AN X-RAY PINHOLE CAMERA SYSTEM FOR DIAMOND

C.A. Thomas, G. Rehm, DIAMOND, RAL, Great Britain

Abstract

In this paper we present the X-ray pinhole camera designed for the measurement of the size, the emittance and energy spread of the electron beam at Diamond. The system has been kept as simple as possible. The pinhole and the imaging system are in air, and the X-ray beam from the bending magnet is filtered out through an Al window. The beam is imaged using a fluorescent screen and an IEEE 1394 camera. We describe the system from the problems encountered for the extraction of the X-ray beam, to the optimisation of the imaging system. Taking into account the results of preliminary tests, we estimate the expected performance of the system.

INTRODUCTION

The DIAMOND synchrotron light source is the third generation light source under construction in the UK [1]. The expected performance of the source, in terms of brightness, imposes the electron to occupy a very small phase space volume. To measure the energy spread ($\approx 10^{-3}$) and the emittance ($\approx$ 2.7 nm rad) of the DIAMOND electron beam, an X-ray pinhole camera [2] is probably the most simple and accurate device. The pinhole camera is a known device and the instrumentation very straightforward. However, the adaptation and the optimisation of the camera to the case of Diamond requires to investigate in details the extraction and the imaging of the of the X-Ray beam. For the extraction of the beam, the number of X-Ray photons is an issue, but at the same time, the heat-load of the extraction window has to be considered. To image the electron beam profile, two steps are considered. The first one is to find the best screen that would absorb the X-ray photons and convert them into visible photons. The second step is to investigate the best way to image the fluorescent screen.

In this paper we present the design of the pinhole camera, showing the heat-load taken by the Al window, and then the optimisation of the imaging system.

X-RAY PINHOLE CAMERA

The X-ray pinhole camera, like any pinhole camera, is composed of a source, a pinhole and a screen to image the source. At Diamond, two X-ray pinhole cameras will be installed to measure the beam size in high and low bending magnet dispersive sections. The two systems are identical, as described in figure 1. The X-ray beam from the bending magnet goes through the beam port absorber. The absorber is a copper block, designed to absorb the totality of the X-ray beam, and in our case a modification allows the

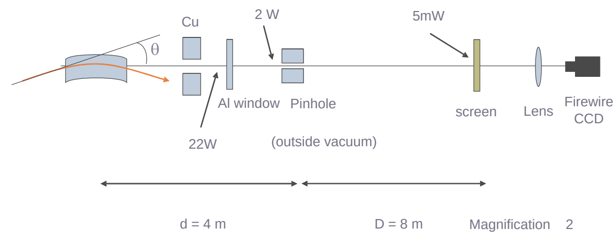

Figure 1: Scheme of the pinhole camera system for measuring the electron beam transverse profile. Electron beam size, emittance and energy spread can be calculating from the image of the beam profile.

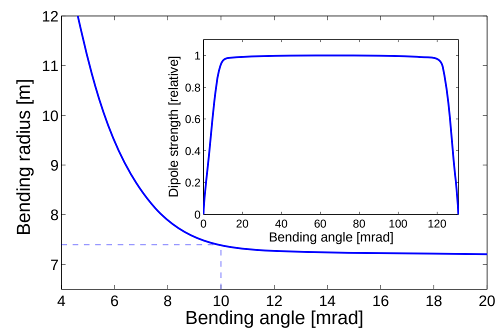

Figure 2: DIAMOND bending magnet radius vs. angle.

transmission of the beam through an aluminium window. The window transmits only the high energy photons from vacuum to air. The position of the window as to be carefully chosen. We show in figure 2 the bending radius as a function of the angle, θ, between the electrons' entering straight direction and the photon beam line. In our particular case, the radiation flux become significant only after 10 mrad (see fig 3). The 25 by 25 μm^2 pinhole is placed behind the window, as close as possible from the source, 4 m in our case. To image the source (2D gaussian, r.m.s 25 by 50 μm^2) we use a fluorescent screen that absorbs X-rays and fluoresces in the visible. The screen is placed at twice the distance source-pinhole, so that the image is magnified by a factor $\approx$ 2. Three different screen have been tested at ESRF, $CdWO_4$ (0.5 mm thick), P43 (5 μm thick) and YAG:Ce (0.1 mm thick). To acquire and measure the size of the source we image the screen with a macro-lens (Componon 2.8/50 from Schneider-Kreuznach) focussing on a compact IEEE 1394 CCD camera (Flea from Point Grey). A Matlab application has been developed to control the camera.

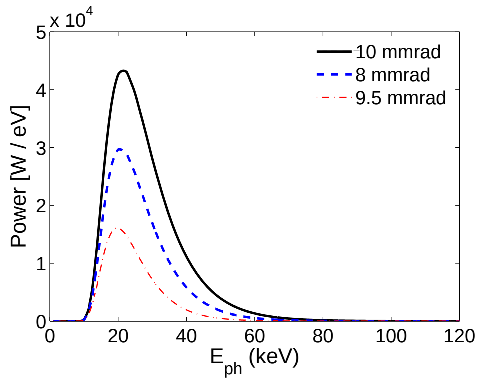

Figure 3: Power radiated from the bending magnet for different angles.

Extraction of the X-Ray Beam

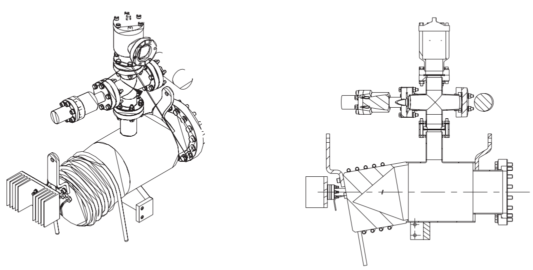

Figure 4: Modified beam-port absorber. The X-ray beam traverses a slit in the absorber and hit the the 1 mm thick Al window. A heatsink is used to cool passively the window.

The scheme of the modified beam-port absorber is shown in figure 4. The X-ray beam traverses a vertical slit in the beam-port absorber before traversing a 1 mm thick Al window. The vertical slit has 1 mm aperture, so that the flux is reduced to a minimum and the heat-load on the window due to the absorbtion becomes acceptable. A heatsink is attached to the window and is able to conduct out 20 W of heat into the air. The aluminium alloy used for the window is AA 6061. Table 1 summaries its properties. The window has to be thin enough to transmit a sufficient radiation flux, and thick enough to be able to sustain the mechanical stress due to the pressure difference and the temperature variation. In addition, the elevation of temperature due to the absorbtion of the radiation should be much less than 500 °C. Finally, the fatigue strength of the window must be high enough to ensure a the lifetime of the window. In order to ensure for the heat-load and for the mechanical stress, we needed to perform a Finite Element Analysis to simulate the heat flux through the window. The result shows that the temperature at the centre of the window - where the power density of the synchrotron radiation is maximum - rises up to 110 °C. The mechanical stress induced by the heat-load is, also at the center, 74 MPa. These two results shows that the Al window is able to sustain the thermal and mechanical stress and to transmit enough flux.

A previous study [3] showed that with 1 mA current in the ring, and with the 1 mm Al window, 10^9 photons/s could be seen by the CCD camera (to be discussed in the next section).

Imaging system

The role of the imaging system (fluorescent screen, lens assembly, CCD camera) is to take a measurable picture of the X-ray beam profile, in order to measure the electron beam size and calculate the emittance and energy spread of the stored electrons. The fluorescent screen has to convert X-rays in visible light, and the lens assembly focusses the image of the X-ray beam profile onto the CCD camera. The conversion efficiency of the screen, the resolution of the screen, of the lens and of the camera have to be taken into account.

We report here on the results of tests performed at ESRF on the P43 and the $CdWO_4$ screens. The conversion efficiency of the screen parameter determines the image quality, i.e. the number of photons hitting the CCD, as a function of the electron beam current. We have deduced, from the experimental results from the tests at ESRF, the minimum flux at Diamond the imaging system would need to acquire a good quality image. Then we calculated that the minimum current in the DIAMOND storage ring, which generates the minimum detectable flux, would be much less than 1 mA for $CdWO_4$ and and of the order of 1 mA for P43. But, if the P43 screen is relatively less sensitive than the $CdWO_4$, it has a better resolution (10 μm compared to 30 μm respectively). As a consequence we may want to use both two screens. In addition, because the image of the P43 is made from the back through the glass, another problem has to be solved. The glass substrate of the P43 becomes dark after some time in the X-ray beam (see fig 5). This problem doesn't appear with self supported crystals, which is the case for the 0.5 mm thick $CdWO_4$. The P43 can be used then if deposited either on a non marking substrate or on a very thin glass and back illuminated.

PERFORMANCE OF THE PINHOLE CAMERA

The overall performance of the pinhole camera depends on quality of the image given by the fluorescent screen, and on the quality of the optical system imaging the screen. In other words, it depends on the resolution of the full system (pinhole, screen, lens, CCD), and on the quality of the image of the beam. In our case, using the $CdWO_4$, or the P43, the resolution is of the order of 25 μm, and the minimum flux (10^6 photons/s) to make a good image is reached at less than 1 mA. This will allow us to measure the electron beam transverse size with less than 1 % error [3].

Knowing the electron beam size and the Twiss parameters allows to calculate its emittance and energy spread. We need to estimate the error due to the uncertainty in the beam size and in the Twiss parameters. To estimate the error due to the Twiss parameters we used a statistical approach. Firstly, we generate a distribution set for the Twiss parameters, where the r.m.s values give the incertitude. With the Twiss parameters distribution and using a given energy spread and emittance, we generate then a distribution set of sizes. Finally, we use the set of sizes to recalculate the energy spread and emittance with a least squared method and taking the nominal Twiss parameters. The incertitude in the measure is given by the comparison between the standard deviation of the emittance and energy spread distribution, compared with the nominal values. Table 2 summarises the results.

CONCLUDING REMARKS

This paper presents the design of the pinhole camera for DIAMOND. The system is expected to measure with a very good accuracy the beam size of the order of 25 by 50 (μm), with 1 mA and above current stored in the ring. For that, the optimum X-ray beam flux have been is reached with a 1 mm thick Al window to extract the beam from vacuum to air. The window is robust, passively cooled in air, and is able to sustain the heat-load from the X-ray beam, and the pressure difference.

The image of the beam is obtained with a fluorescent screen combine with a macro-lens and a 'firewire' CCD camera. The best screens identified so far are P43 and $CdWO_4$. They have the best conversion rate, which provides a good quality image at 1 mA and above, and the best resolution. P43 has the best screen resolution (10 μm) whereas $CdWO_4$ has the best conversion rate. We will use these two complementary screen.

In addition, we computed the error in the calculation of the energy spread and the emittance of the electron beam. This computation shows that the Twiss parameters have to be known at better than 1%.

REFERENCES

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Table 1: Aluminum 6061 properties (Source from http://www.matweb.com)

Mechanical Properties	
Tensile Strength, Ultimate	310 MPa
Tensile Strength, Yield	275 MPa
Elongation at Break	12 % - In 5 cm; Sample 1.6 mm thick
Fatigue Strength	95 MPa - 500 10^6 Cycles
Thermal Properties	
Heat Capacity	0.896 J/g °C
Thermal Conductivity	166.9 W/m K
Melting Point	582 - 652 °C

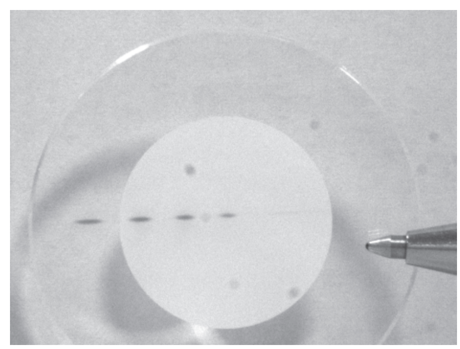

Figure 5: Picture of the P43 screen, from the back, showing the darkening of the glass substrate, image of the 4 pinholes. The glass was exposed for one hour in the ESRF beam.

Table 2: Estimation of the errors vs. the uncertainties on the Twiss parameters (error); we show the relative difference between the initial values and the mean values of the calculated distribution sets of relative energy spread and emittance ($\Delta\sigma_{\epsilon,0}$ and $\Delta\epsilon_0$); the relative uncertainties on the final result ($\Delta\sigma_\epsilon$ and $\Delta\epsilon$) are given by the standard deviation of the distributions.

error	$\Delta\sigma_{\epsilon,0}$	$\Delta\epsilon_0$	$\Delta\sigma_\epsilon$	$\Delta\epsilon$
0.01	0.002	0.001	0.035	0.034
0.05	0.003	0.013	0.164	0.181
0.1	0.067	0.060	0.387	0.358