DETECTION OF HARD X-RAYS IN AIR FOR PRECISE MONITORING OF VERTICAL POSITION & EMITTANCE IN THE ESRF DIPOLES

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Abstract

The un-used X-rays produced in each of the 64 ESRF dipoles are absorbed in so-called crotch absorbers at the end of the dipole. With 40mm of Copper + 5mm of Steel only 250uW/mrad (out of total power fan of 154W/mrad) traverse the absorber. About 20% of these ~170KeV energy X-rays are converted by a 0.5mm thick Cadmium Tungstenate (CdWO4) scintillator into visible light that is collected and focussed by simple optics on to a commercial CCD camera. This compact monitor operates in air and is situated just behind the crotch chamber. Knowing the small vertical divergence of the 170KeV photons and the distance of the source-point to the scintillator, it possible to calculate precisely the vertical electron beamsize at this sourcepoint. The light yield is enough to measure at >1KHz frequency, with a sub-micro-meter resolution of the beam position, thereby also constituting a powerful tool for beam stability measurement in the vertical plane. The principle, the practical realisation and the results obtained with a prototype since Jan.2005 will be presented.

X-RAYS TRAVERSING THE CROTCH

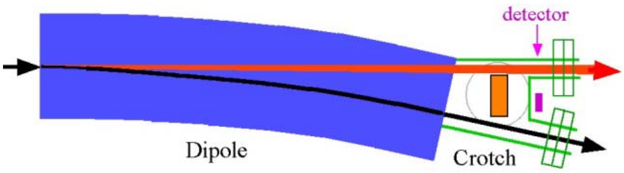


Figure 1: Position of the detector in air just behind crotch

Only 10% of the synchrotron light generated by the ESRF dipole (B=0.86T, E=6GeV) is accepted for possible passage into an X-ray beamline's front-end. The other 90% are dissipated directly by a crotch absorber (fig.1). The dipole's spectral flux characteristics (fig.2 & 3) show, with respect to 1-20KeV photons typically used for scientific work on a beamline, a reduced intensity of ~3 orders for the 150-200KeV range. The latter are attenuated another factor of ~3 orders by their 40mm path through the copper crotch absorber and 5mm through the steel vacuum chamber. Nevertheless, the fraction that enters the free air after the crotch chamber is still of an intensity of ~2E7 photons per second and per mrad horizontal angle in a 0.1% bandwidth at 200mA current.

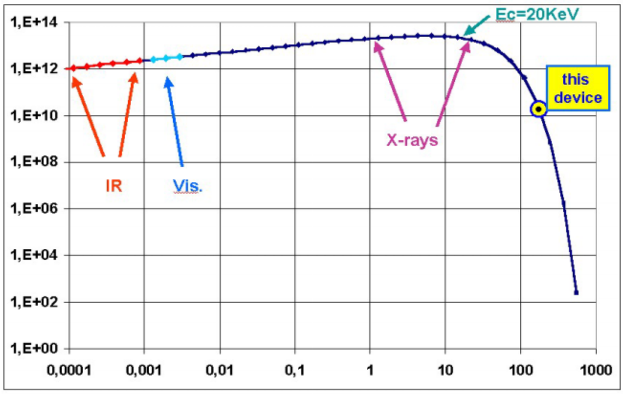


Figure 2: Dipole spectral flux (photons/sec 0.1%bw mrad)

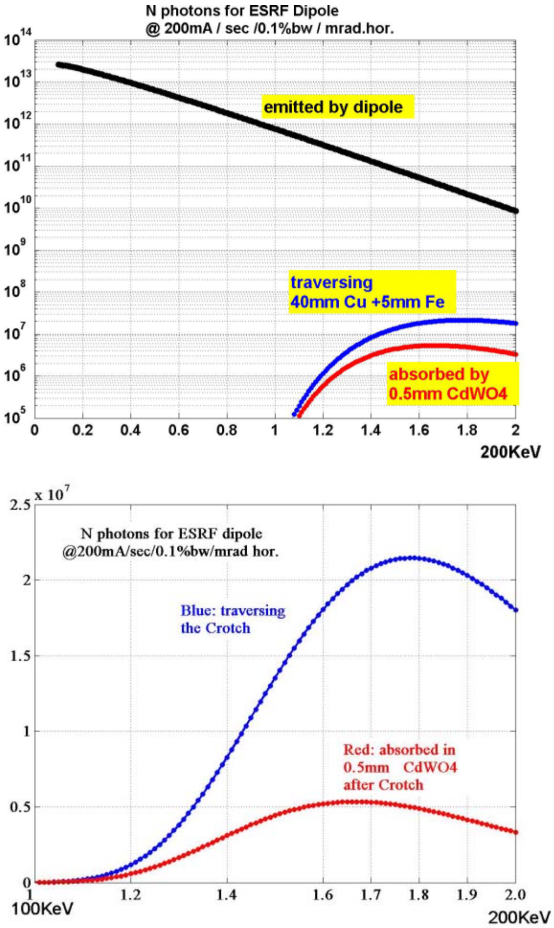


Figure 3: A spectrum of X-rays emitted by the dipole, entering the air and absorbed in the CdW04 scintillator

The blue curve in the lower graph of fig.3 with a linear scale shows a sort of bandpass shape that is determined at the left-side by the increasing copper attenuation to lower energy photons, and on the right side by the slope of decreasing flux for higher energy photons.

X-RAYS DETECTED BY SCINTILLATOR

Cadmium Tungstenate (CdWO4) is a high-Z crystal of nearly 8gr/cm3 density. [1] Thanks to its mechanical hardness it can be manufactured and polished to a thickness below 0.5mm. It is transparent to visible light and has a good light yield for the hard X-rays with a short decay time of ~1us. The red curve shows the X-ray spectrum absorbed by a 0.5mm thick CdWO4 screen out of the spectrum that traverses the crotch.

The fig.4 shows the detector with the scintillator screen directly behind the crotch chamber. The light emitted by the screen is deflected upwards by an aluminium mirror just 7mm behind to an achromat pair (f1=50mm, f2=75mm) that collects and focuses an image on the CCD matrix. The entire detector is mounted together and adjusted optically in laboratory before installation. The effective F-number of the optics is ~4. The CCD used is the Sony ST-30 (1/3" format), the pixel size at the source-point is ~4.4um. The optical resolution of the system was assessed in laboratory and estimated at ~10um. It is determined by depth-of-field blurring by the F of the optics and the thickness of the screen.

The schematic does not show the lead shielding of 3mm thickness around the lenses and CCD. The entire assembly is as small and compact as possible since the space behind the crotch-chamber and the flanges just a few cm further down-stream is very limited.

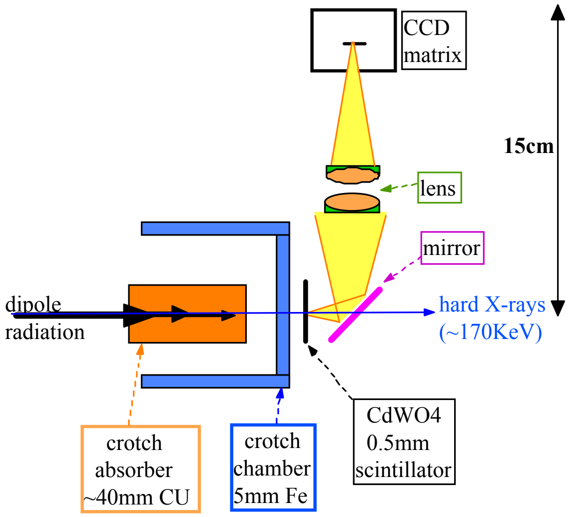
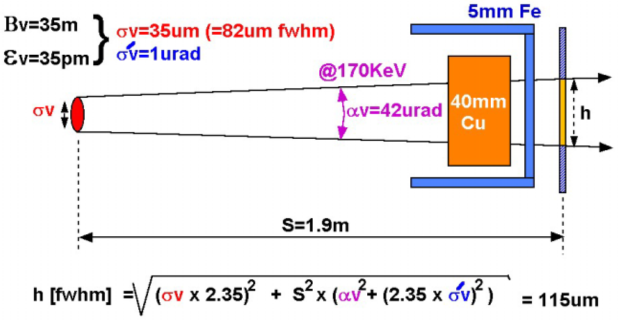


Figure 4: Side-view in the vertical plane of the detector

CALCULATION OF VERTICAL ELECTRON BEAM SIZE

The 170KeV X-rays travel 1.9meter before hitting the screen where they project a stripe-line image. Horizontally this line covers the full-recorded image width because of the horizontal fan of dipole light, and obviously no data of interest can be obtained in this horizontal plane. In the vertical plane however, the relation between the height (h) of the projected image on the screen, and the size of the source-point (i.e. electron beam) can be established in simple and precise terms (see fig.5). Because of the very narrow divergence of the 170KeV photon beam (42urad fwhm, and of gaussian distribution) the projected vertical beam size (h) is only 115um fwhm compared to the vertical electron beam size of 86um fwhm at nominal ESRF emittance of 35pm.rad.



$$h\,[\mathrm{fwhm}] = \sqrt{(\sigma v \times 2.35)^2 + S^2 \times (\alpha v^2 + (2.35 \times \sigma' v)^2)} = 115\mathrm{um}$$

Figure 5: Relation source-point size to projected image size.

The precision of this deconvolution depends on the precision with which the distance (S) and the exact photon beam divergence (αv) can be determined. It can be shown that the uncertainty on both is small and that therefore the precision of the electron beamsize measurement is estimated at better than 2%.

PROTOTYPE RESULTS

A first prototype was installed in Jan-05 and yielded results for only 2 days of operation due to damage by the strong ambient radiation to the CCD camera. This was largely due to a very simple and insufficient lead shielding applied at that time. Nevertheless during some measurements in these 2 days the system provided a clear proof-of-principle with 2 measurements at respectively 23pm and 100pm vertical beam emittance. The ESRF emittance measurements are obtained by an independent emittance measurement system based on an X-ray pinhole camera [2]. The graph in fig.6 shows a curve with the theoretical value for projected vertical size h [um fhwm] versus emittance and the 2 measurements in yellow that are in excellent agreement.

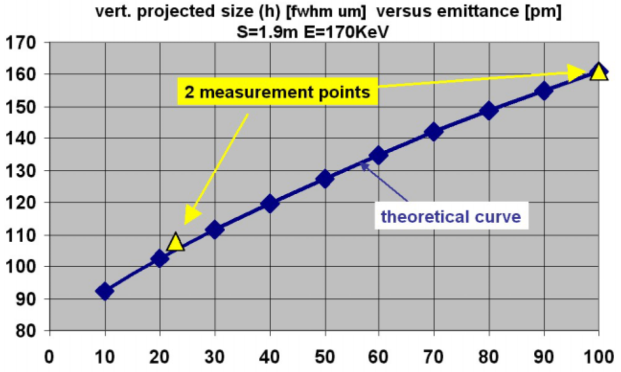


Figure 6: Results of 2 measurements compared to theory

A 2nd prototype was realised with a more rigorous lead shielding structure applied. The average thickness of the lead was 3mm, and the aperture to let the light cone in was reduced to a minimum of 8mm for an optical F of ~4.

The results obtained with the 2nd prototype are shown in fig.7 with an image and a vertical profile plot. The noise in this data is low enough to assess the vertical stability of the electron beam by measuring precisely the centre of the profiles of a series of measurements.

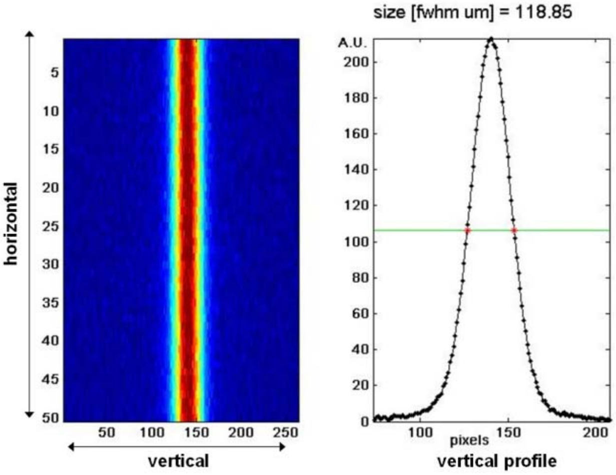


Figure 7: Image results with vertical profile plot

The results of this series of measurements are shown in fig.8 with 60 individual measurements taken with an integration time of 1millisec and at a 1Hz repetition rate. The latter is imposed by the slow transfer rate of the camera and its acquisition system.

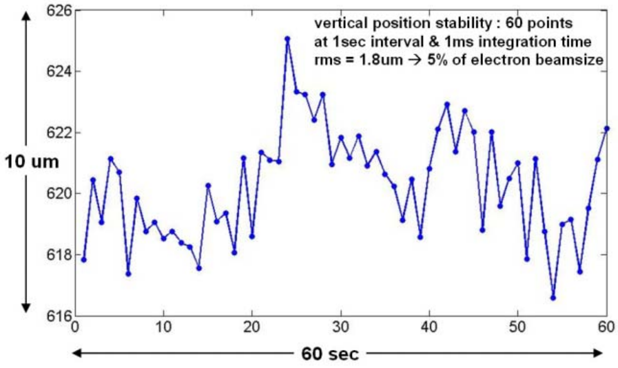


Figure 8: Vertical beam stability measured during 60s

Even with a pixel resolution of 4.4um the low noise of the data allows to see beam displacements of less than a micrometer. The position fluctuations shown in the fig.8 are believed to be caused by the electron-beam itself (with an rms amplitude of 5% of the vertical beamsize) and not by noise in the detector system.

RADIATION SHIELDING

The location of the detector directly behind the crotch implies a strong exposition to radiation caused by particles that are generated inevitably by the interaction of 13KW of high energetic synchrotron light with the crotch absorber. [3]

The lead shielding of the 2nd prototype was sufficient to avoid camera break-down but non-effective in avoiding the blackening of the pair of achromats. Over a run of 2 months the consequent loss of sensitivity was more than a factor 20.

A new type of lead shielding was conceived with 2 additional flat mirrors inside the lead that direct the light cone in a chicane type structure to the lenses. Initial tests over a 2 months period showed that the lenses did not blacken.

CONCLUSION AND PROSPECTS

With a simple, low-cost and compact detector it is possible to detect in air the high-energy photons that traverse the crotch absorbers. The use of a 0.5mm thick CdWO4 scintillator screen results in an effective X-ray detector centred at a 170KeV energy. The precise knowledge of both the distance of the screen to the electron beam and the small divergence of this detected photon beam makes it possible to measure the vertical electron beamsize with very good precision.

With a suitable optical system assembled to it, the whole detector can be kept small and compact and thereby meet the very limited space requirements available just behind the crotch chamber.

The sensitivity of the system allows to measure with simple commercial CCD cameras with integration times as small as 200us without any intensifier device. The future use of a high-transfer-rate camera should then allow measuring the vertical beam stability at frequencies above 1Khz. The resolution with which such stability, at that frequency, can be measured depends on the noise-level of the whole system but results with the prototype indicate that submicro-meter resolution is attainable.

In principle such detector could be implemented on each of the 64 ESRF dipoles and potentially constitute a new device for monitoring vertical beam stability over the full DC-AC frequency range, and possibly serving in a global feedback system.

The strong radiation environment requires an adequate shielding structure to avoid degradation or damage. Initial tests show that this is possible without exceeding the restricted space availability.

REFERENCES

[1] Saint-Gobain Crystals, http://www.detectors.saint-gobain.com/

[2] P. Elleaume et al, "Measuring beamsize and ultra-small electron emittance using X-ray pinhole camera", J. Synchrotron Rad., June 1995 2, 209-214

[3] G. Naylor et al, "Bremstrahlung Detection and Chamber Obstruction Localisation Using Scanning Radiation Detectors", this DIPAC-05 workshop