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.

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 \(\sim 1\)us. The red curve shows the X-ray spectrum absorbed by a 0.5mm thick CdWO\(_4\) 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 \((f_1=50\)mm, \(f_2=75\)mm) 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 \(\sim 4\). The CCD used is the Sony ST-30 (1/3” format), the pixel size at the source-point is \(\sim 4.4\)um. The optical resolution of the system was assessed in laboratory and estimated at \(\sim 10\)um. 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.

**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 \((42\)urad 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.

**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 fwhm] versus emittance and the 2 measurements in yellow that are in excellent agreement.
stability of the electron beam by measuring precisely the
centre of the profiles of a series of measurements.

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

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

gobain.com/
small electron emittance using X-ray pinhole
Chamber Obstruction Localisation Using Scanning
Radiation Detectors”, this DIPAC-05 workshop