RECENT DEVELOPMENTS OF NOVEL BEAM DIAGNOSTICS AT THE ESRF

B.K. Scheidt, ESRF, Grenoble, France

Abstract

A number of rather novel and particular electron beam diagnostics have seen their development in 2012 for the ESRF Storage Ring. A vertical Beam Halo detector that measures the bunch population at millimetres, i.e. hundreds of sigmas of nominal beam size, away from the central core. This measurement is based on X-ray synchrotron radiation from a bending magnet and is totally non-destructive to the electron beam itself. Another diagnostic use of the very hard X-rays available from the bending magnets is the detection of electron beam energy fluctuations. The detector hardware is simple and in-expensive and has shown a resolution of energy fluctuations of less than 10ppm. Also a single orbit turn measurement of the injected beam shape and size is now possible through the use of visible synchrotron light combined with a fast gateable intensifier, which can be triggered on any of the desired orbit turns after injection. Detailed results of each of these new diagnostics will be presented.

NON-DESTRUCTIVE MEASUREMENTS OF VERTICAL BEAM HALO

The European Synchrotron Radiation Facility operates with a typical vertical emittance of below 10pm, which means a sigma beam size at the highest vertical Beta values (~40m) of ~20 micrometers. While the central beam core has a profile of Gaussian shape, the beam's profile at larger distances is very different. In fact, at distances up to 10mm away (i.e. 500 sigmas) there is still a continuous population of electrons.

This is easily measurable by the combination of a vertical scraper and a sensitive Beam Loss Detectors (BLD) positioned down-stream this scraper : by inserting the scraper jaw the so induced electron losses (seen by the BLD in the form of an electromagnetic shower caused by the 6GeV electron penetrating the jaw) increase inversely proportional with the distance between jaw and beam.

However, even though this method is very sensitive thereby allowing a measurement in the 9 to 10mm distance from beam without any significant effect on the beam's lifetime (typically 50hrs) this method is destructive to the beam and not useable for assessing the halo population at shorter distances while serving normal users operation.

Projection Imaging via X-rays from Dipole

The synchrotron light emitted from the dipoles (0.86T, Ec=20KeV) is used already for a number of diagnostics, mainly in the X-ray domain and for emittance measurements [1, 2]. The projection of these X-rays onto an imager device (typically a scintillator screen with optics collecting and focussing onto a CCD camera) makes possible the measurement of a beam profile even if that measured profile itself is blurred because of the convolution with the divergence of the emitted X-rays multiplied with the distance between the source point and imager. Yet, even in its simplest form this device clearly shows the strong difference in the halo population at (rare) conditions of bad Storage Ring vacuum as experienced after the installation of five new 6m long ID vacuum chambers in the 2012 long shut-down. The Fig.1 shows the profiles observed at normal vacuum (black) and at initially very bad vacuum (red) and improving vacuum (blue) 2 days later.

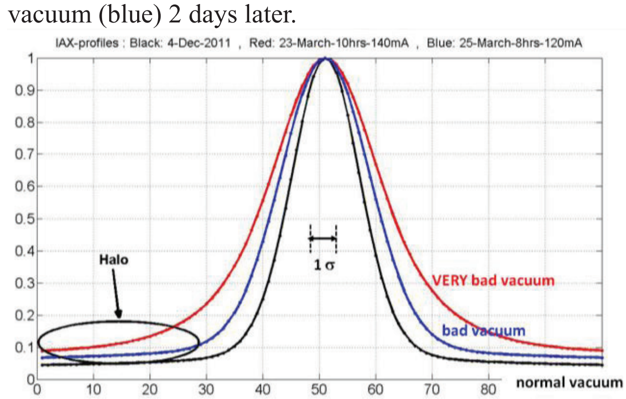

Figure 1: X-ray projected profiles at different vacuum conditions before and after shut-down (red and blue).

Long-distance X-rays Projection with Additional central Absorber to stop the intense beam core

While this allowed the observation of a very strong halo (i.e. a few percent of the peak centre) at a relatively close distance from the centre (a few sigmas) it does not allow to see much weaker halo levels at further distances, and in fact it cannot detect anything at all once the normal good vacuum conditions are recovered which is typically a permanent case at the ESRF.

Therefore a different device, but still based on 'long-distance X-ray projection' technique was elaborated and temporally installed on a dipole's beamport in cell 25. It includes a central absorber, a Tungsten blade, to completely stop the X-rays emitted from the core of the electron beam. This blade is of 4mm vertical height and 10mm thickness and is positioned just behind (i.e. down-stream) the 3mm thick Aluminium beamport window that separates the Ring's UHV from the normal air pressure. This blade is vertically centered on the X-ray beam axis and is about 4m down-stream the dipole source point.

Then a further 12m down-stream is the X-ray imager with an enhanced sensitivity through the use of an

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implemented MCP intensifier. This detector is vertically positioned 2mm above the X-ray beam axis.

The 3mm thick Aluminium window determines both the median X-ray energy transmitted (~40KeV) and the divergence of this X-ray beam (~86urad fwhm).

At a total distance of 16m from the source point this implies a very modest spatial resolution of about 1.4mm fwhm. However, the aim of this proof-of-principle prototype was to demonstrate that the signal that the imager detects is indeed from the (relatively low number of) electrons that are, very roughly, ~2mm above the electron beam core. The 2mm value is defined by the vertical alignment of the blade and the imager. However, the difference in intensity between the beam core and this halo population at 2mm is estimated at 6 to 8 orders of magnitude. It is thus reasonable to suspect that this detected signal could result from some small leakage of the intense core beam, or from some scattering effect, or some other artefact in the set-up.

In order to irrefutably proof that this clean signal was obtained from the halo only we used the vertical lower scraper in cell 5 of the Ring. The control of this scraper was programmed to make a quick excursion from -4.5mm to -1mm from the electron beam centre. While executing this scraper excursion the images of this halo-beam-imager were recorded in synchronization at each step (of 0.1mm) with the values of two BLDs (behind this scraper) and the rapid beam current & lifetime (obtained from the Sum of all BPM signals). The Fig.2 shows the results. The whole excursion caused a beam current loss of only 0.35%, while the signal of the halo detector completely disappeared.

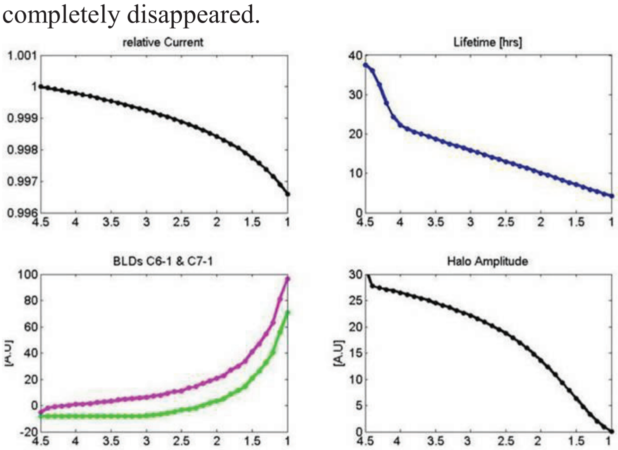

Figure 2: Recordings of relative beam current, Lifetime, BLDs and the amplitude of the Halo detector during a rapid scan of the scraper from 4.5 to 1mm.

The temporary installation of this device on the cell 25 beamport has validated the principle of very sensitive detection of the halo population through the use of X-rays. However, the limitations of spatial resolution, and also the absence of a direct calibration technique that allows to express the halo level in terms of a fraction of the central core intensity has lead us to seek certain improvements to its concept while at the same time finding a place for a permanent installation in the Ring

Therefore a new device was developed and installed in December 2012. It implies the detector position much closer to the dipole source point (3.2 m in this case) and also omits the so-called core light blocker : the detector is precisely situated (in UHV) above the central X-ray beam at a minimum vertical distance of 1.5mm. However, at this location the detector is unfortunately at only 0.6m down-stream a so-called crotch absorber that presents some surface at nearly grazing incidence to the impinging X-ray beam : the resulting scattering produces a strong background signal on this new halo detector which makes it unexploitable for sensitive halo measurements.

New solutions and designs are under study, based on the same principle of non-destructive measurement using X-rays from the dipole magnet.

ENERGY FLUCTUATIONS MEASUREMENTS

The ESRF Storage Ring now successfully applies a Fast-Orbit-Correction (FOC) to stabilize its orbit down to sub-micron values [3]. This same FOC system also controls the RF frequency since the tidal variations of the Ring's circumference are to be compensated through this RF frequency in order to keep the nominal 6GeV electron energy constant. Initially it was found that this so-controlled RF frequency made much faster variations that could not be explained, although the Insertion Devices (with their numerous gap variations) were first suspected of having an impact on the electron beam energy.

This phenomenon gave rise to trying to measure any real or supposed electron beam energy variation through the measurement of the flux variations of some other existing X-ray diagnostics [2] in our Ring. These devices (of which 11 independent units installed around the Ring) are normally used only for measuring the vertical emittance by a projection & imaging of the very hard X-rays (>160KeV). It can be calculated that at these energies (a factor 8 above the 20KeV critical energy of our 0.86T dipoles) the flux varies non-linearly with the electron energy : an electron beam energy variation of 1ppm produces an X-ray flux variation of 17.2 ppm.

This magnification factor is beneficial in making these devices relatively sensitive to even small variations of the electron beam energy. The read-out devices are IEEE-1394 standard CCD cameras that provide full data at 15Hz rate. With 11 units being available and the above reported fluctuations being in the 1 or 2 sec range there was scope for averaging (in time domain and over the available 11 units) and this then constituted this high resolution Energy Fluctuation Monitor.

However, these camera devices tend to age and suffer a degradation of their linearity. Also, the images are being small stripes meaning that only a relatively low number of pixels contain a real beam signal.

In order to compensate these drawbacks a fresh new unit was installed in a location with better radiation shielding and therefore supposedly less degradation. Also the optics was adapted to collect more light and to spreadout over a larger surface of the CCD array. This single unit now attains the same quality of resolution of all 11 other units together, i.e. 10ppm.

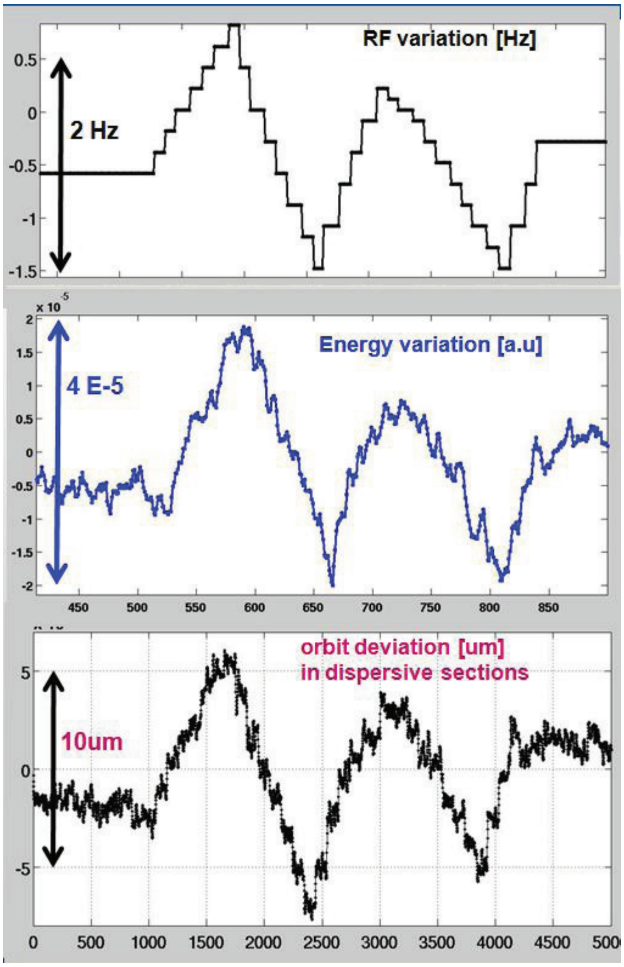

Figure 3: An 8 minutes recording of the RF frequency. variation [Hz], the relative energy fluctuation, and the horizontal orbit deviation (in dispersive sections) [um].

The Fig.3 shows the strong correlation between the RF frequency, the signal from the Energy Fluctuation Monitor and the horizontal orbit deviation. This at the time when the FOC's RF control was mal-functioning which has been remedied since.

Since the recorded flux also depends on the beam current, the here presented energy fluctuations measurements take this into account by an independent and precise beam current measurement.

Although this device is intrinsically calibrated, a precise verification of this was done by a precise change of the current in the dipoles.

TURN-BY-TURN IMAGING OF THE INJECTED BEAM

The transverse (hor. & vert.) image of the injected beam into the Storage Ring can now be recorded on a Turn-by-Turn rhythm by the use of a fast gateable image intensifier in the optics system of our visible synchrotron light beam monitor [4]. The essential components in this system are in place since long [5] with a 3meter focal length achromat at ~8m from the dipole's source point collecting and focussing the light onto the intensifier. With this gateable intensifier and its read-out camera behind both being triggered by the injection trigger it possible to take clear images of this injected beam at currents well below the nominal injected current. By adjusting the timing of the gate it is possible to select a single and well defined turn after the injection and so to obtain an image of the beam at that turn only. The Fig.4 shows images obtained over Turns 1 to 4.

However, this Turn-by-Turn imaging (used only during accelerator studies) does not work at the Rings' revolution frequency (355KHz), i.e. to obtain a series of N images at N different Turns the system needs N injections. Also, for different reasons the electron beam can not be allowed to store and accumulate. So the injected beam is being killed before a new injection, and before each new injection the timing of the gate is delayed by the orbit revolution period. This mechanism aims soon at working at 1Hz rate.

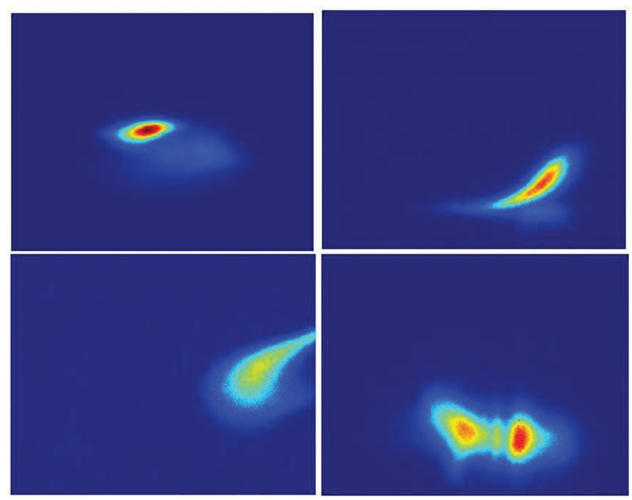

Figure 4: Images of the transverse beamsize of the injected beam at the first 4 turns in the Ring. The hor. and vert. scales are respectively ~16 and ~12mm.

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