MEASUREMENT OF VERTICAL EMITTANCE WITH A SYSTEM OF SIX -In-Air-X-Ray- PROJECTION MONITORS AT THE ESRF

B.K. Scheidt, ESRF, Grenoble, France

Abstract

The ESRF Storage Ring is now equipped with a system of 6 independent imaging monitors that measure the vertical emittance of the electron beam in the middle of the bending magnet through the very hard X-rays that fully traverse the 40mm thick Copper dipole absorbers and enter the free air space behind it. The tiny power that leaks through the absorber, and carried by X-rays of ~170KeV of very narrow vertical divergence, is simply projected onto a scintillator screen at ~1.8m from the source-point and imaged by optics & camera. These inexpensive & compact detectors are fully operated in free air and are easily installed and maintained without any vacuum intervention. They now work reliably and measure routinely the ESRF's vertical emittance with high precision and resolution. Results will be presented together with the underlying principles of the IAX projection detector, and the practical design solutions applied.

X-RAYS TRAVERSING THE ABSORBER

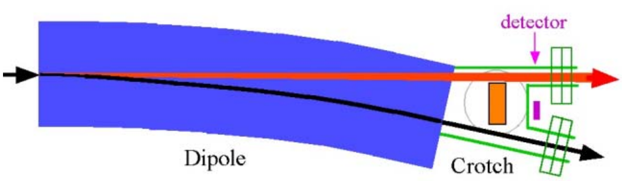

Figure 1: Position of the detector in air just behind crotch.

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). However, ~4ppm of this power (i.e. 600uW/mRad hor. angle) is not absorbed and traverses the complete structure (of ~35mm Copper and 5mm Steel) to enter the free air behind.

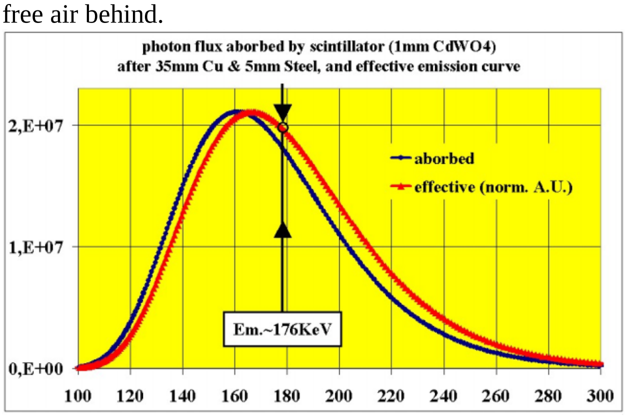

Figure 2: The spectrum (photons per sec. in 0.1%bw & 1mrad hor.angle, at 200mA) absorbed in the scintillator.

This leakage power is carried by the high energetic photons in the 100-300KeV range and can be detected through the use of a high-Z scintillator [1,2]. The fig.2 shows the energy spectrum of the absorbed photons in a 1mm thick CdWO4 scintillator (blue), and the curve of the scintllators' effective emission sensitivity (normalised and in arbitrary units, in red). The median value of the latter lies at ~176KeV. At this energy the photon beam divergence has a nearly perfect gaussian distribution of ~42urad fwhm. This small divergence, in addition to the relative short and precisely known distance of the scintillator to the source-point makes it possible to measure the vertical beamsize of the electron beam [3,4,5].

DETECTO: THE OPTICAL SYSTEM

The fig.3 shows a simplified (side-view) schematic of the IAX detector with : a) the scintillator screen b) an aluminium mirror just behind to deflect the emitted light to c) a lens pair that collects and focuses an image onto d) the CCD matrix of an IEEE-1394 standard camera.

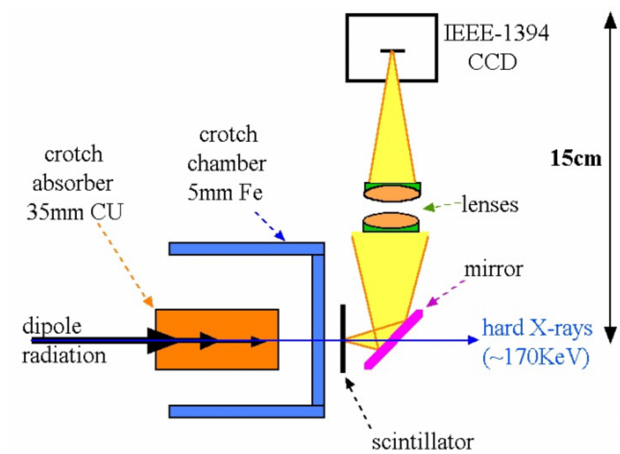

Figure 3: side-view in the vertical plane of the detector.

After going through some test & prototype phases in 2006 in which various optics, cameras, shielding techniques and mechanical assemblies & supports were employed, the detector has now reached a mature and final state that is fully compatible with its performance potential (precision & resolution), the very hostile radiation environment of its location, and the very limited physical space available at this location.

The entire detector is mounted together and adjusted optically in laboratory before installation. All the parts are held by a single aluminium support allowing a rapid and easy (re-)installation.

The optical aperture is 5mm at 60mm distance to the scintillator. The Flea camera of PGR (640x480pixels of 7.4um) which was chosen for its miniature dimensions and for the ease of operation : gain & exposure control, power-supply and read-out all through a single IEEE-1394 cable [6]. The camera covers a 3.6x2.7mm (hor.-vert.) field at the scintillator with a double achromat system of 60 & 80mm focal length (magn.=1.33).

The lenses & camera are now thoroughly shielded by a Lead tubical structure (machined in a single piece) to avoid damage & degradation by the particles (generated by 13KW of X-ray beam absorbed at a short distance) that scatter around in this area.

CALCULATION OF VERTICAL ELECTRON BEAM SIZE

The X-rays travel 1.78meter before hitting the screen where they project a stripe-line image. In the vertical plane, 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 176KeV photon beam (41.5urad fwhm, and of quasi-gaussian distribution) the projected vertical beam size (h) is only 111um fwhm compared to the vertical electron beam size of 82um fwhm at nominal ESRF emittance of 35pm.rad.

The precision with which the distance (S) and the photon beam divergence (αv) can be determined is such that the absolute precision of the electron beamsize measurement is estimated at better than 2%.

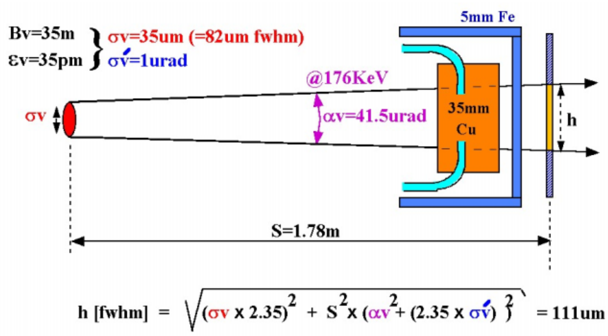

Figure 4: source-point size to projected image size.

DETAILS, IMPROVEMENTS AND TESTS OF THE DETECTOR

The initial problem of camera damage is now totally resolved by a nearly hermetic and (average) 6mm thick Lead shielding. The same Lead tube also holds the 2 achromat lenses that however still suffer from some blackening over time since the inevitable optical aperture for the light signal also lets through particles responsible for this blackening. This achromat blackening was reduced by the application of a 2nd mirror (forming a chicane type of light path inside further Lead shielding), and the application of the CdWO4 (shielding) window just in front of the lenses.

Despite these measures the achromat blackening is not fully avoided and presently still causes a loss of 50% sensitivity after a few months of use. Therefore a set of commercial Quartz lenses (completely immune to blackening) are also being used in some of the 6 individual detectors. However, the intrinsic spatial resolution (or blur) of such optical system would be impaired mainly by the chromatic aberrations and the relatively broad visible emission spectrum of the CdWO4 scintillator. The final image blur would also be worsened by the scintillator's non-negligible (1mm) thickness.

The use of a LuAg:Ce scintillator offered a solution since it has a narrower emission spectrum (~50% less) and is (despite reduced density of 6.7 to 7.9gr/cm3 for CdWO4) even more sensitive (for equal thickness) to the hard X-rays. Using Quartz lenses (50 and 75mm focal length) with 3.5mm optical aperture in combination with a 0.5mm thick LuAg scintillator the system parameters are optimised for spatial resolution & sensitivity.

The blur of the detectors is assessed at ~20um fwhm which is just about acceptable for the typical vertical sizes that we are measuring (i.e. projected beamsize h ~111um). The exact value of the blur is difficult to asses in laboratory only. While the type and thickness of scintillator and the choice of lenses & apertures have an impact on the ultimate value, the main uncertainty comes from the quality of the focussing since the extreme compactness of detector does not allow for a remote control of focus adjustment.

For this reason a simple test-bench was implemented behind an un-used beamport absorber where more space is available then on the real location of the detectors. This test-bench allows to install a fully mounted detector, to expose it to the same energy range of X-rays, and to limit the vertical size of these X-rays by the use of a 5um slit of 3mm thick Tungsten. The profile plot in fig.6 shows the result of such intrinsic spatial detector resolution (red curve) , compared to that of typical result values for beam measurements (black curve).

RESULTS WITH A SYSTEM OF 6 INDEPENDENT DETECTORS

A total of 6 detectors are installed at the up-stream dipoles of the ESRF cells 3, 5, 10, 18, 25 and 26.

Together with the already existing emittance monitors of the X-ray pinhole cameras in cells 9 and 25 [7] the ESRF Storage Ring' vertical emittance is now monitored by 8 independent devices. The corresponding IEEE-1394 cameras are controlled by a set of 5 PCs that run under Linux. A specific Tango device server takes images a rate of 15Hz, and after some selectable range of averaging then calculates the position and fwhm-size (h) of the vertical profile over a selected width of the 'stripy'-like image. The vertical emittance is calculated from h taking into account the (fixed) parameters of distance and photon-beam divergence, and the accelerator's Beta-vert. value at the source-point. The device server provides automatic gain and exposure time control for each camera, and correct background substraction. A panel for read-out & control was created using the Tango application toolkit framework (ATK).

The figures 5a & 5b show images of the 6 IAX detectors plus that of the 2 X-ray pinhole cameras. The first are with small emittance values while the latter are taken with a strong offset current in a skew-quadrupole corrector causing a huge increase of the vert. emittance. Note that the variation of intensity along the hor. axis seen in the IAX images is caused by the water cooling tubes inside the Copper absorber, this has no effect on the measurements in the vertical plane.

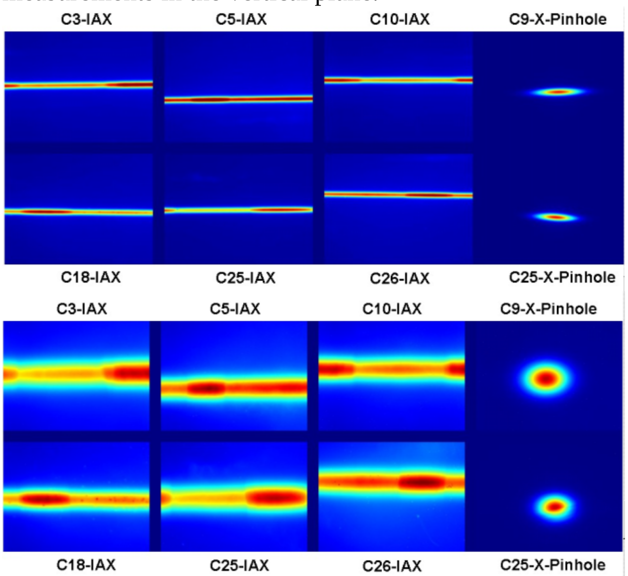

Figure 5a-b: images from the 8 devices under extreme different values of vert. beam emittance (~20 & ~500pm).

The fig.6 shows the vert. profiles of these extremes. It is noted that the scintillator is sensitive to other particles causing a background level in the image. This background level is dependent on the type and thickness of the scintillator, and has been successfully reduced by further detailed Lead shielding around the scintillator itself.

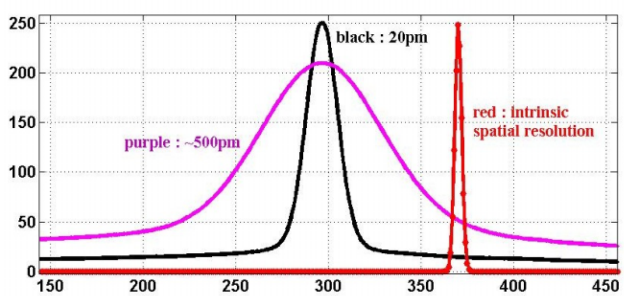

Figure 6: profile plots [A.U. & pixels) of the images shown in Fig. 5, and that of a 5um sized slit of a test set-up (red).

The capacity of the 6 IAX devices to measure very small emittance values (down to ~10pm) is proven. However, their absolute precision at these small values is more difficult to asses, in particular the direct comparison between their absolute result values (and that of the 2 Pinhole devices) is of limited significance because of the variation of the local hor.-vert. beam coupling correction obtained through a large set of local skew-quadrupoles.

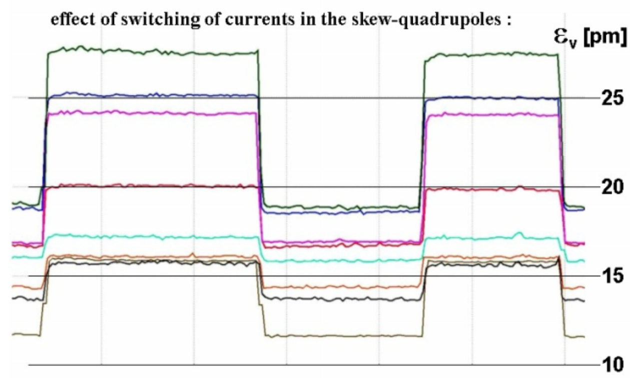

Figure 7: small result values of the 8 devices showing the effect of skew-quad current variation at high resolution.

The resolution (at 1sec measurement time) is estimated at <0.1pm which allows to see tiny effects on the beam of various systems (undulator gap changes, skew-quad correction, vacuum incidents, orbit position control, etc.).

In addition to the beamsize, the vertical beam position of the projected image is also monitored. It provides another tool for surveying the vert. beam position stability around the Storage Ring. The fig.8 shows the excellent correlation of the position results (30sec & 1um /div) of the Cell 25 IAX detector and the X-ray pinhole camera (separated 1.2m in the same dipole).

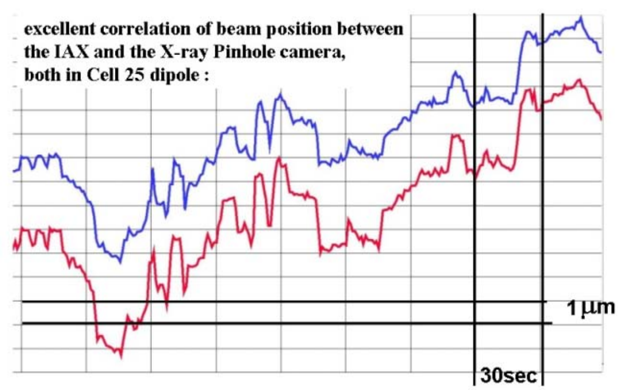

Figure 8: correlation in vert. beam position of 2 devices.

REFERENCES

[1] http://www.detectors.saint-gobain.com/ .

[2] http://www.crytur.cz/ .

[3] B.K.Scheidt, "Detection of Hard X-Rays in Air for Precise Monitoring of Vertical Position & Emittance in the ESRF Dipoles", DIPAC'05.

[4] A-S.Müller, et al., "Precise Measurements of the Vertical Beam Size in the ANKA Storage Ring with an In-air X-ray ", EPAC'06.

[5] B.K.Scheidt, "In-Air X-Ray Detectors : a New Field of Extremely Simple and Powerful Beam Diagnostics", BIW06 May 2006, Fermilab-fnal.

[6] http://www.ptgrey.com/ .

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