are attached to a frame of aluminium profiles. Additional shielding against electromagnetic radiation can be installed if necessary.

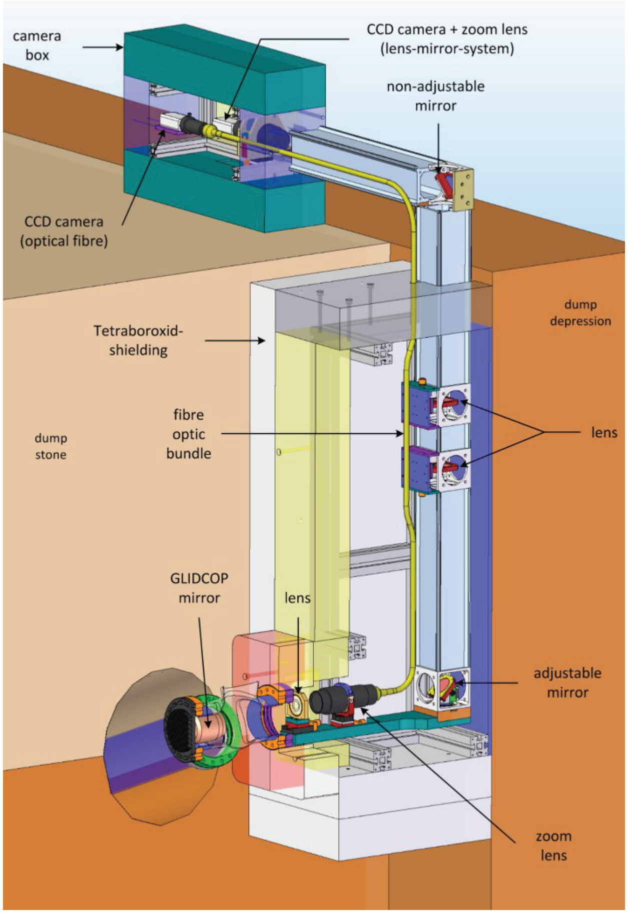

Figure 2: Optical system (3D-CAD-model) [2].

The vacuum mirror (see Fig. 3) at the diagnostics chamber, which reflects the emitted light through the vacuum window, is a massive mirror made of GLIDCOP AL15, a sintered alloy consisting of copper and particles of aluminium oxide. GLIDCOP is able to deflect the light with the wavelength generated at the screen. Furthermore it combines high strength with good thermal conductivity. Since the mirror extends no more than 20 mm into the beam pipe, the risk of being hit by electrons of the beam halo is reduced. However, a thermal simulation was made to get a rough estimate of the resulting mirror temperatures in case of electron input [2]. This simulation revealed that if only 1 % of the possible thermal beam power (25.7 W) of FLASH II clipped the protruding mirror, it would reach a temperature of up to 130°C. In this case, the generated heat should be dissipated into the environment as quickly as possible. Therefore, the mirror is manufactured in one solid piece with a 70 mm diameter round section, and it is soldered directly onto the vacuum flange. Gold foil is used as brazing solder in order to assure best possible conduction. The reflecting surface is lapped, polished and manufactured at an angle of 46.1° to the electron beam to guide the light to the centre of the first collimating lens.

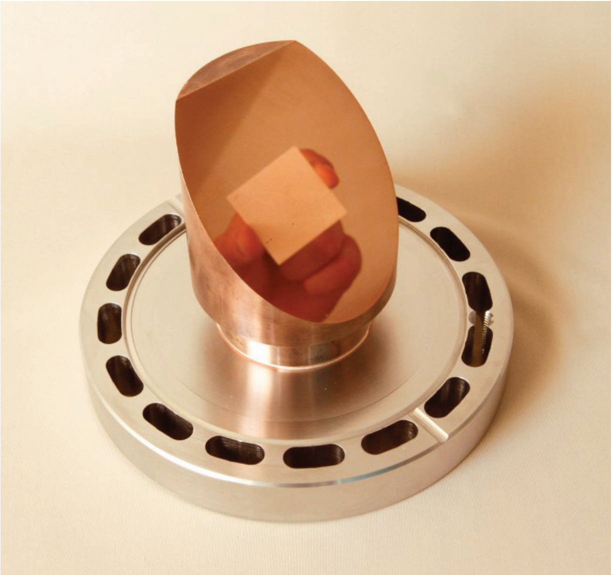

Figure 3: Vacuum mirror made of GLIDCOP.

Lens- Mirror-System

The first optical system is a conventional one, using mirrors and lenses to guide the light to the CCD camera. Since this kind of optical system is commonly used, there is a wide variety of suitable components. Disadvantages can be seen in the specialized optics required to meet the specifications, which increases the costs of such optical systems.

The schematic design can be seen in Fig. 4. The sensor size of the CCD camera is 5 mm (height) times 10 mm (width). Since the electron beam has to be detected over the entire luminescence screen, the size of the object to be imaged is 100 mm. Consequently, the reproduction scale is 0.05. The lenses are biconvex collective lenses, using different focal distances. Lenses made of Borosilicate Crown glass with antireflective coating for the visible range are suitable. To avoid the lenses being damaged by radiation, the glass type "N-BK7-NH_4 grade", manufactured by CVI Melles Griot, will be used.

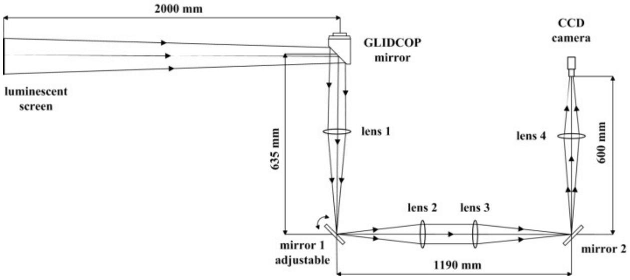

Figure 4: Lens-mirror-arrangement (schematic).

To minimize aberrations and maximize the image quality, the optical system was simulated with the help of the program package ZEMAX [3]. Due to the long distances between the mirrors and the camera, the use of four lenses is preferable to get an adequate image quality. The first lens is located in front of the vacuum window and relays the light to the first mirror. It has a focal length of 325 mm. Since the light is then diverging again, the second

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and the third lens, both with a focal length of 500 mm, relay the light again to the second mirror. Substitution of the two lenses by one single lens proved insufficient due to a significant loss of light intensity. The forth lens with a focal length of 150 mm further scales down the image to 10 mm, which represents a reproduction scale of 0.1. To reach the desired reproduction scale of 0.05, further optimization is mandatory.

To get an estimate about the resolving capacity of the optical system, a modulation transfer function diagram (MTF) can be used. Figure 5 shows such a MTF-diagram at the centre of the screen. The diagram displays the resolution both in the sagittal and the tangential plane. Ideally, in the screen centre the resolution in both planes should be identical, but due to aberrations caused by the mirrors the resolution in the tangential plane is inferior. Therefore the resolution is determined in this plane. Here the resolution, which is usually determined at 0.1, is about 3 line pairs per mm. Towards the screen margins the resolution deteriorates and reaches only 2 line pairs per mm.

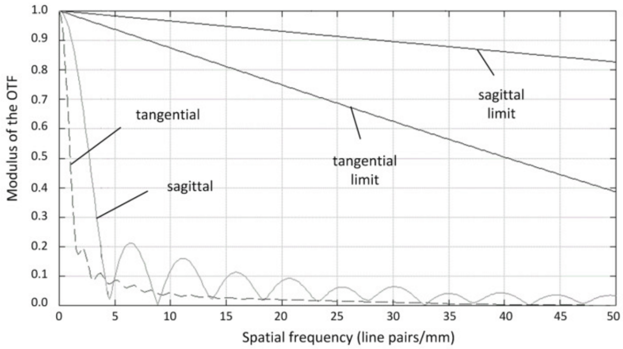

Figure 5: Modulation transfer function (screen centre).

In addition to the theoretical estimate of the resolving capacity, a practical verification was performed by installing a test setup, using the same geometric conditions as will later be found at FLASH. Since the test was performed outside the vacuum, the GLIDCOP mirror was substituted by a mirror dummy with similar properties. The resolving capacity was defined with the help of the USAF test target 1951 which was illuminated from the backside by a constant light source. The image as seen by the CCD is displayed in Fig. 6. Although this test is quite subjective, it can be said that the observer is able to distinguish between the lines at least in the Element 6 of the group number -1, which represents a resolving capacity of 0,89 line pairs per millimetre (see table 1). This is only about one third of the theoretical resolving capacity. However, this still meets the requirements.

Table 1: Evaluation Table of the USAF 1951 Test Chart

	group number				line pairs/mm
Element	-2	-1	0	1	2
1	0,250	0,500	1,000	2,000	4,000
2	0,281	0,561	1,122	2,245	4,490
3	0,315	0,630	1,257	2,514	5,040
4	0,354	0,707	1,408	2,816	5,644
5	0,397	0,794	1,577	3,154	6,350
6	0,445	0,891	1,766	3,532	7,127

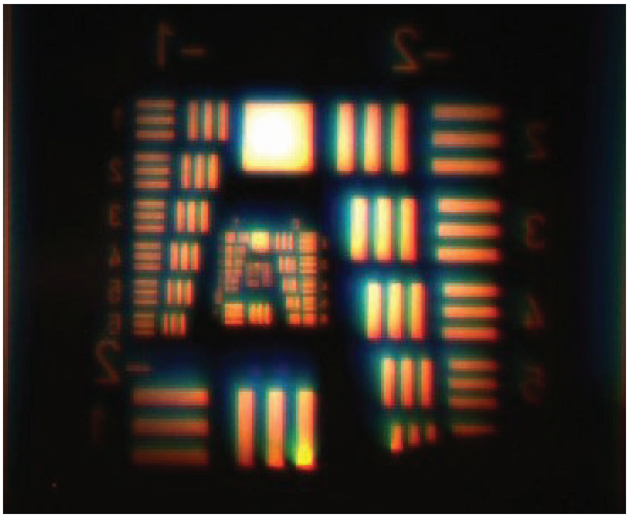

Figure 6: Resolving capacity test with USAF test target.

Radiation ard optical fibre system

Light transport over rather long distances with a lens-mirror arrangement requires considerable investment concerning the amount of optical components as well as their fine adjustment. When using flexible optical fibres to transfer the beam image to the camera, the number of optical components can be significantly reduced. Furthermore fine adjustment is much less complex. Despite this, there is still little knowledge about the use of radiation hard fibres in accelerators and their long-term radiation resistance.

As can be seen in Fig. 2., a zoom lens, located approximately 50 mm from the vacuum window, captures the detector image on the GLIDCOP mirror. The fibre bundle is coupled directly to the zoom lens via an adapter. At the far end of the bundle it is attached to the CCD camera which is located inside the camera box. The fibre bundle is fixed several times on the outer side of the rail system.

The wound fibre optic bundles used for the beam dump detector are delivered by the Schott AG. The bundles available differ concerning image format size (2x2 up to 40x35 mm^2) and length (standard lengths from 0.61 to 4.5 m). The single fibres, with a 60 micron diameter, are combined in arrays of 6x6 (see Fig. 7). A transmission of 40 % is guaranteed by the manufacturer. For the beam dump detector a 2.7 m long bundle with a format size of 4x4 mm is utilized.

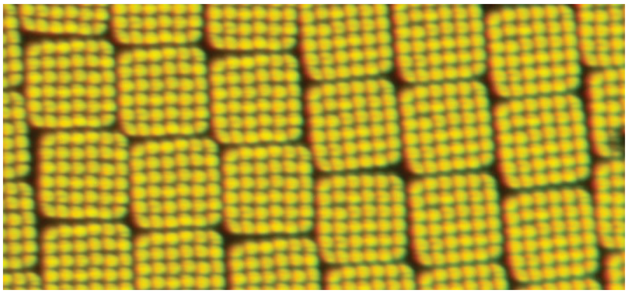

Figure 7: Optical fibre bundle (enlarged detail).

As for the lens-mirror-system, the resolving capacity for the fibre optic bundle was practically performed by using the USAF test target (see Fig. 8). This test revealed that the resolving capacity is about 1 line pair/mm, which is even better then with the lens-mirror-system.

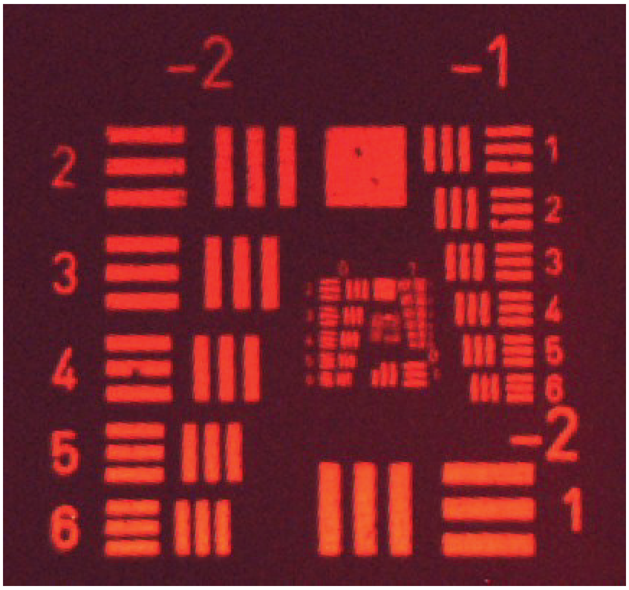

Figure 8: Resolving capacity test (optical fibre bundle).

Unlike information about the optical properties, detailed information about the radiation hardness of the fibre optic bundles is not available. Therefore a test setup is planned to investigate the deterioration of the optical qualities under irradiation. Therefore a second fibre optic bundle with a length of 600 mm will be installed at FLASH at a radioactive hot spot for several weeks. The fibre bundle will be placed directly onto one of the Bunch Compressors, where a radiation dose of several Grays is expected during accelerator operation.

A scheme of the experimental setup can be seen in Fig. 9 An LED, mounted in a small enclosure and triggered by a pulse generator, serves as light source. Two single optical fibres diverge from the enclosure. The first is attached directly to a photomultiplier and serves as reference. The other one continues to the fibre bundle which is connected to the second photo multiplier with another single optical fibre. Both photomultiplier signals are amplified and conducted to an oscilloscope which is located outside the accelerator. The signal information is saved to a PC in steady time intervals.

Since the optical components and the single optical fibres are protected against radiation by a lead shielding, it is assumed that radiation will exclusively lead to a deterioration of the fibre bundle. The initial measurement will be executed without the influence of radiation. These first measuring results will be taken as standard values. After the irradiation the measured results will be compared to the standard values to get the rate of deterioration.

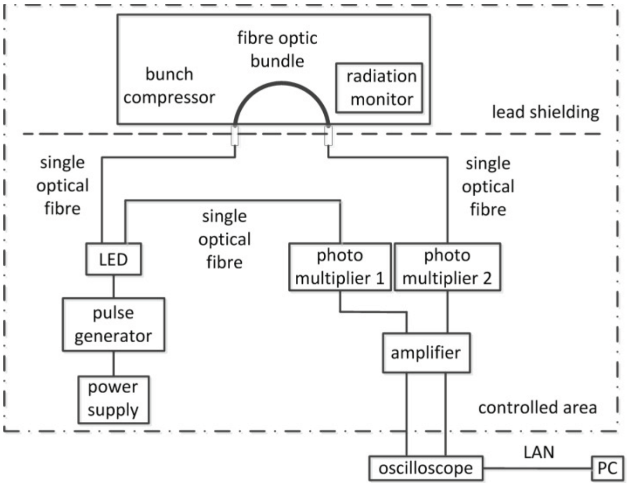

Figure 9: Optical deterioration test setup (schematic).

SUMMARY AND OUTLOOK

The development of an electron detector at the FLASH II beam dump requires special efforts concerning the optical system and means of radiation protection. Two different optical systems will be installed: a conventional lens-mirror-system and an optical system using a radiation hard fibre optic bundle. Initial tests showed that the desired resolving capacity of 0,5 line pairs per millimetre can be achieved with both optical systems. Eventually, an irradiation test will soon be performed at a “radioactive hot spot” at FLASH to get an estimate of the radiation impact on the optical qualities of the fibre bundle.

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