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NEW X-RAYS DIAGNOSTICS AT ESRF: THE X-BPMs AND THE HALO-MONITOR

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Abstract

Two new X-ray diagnostics have been installed in the Front-Ends of the Storage Ring of the ESRF's Extremely Brilliant Source (EBS) recently.

Two independent optical X-BPMs at 23 m distance from their bending magnet source-point are giving extremely useful additional information on the vertical beam stability in comparison to the e-BPMs data.

A vertical beam Halo-monitor allows to measure permanently and quantitatively the level the electron density at large distance (1 – 3 mm) from the beam core, in a non-destructive manner.

INTRODUCTION

The Extreme Brilliant Source (EBS) ring at the European Synchrotron Radiation Facility (ESRF) is operational since mid-2020, generating coherent and bright x-rays for the scientific users [1]. The X-rays are generated by an electron beam of 6 GeV and 200 mA, with horizontal and vertical emittances of 120 pm and 10 pm, respectively. EBS can run with different filling schemes, such as 7/8 multibunch with a single bunch up to 8 mA, uniform, 16 bunches and 4 bunches.

A large range of diagnostics are in operation since the commissioning to measure the parameters, characteristics and behaviour of the beam [2].

Since last autumn we have added two new X-rays diagnostics: 1) the X-rays Beam Position Monitor (X-BPM) to check the vertical beam stability and 2) the Halo-monitor to measure the vertical halo at large distance from the beam core. In this paper we present the systems and the first results.

THE X-BPMS

Two optical X-BPMs have been implemented in the Front End (FE) of the beamlines BM8 and BM16 that have 0.85 T bending magnets as their X-ray source. These X-BPMs are of a first version that aimed at satisfying the proof-of-principle of getting a reliable image of the passing X-rays and to use that for verifying the mid- and long-term positional stability of these X-rays. This first version allows, through use of UHV-bellows etc., the sensor to be inserted, and so to measure, but not to serve the beamline, or to be extracted, thereby letting the full X-rays to the beamline. After the here below reported success with this first version we are now installing a 2nd version (in October) that will measure permanently while leaving the X-rays for the beam line users unperturbed.

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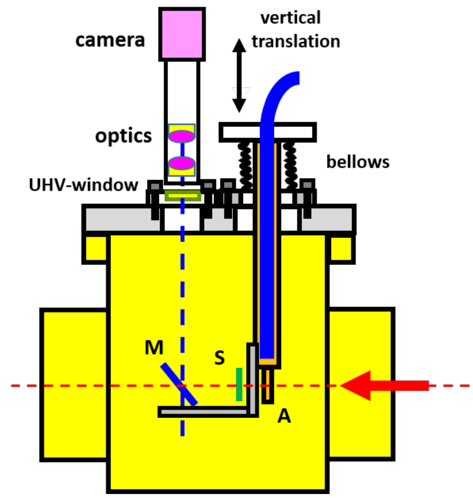

Figure 1: The X-BPM shown in inserted position.

The X-BPM (see Fig. 1) consists of a scintillator (S) behind a cooled copper absorber (A), a 45-degrees mirror (M), an UHV viewport and a camera with a set of achromats. The latter focusses on to the camera array the image that the X-rays emits by passing through the scintillator screen. (see Fig. 2).

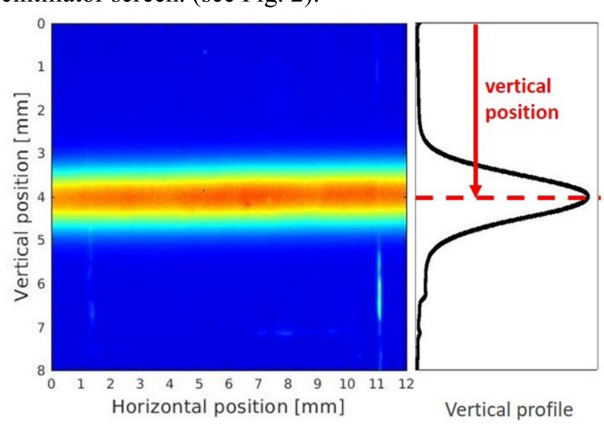

Figure 2: The BM8 X-ray image with 200 mA beam current, 1 ms exposure time, 0 dB gain, 2*2 binning.

The centre of the vertical profile is essentially the vertical X-ray beam position, and the only value of interest to us. It is calculated and stored at 1 Hz and these vertical X-rays positions can then be compared with fully independent readings obtained from a duo of standard electron e-BPMs in the region of the source-points of these BMs. From these 2 e-BPMs both the angle and the position of the electron beam at the BM source-point is obtained, thereby allowing a calculation of the position of the X-ray beam at 23 m distance.

In Fig. 3 is shown the vertical position of the BM8 X-rays as measured by our new X-BPM (purple) and that obtained

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from the e-BPMs (blue) over few minutes. Both signals show a sub-µm resolution and are in very good agreement.

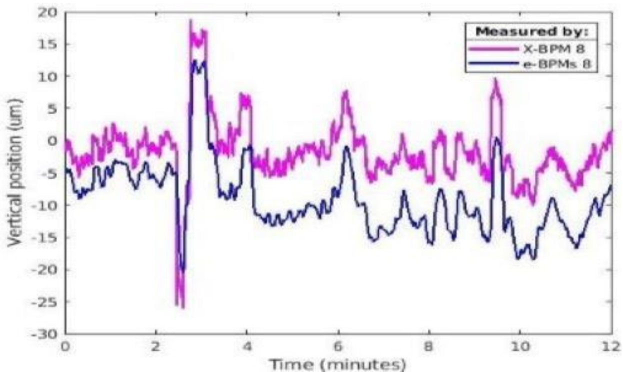

Figure 3: The (BM8) X-rays vertical position measured by the X-BPM and obtained from e-BPMs over few minutes.

In Fig. 4 these same two independent vertical positions of the BM16 X-rays over 15 hours are shown and we can note two issues: (a) the top-up injections (30 min interval) are detected by both devices, but (b) the positions no longer agree and show significant drift.

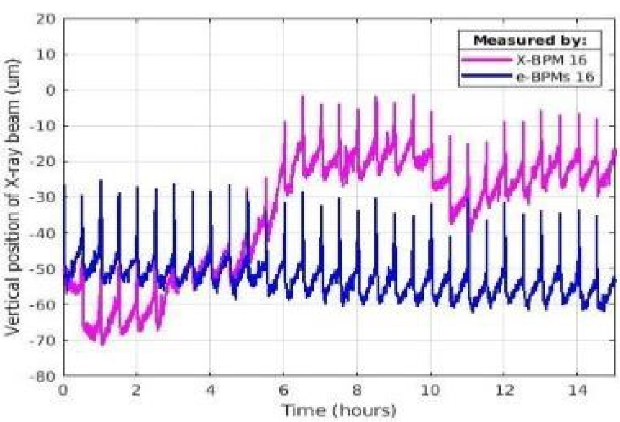

Figure 4: The (BM16) X-rays vertical position measured by the X-BPM and obtained from e-BPMs over 15 hours.

During 2 periods in December and March we could keep the X-BPMs inserted for a full week (the beamline users were exceptionally not taking the X-rays) and this has been very helpful in tracking the origin of these drifts. These are effectively introduced by variations of the temperature of the e-BPM electronics that affect their correct electron beam position readings. These devices being in the orbit control loop means that an angular error (typ. a few µrad) of the beam steering is introduced, which becomes very manifest in the X-BPM being at 23 m distance.

As a consequence, we are now adding a simple but effective temperature stabilization to those cubicles that hold these e-BPM electronics, in particular in those zones that serve the orbit control in bending magnet sources of which the ESRF has 17 in total.

THE HALO MONITOR

The X-rays of a 0.57 T dipole magnet being accessible in the (partial) Front-End module of a non-existing beamline offer us the possibility to install a few simple components to constitute a novice diagnostic that allows to measure the so-called halo population of the electron beam. In this case it concerns the halo in the vertical plane and at a distance of roughly 1 to 3 mm from the central beam-core [3].

Concept and Components

The main components are shown in Fig. 5 in the vertical plane together with the (simplified) trajectory of the X-rays that are emitted from the electrons (at extreme left of the picture) and travel towards the detector (extreme right) which is a two-dimensional X-ray imager read-out by a standard camera. It is important to note that the X-rays from the central beam-core are many orders of magnitude stronger than those emitted from the electrons that make up the weak halo population. The specificity in our concept is to attenuate this powerful X-ray beam by an absorber that is vertically positioned so to intercept that beam.

However, the X-rays of typically 60 keV have a small but not a zero divergence as is supposed in the illustration. In fact, this divergence amplitude is 1E-9 for a divergence angle of 200 µrad. This means that the absorber (at roughly 6 m from the source) needs to positioned at least 1.2 mm below the central axis, so to reduce this unwanted divergence signal to a negligible level compared to the level of the X-rays emitted by the Halo. Consequently, it implies that this system can only detect the halo levels at say 1 to 3 mm distance from the beam-core.

The UHV of the Front-End is separated from the free air further down-stream by a 6 mm Aluminium window. At this point a further (movable) attenuator (1 mm thick Tungsten), provides flexibility in attenuation, and the detector on a two-axis translation stage are situated.

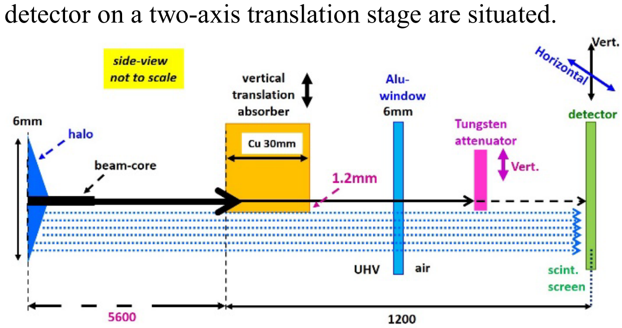

Figure 5: The main components and the paths of the X-rays of both the beam-core and that of the halo population.

The detector is protected by a 5 mm thick lead box, and contains a 2 mm thick LYSO scintillator (15 x 15 mm), a double chicane with 3 mirrors, a set of achromat lenses and a CMOS camera and covers a 8 x 6 mm field of view. The system has given permanent results since its installation in March without any need for repair or maintenance.

Verifications and Calibration

The Fig. 6 shows a typical image (left) and its vertical profile (right). The beam-core signal there is produced by the main beam with its X-rays very strongly attenuated by the 30 mm Copper, the 6 mm Aluminium (although negligible in comparison) and the 1 mm Tungsten. While

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for the halo signal beneath, the X-rays are only attenuated by the 6 mm Aluminium window. In the commission period of this device, the edges of the Copper and Tungsten absorber had been correctly positioned vertically, so to satisfy two conditions: a) let the X-rays emitted from the halo signal avoid these absorbers and b) intercept the divergent X-rays emitted from the main central beam so to ensure that these do not create a fake (background) signal in that lower zone where the system is supposed to only measure the genuine halo level. It implies that there is blind zone where the system cannot measure.

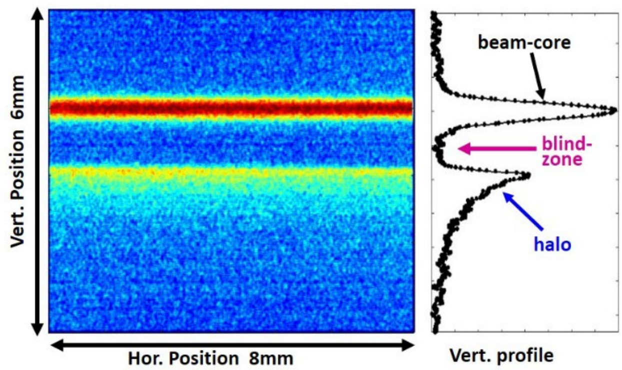

Figure 6: The typical image obtained shows clearly the beam core and the halo (below).

It is important to verify that this signal that we attribute to be the halo is not polluted by some parasitic signal by scattered X-rays, or from an incorrect positioning of the vertical absorber. In our storage ring we can use the vertical scraper to do such verification by positioning this scraper edge very close w.r.t. to the electron beam. By doing this in a relative fast scan, during which the scraper is typically put at distances of 3 to 0.3 mm in steps of 0.1 mm, and by measuring the halo levels at each step with a 1 sec measurement time, we observe the progressive reduction and the final extinction of the halo level in our halo monitor.

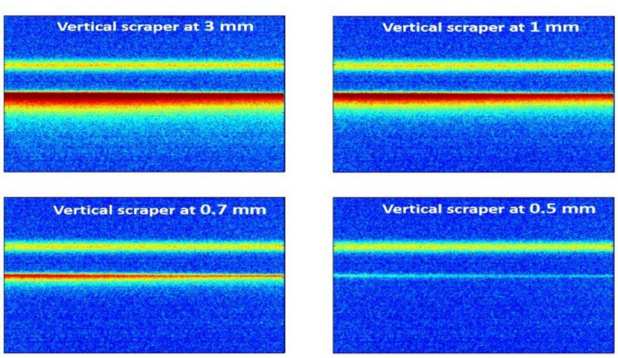

Figure 7: Verification results using the vertical scraper to check that halo signal is not polluted by parasitic signal.

The Fig. 7 (images) and Fig. 8 (profiles) shows the very satisfying results of such verification. At that particular moment and by pure coincidence the UHV vacuum in our ring was strongly impaired which created a strong halo. This explains why the halo signal in this data appears stronger then the beam-core signal.

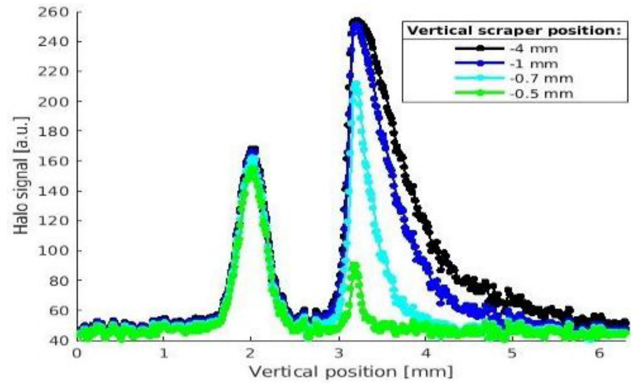

Figure 8: Verification results using the vertical scraper to check that halo signal is not polluted by parasitic signal.

Having the possibility, during dedicated accelerator studies times, to either fully insert, or to fully extract the Cu absorber and W attenuator, allows performing a simple calibration of our detector, by measuring at:
a) low beam current (0.018 mA), the absorber & attenuator withdrawn, and a 2 ms camera's exposure time
b) at nominal (200 mA), the absorber & attenuator inserted, and a 200 ms camera's exposure time.
This yielded an attenuation value of 3E-7 of those X-rays detected from the beam-core w.r.t. those from the halo-population. Applying this calibration to the standard obtained data allows to express the halo-population directly in beam current as shown in Fig. 9.

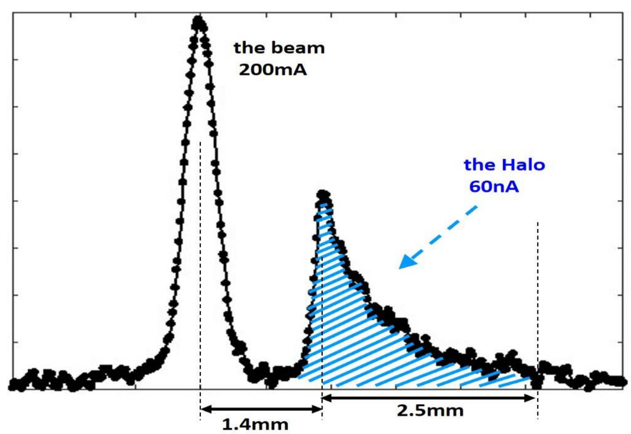

Figure 9: typical results with a calibrated value of halo population expressed in beam current.

Results Under Numerous Beam Conditions

The level of the halo population in an electron ring like our EBS is strongly determined by the scattering rate of which there are two distinct types: a) vacuum scattering due to interaction of the electrons with residual gas molecules and b) Touschek scattering due to the high density in the central beam-core. In Fig. 10 the effect of the latter is shown by operating the beam with 2 different settings of the vertical emittance, i.e. 2 pm·rad and 10 pm·rad. Strictly speaking the Touschek scattering, affecting the electrons essentially in the horizontal plane, show-up on this (vertical plane) halo monitor due to the small but inevitable H-V coupling in the lattice.

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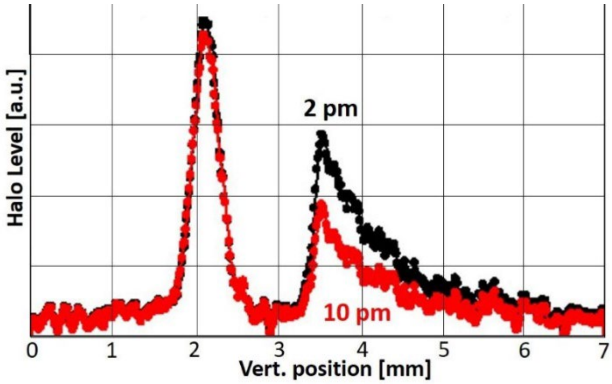

Figure 10: Stronger halo level for lower vertical emittance.

The effect of vacuum quality was assessed very neatly by creating temporarily an impaired local vacuum by switching on one of the titanium sublimators in the ring. The Fig. 11 shows the result of this manipulation.

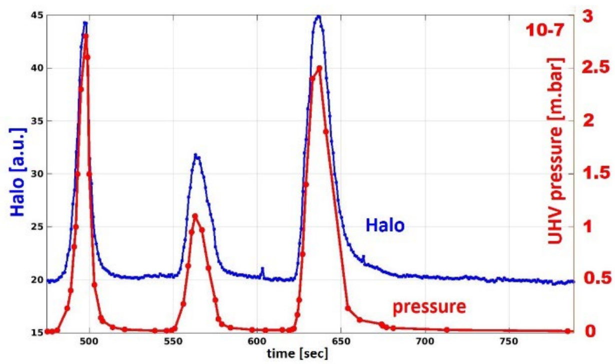

Figure 11: The excellent correlation between the halo level and the vacuum pressure on three specific events.

During normal USM operation the halo signal is conveniently correlated with numerous signals from other diagnostics. An example is shown in Fig. 12.

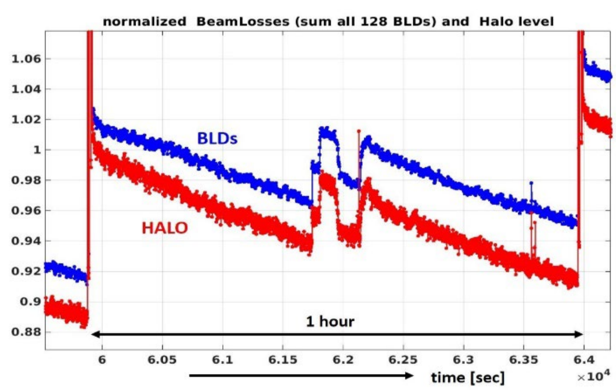

Figure 12: A typical 1 hr recording of the sum of signals of our 128 beamloss detector units and the halo-signal.

CONCLUSION

New X-ray diagnostics were successfully implemented in available Front-Ends: Two optical X-BPMs with µm resolution will be very useful to assess the long-term beam stability. A vertical non-destructive halo-monitor is a novice and very sensitive diagnostics giving additional info on many beam parameters and the vacuum quality.

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