Diamond-Based Photon BPMs for Fast Electron-Beam Diagnostics in Synchrotron Radiation Sources

Elettra Sincrotrone Trieste

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MOTIVATION

Electron-beam **monitoring** and **stabilization** are primary concerns in modern Synchrotron Radiation facilities, typically equipped with a **Fast Orbit FeedBack** (FOFB) based on the **electron Beam-Position Monitors** (eBPMs). Nevertheless, the photon beam exhibits **residual position** and **intensity fluctuations**.

These phenomena can be detected by fast **photon Beam Position Monitors** (pBPMs). The information provided by these detectors is **useful** for the **electron-beam diagnostics** and it can be integrated into the FOFB.

Amongst the available technologies for pBPMs, **single-crystal CVD diamond** is one of the most suitable materials thanks to its **outstanding physical properties** (high radiation hardness, semitransparency to X-rays, low thermal noise, high electron and hole mobility).

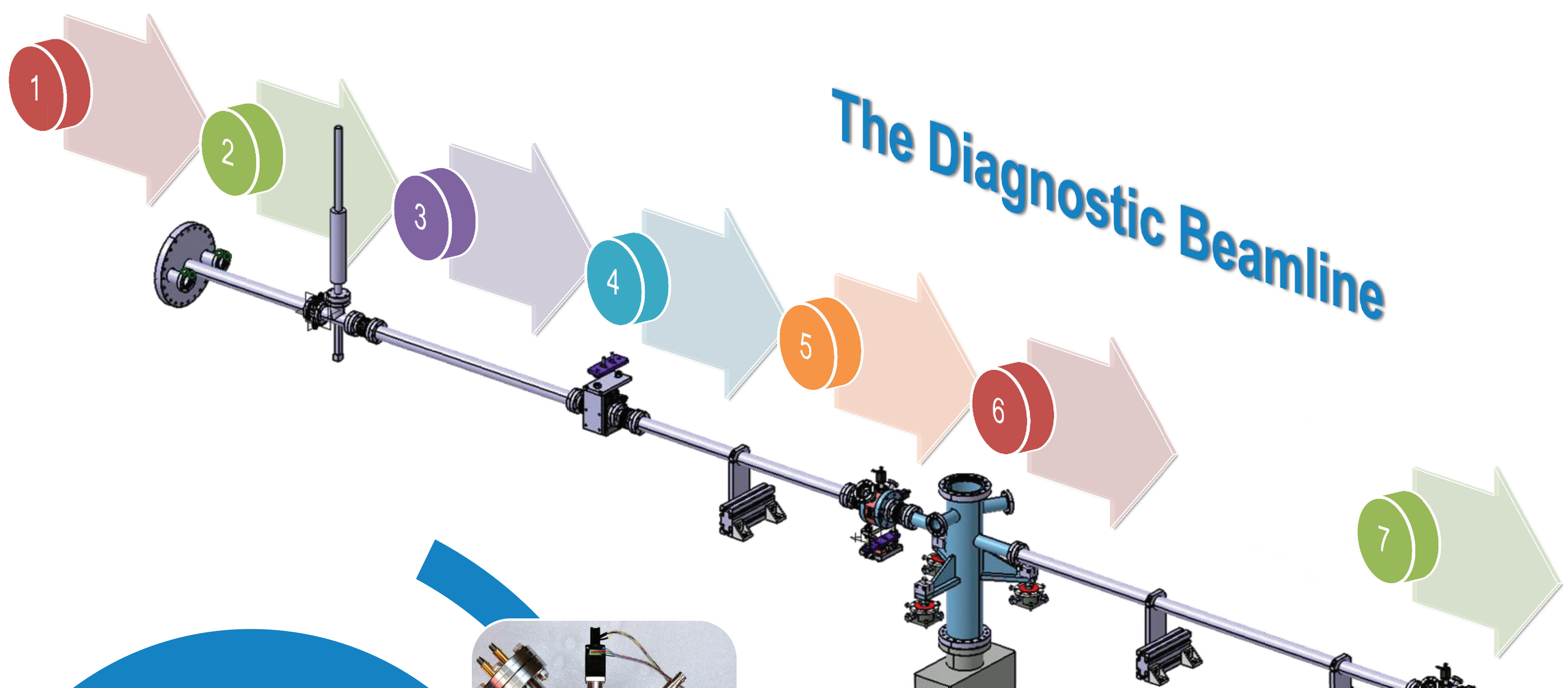
SOLUTION

A **diagnostic beamline** has been built at the exit of one of Elettra's bending magnets, **with** the aim of providing Elettra's future **FOFB** with **additional information** coming from state-of-the-art **diamond pBPMs**.

This line has been accommodated inside the shielding wall of the storage ring, between lines 10.1L and 10.1R, by exploiting the **central dead-end outlet** at the bending-magnet front end 10.1 in order to continuously **monitor the photon beam without interfering** with normal beamline operations.

This beamline features a 2-mm-thick water-cooled Al window, a remotely controlled shutter, a motorized slit system, an upstream pBPM (D1) and a downstream pBPM (D2). Outside the shielding wall, a **PC-based control system** allows **acquiring and processing pBPM data**. It also **controls motors** and **biasing** modules.

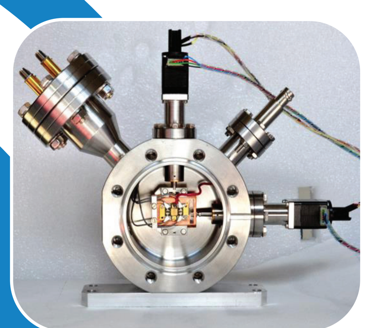
The Diagnostic Beamline

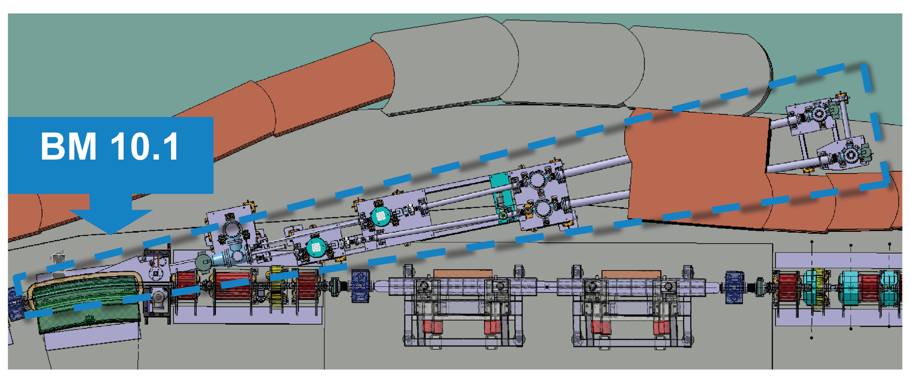


1. **Synchrotron radiation:** white beam delivered by bending magnet 10.1
2. **Front end outlets:** right (to beamline 10.1R) CENTRAL (previously dead-ended; currently to the diagnostic beamline) left (to beamline 10.1L)
3. **Window and shutter:** 2-mm-thick, water-cooled Al filter; accepting 1 mrad of the beam cone (horizontally), stopping undesired low-energy photons (to reduce heat load); separating the UHV of the storage ring from the local vacuum; followed by a remotely controlled push-pull shutter.
4. **Motorized slits:** 4 slits moved by stepper motors; remotely controlled from PC station; horizontal and vertical beam shaping; pin-hole (300×300 μm²) for the *camera obscura* geometry (between source and pBPMs).
5. **Upstream pBPM (D1):** 50-μm-thick, single-crystal CVD diamond (4.7×4.7 mm²); front and back surfaces coated with 100-nm-thick Al electrodes on 100-nm-thick DLC layers; *quad* layout obtained by lithographic segmentation of the front electrode;100-μm-wide gap between quadrant; housed in UHV motorized chamber.
6. **Vacuum pump:** maintaining the local vacuum of the diagnostic line, which is separated from that of the ring
7. **Downstream pBPM (D2):** 500-μm-thick, single-crystal CVD diamond (4.7×4.7 mm²); front and back surfaces coated with Cr-Au electrodes; *quad* layout obtained by masked metal deposition; 100-μm-wide gap between quadrants; housed in UHV motorized chamber.

UHV motorized chamber

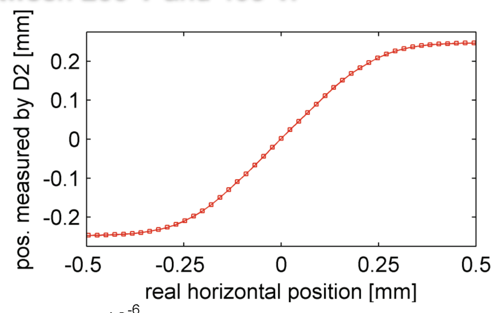
- Diamond detectors housed in very compact (CF-63-flanged) UHV-compatible chambers
- Devices glued and wire-bonded onto 50-Ω-matched carrier boards
- Boards mounted on motorized X-Y stages (controlled by external PC station)
- Detectors connected via BNC (biasing) and SMA (readout) feedthroughs
- Readouts fed into AH501B picoammeters to acquire the photo-generated currents (at a maximum rate of 6.5 kHz)
- These diamond pBPMs can monitor SR beams on a bunch-by-bunch basis, even at a 500-MHz repetition rate

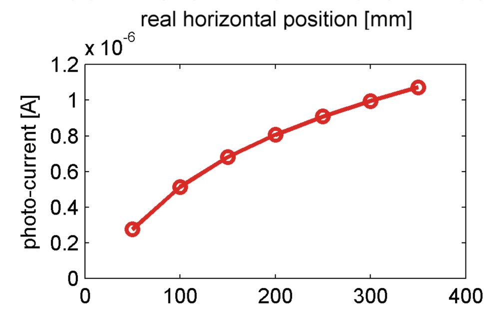




Preliminary pBPMs characterization

D2 moved w.r.t. the stationary photon beam by using the stepper motors of its UHV chamber. 124-nm precision in position estimation at a sampling rate of 10 Hz.
If projected to 10-kHz operations it gives a 3.9-μm precision. However, the deviation in this results is dominated by systematic errors (stepping precision, slow beam fluctuations).
Saturation-curve measurements show a good operation range between 200 V and 400 V.

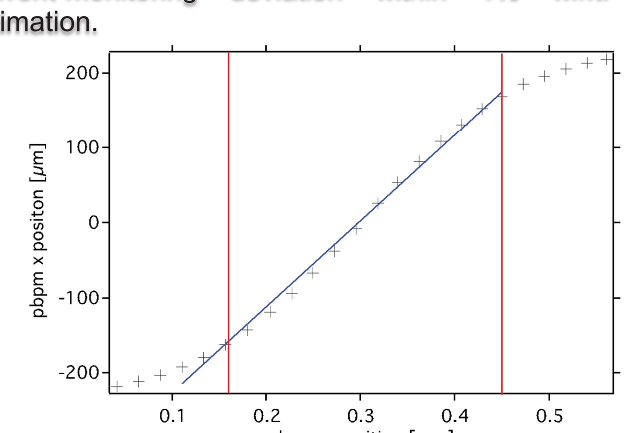


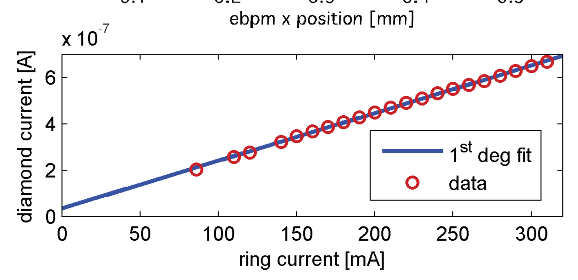


Monitoring performances

Deliberate electron-beam motion and current ramping

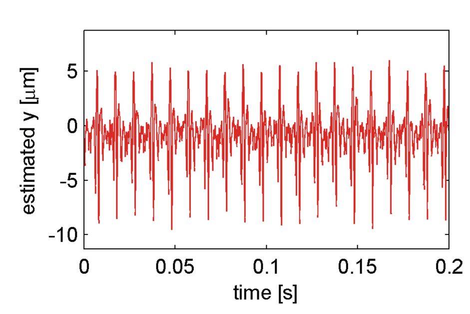
Comparison between pBPM and eBPM estimated positions.
Linear range of about 400 μm.
Quasi-periodic deviation from linear trend (imputable to the optics-simulation algorithm used by the machine control system).
Current-monitoring deviation within 1% w.r.t. eBPM estimation.

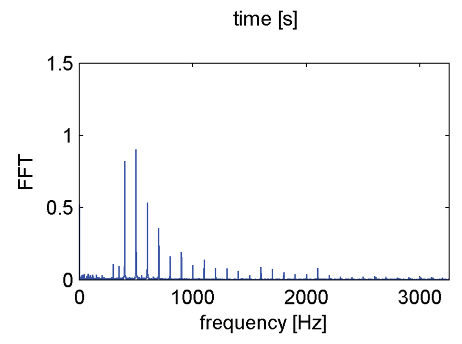




Fast monitoring

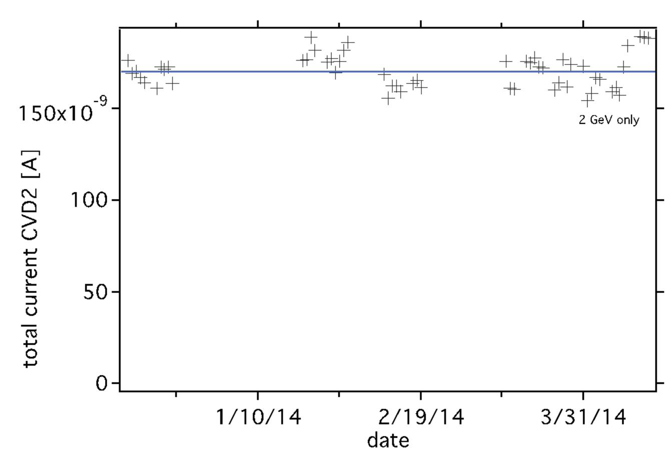
Stationary centred beam monitored in normal operations at a 6.5-kHz acquisition rate.
Stochastic uncertainty of 500 nm, considered as resolution limit for the system in these conditions.
Periodic fluctuation of 2 μm RMS.
A number of systematic components contributing to such fluctuations revealed by FFT (17 Hz and 23.5 Hz, 100 Hz and harmonics).





Long-term stability

20 nA and 0.19 μA read from D1 and D2, respectively (for a 300-mA machine current).
Precision in intensity monitoring better than 1%.
Sparse data available on radiation damage of this kind of CVDs caused by long-term exposure with x-rays.
Demonstrator operated continuously over a period of 9 months.
Total intensity measured by D2 reasonably constant over the span of time.



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FUTURE WORK

Upgrade of the readout electronics to acquire at 10 kHz (to integrate pBPM information into the FOFB)
Increase of the vertical aperture of the slits (to allow more photons in and exploit D1 in vertical monitoring)
In-house device fabrication (i.e. metallization process and wire bonding)