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TOWARDS ELETTRA 2.0: BEAM DIAGNOSTICS OVERVIEW

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Abstract

Diffraction Limited Storage Rings, the 4th generation machines, provide transversely coherent beams with uniform phase, maintaining high photons flux and stability. Diagnostic systems play an essential role for both commissioning and operating tasks of Elettra 2.0. The small beam dimensions make measurements of both position and size challenging. Elettra 2.0 diagnostics will rely mainly on Beam Position Monitors (BPM) and Synchrotron Radiation Profile Measurements. This article will provide an overview of all the beam diagnostics systems that will equip the new storage ring, together with the diagnostics systems involved in the main machine controls.

INTRODUCTION

The 4th generation light sources are characterized by an electron beam having transverse dimensions much smaller than that of the previous generation accelerators (σ_x:245→36 µm, σ_y:14→4 µm). This feature leads to a significant increase in the brightness of the sources and also calls for diagnostic systems exhibiting higher performances. In addition, the higher power density of the generated photon beams poses significant requirements on the overall performance of interlock systems used in the machine protection system (MPS).

A first division of diagnostic systems is that between systems operating on the electron beam and those operating on the photon beam.

The two fundamental parameters characterizing the beam in a storage ring are the circulating current and the mean trajectory.

While the measurement of accumulated current and related parameters, such as duration and injection rate, do not require an increase in performance, the measurement of beam position requires much higher resolution and stability to match the beam characteristics of the new generation machine.

ELECTRON BEAM DIAGNOSTICS

In this paragraph the electron beam diagnostic systems are presented. The most important parameters controlling the photon beams, produced by the accumulated electron beam, are:

- Beam Current
- Beam Position
- Filling Pattern

Beam Current Measurement

The measurement of the current accumulated in a storage ring allows to control the intensity of the photon beam produced at the source points. By keeping the beam accumulated current constant, it is possible to deliver a photon beam of constant intensity to the beamlines by operating the machine in TOP-UP mode. The circulating charge is constantly measured and the control system automatically injects the current back to the nominal value when it falls below the threshold value.

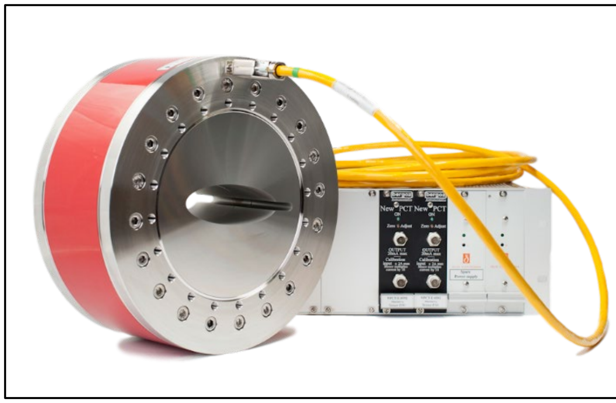

Figure 1: Example of an in flange NPCT (Courtesy of Bergoz Instrumentation).

The current measurement system adopts a Bergoz NPCT sensor (Fig. 1) whose output signal is processed by a dedicated acquisition system that measures the present current, evaluates its lifetime during natural decay, and measures injection rate and injection efficiency when the injector makes a refill. The same acquisition electronics is also used to measure the current in each cycle of the injector booster. The result, sent to the system that acquires the current of the storage ring, allows to measure the injection efficiency.

Beam Position Measurement

Measuring the position of the beam makes it possible to control the beam orbit in the storage ring.

It is clearly one of the most important measurements for the operation of a 4th generation light source, because the small beam size requires high positioning stability. The measurement system developed for Elettra 2.0 has been designed to provide high resolution and high stability over time (12 hours typ.) [1]. The BPM pickups consist of a stainless-steel body with four buttons welded onto it, each fitted with a SMA vacuum feedthrough [2]. While the internal cross section of the BPM pickups (including the four buttons) is the same, they may differ in the mechanical interface to the vacuum chamber and in the support system interface (see Fig. 2).

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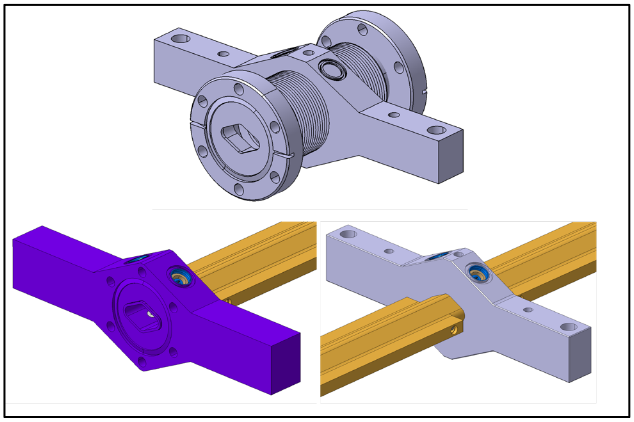

Figure 2: Three types of coupling between BPM body and vacuum chamber.

Upstream and downstream each undulator straight section, the most critical points in terms of beam position stability, the BPM pickups are mechanically decoupled from the surrounding vacuum chamber by means of bellows, as they are rigidly tied to supports to ensure the stability of their position. This solution prevents any displacement in case of vacuum chamber thermal expansion, allowing to obtain an absolute beam position measurement, as accurate as possible.

Elsewhere in the machine, due to the limited available space, the pickups are directly welded to the vacuum chamber instead; any other thermal expansion is handled by bellows placed at suitable junction points.

The signal acquisition system uses the pilot-tone signal technique [3] to improve the accuracy of the measurement against temperature variations and drifts in the acquisition chain. A pilot signal, having a slightly different frequency from the signal generated by the beam, is injected into the amplification and conditioning stage located within a short distance from the pickup. The two signals go through the same conditioning chain and are transmitted through the same long cable to the acquisition electronics located in the rack cabinets in the service area. The acquisition electronics are able to correct the measurements, compensating position variations caused by drifts due to thermal changes that affect electronics and/or cables.

The signal is under sampled by 150 MHz, 16-bit ADCs and is processed by an FPGA. Position measurement is obtained at turn-by-turn (TbT) data rate: appropriate data decimation can be applied to increase the resolution. Each electronic processes the signals of two pickups. Through a 10Gb ethernet link, data is supplied to the feedback system for trajectory control; moreover, the measured position is compared with the threshold values which, if exceeded, activate an interlock output for the machine protection system. The presence of two position measurements in the same electronics will allow, if necessary, to manage an interlock on the angle measured by the pair of BPMs. Each acquisition electronics also receives the signals from Elettra timing system for synchronizing the TbT acquisitions and aligns the data acquired by each unit over time through a timestamp attribute, which identifies each machine revolution. The acquisition system described here is currently in an advanced stage of development and the prototypes have been tested on Elettra's Storage Ring. The test results, scaled for the size of the Elettra 2.0 chamber, lead to an expected resolution value of 10 nm with rep. rate of 10 kHz.

Filling Pattern Measurement

The measurement of the filling pattern indicates how the circulating charges are distributed among the various buckets. When using non-uniform filling schemes, used for simultaneously satisfying the requests of different beamlines that use different measurement techniques, it allows to check the charge present in each bunch. In particular, time resolved experiments are interested in photons produced by single (or few) bunches present in the accumulated beam, typically with higher charge than the average ones present in the other buckets. These beamlines use the synchronization system to lock the acquisition to the instant in which a certain bunch of interest passes. The charge present here must also be kept constant. The charge measurement system gives a precise value of the overall current circulating in the Storage Ring.

The filling pattern measurement is already carried out in the current Elettra Storage Ring and it will be adapted to the new machine. The presently used pickup is a Bergoz fast current transformer capable of measuring the charge variation of the beam with a bandwidth of about 2 GHz. This pick up resolves the charge of each bunch. The acquisition system is being defined: starting with a standard oscilloscope it will be customized to be integrated in the machine feedback and control system.

PHOTON BEAM DIAGNOSTICS

While the intensity, the position and temporal distribution of the beam are directly measured on the electron beam, the brilliance and the high-resolution longitudinal stability are measured more efficiently using the photon beam by using:

- Emittance Measurements
- Longitudinal Profile Measurement

Emittance Measurements

The emittance of the accumulated beam is one of the most important parameters for evaluating the quality of the produced beam. By measuring the transversal dimensions of the beam, and by knowing the βx and βy machine functions at the source point, it is possible to calculate the emittance. The measurement must be carried out in a zero-dispersion point. By comparison with a second emittance measurement taken at a non-zero dispersion point, the energy spread value can be calculated.

The two bending magnets identified as suitable sources for the emittance measurement are shown in Fig. 3. To measure the size of the beam (expected value in the range 5-10 μm), the use of an X-ray pinhole camera is envisaged. We aim at locating the measuring system in the machine tunnel, to avoid the construction of a dedicated beamline in

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the experimental area. Currently, we are in a feasibility phase and calculations are underway to determine the characteristics necessary for the system to achieve the desired resolution values.

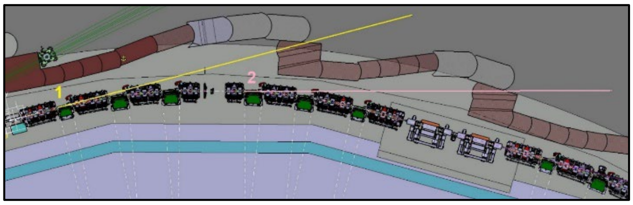

Figure 3: Emittance measurement source points.

Longitudinal Profile Measurements

The stability of the beam is one of the main characteristics in the 4th generation light sources and therefore it has to be carefully measured. Transversal and longitudinal stability is maintained by the Fast Transverse Feedback and Longitudinal Feedback system capable of damping beam oscillations. The measurement system, on the other hand, has the objective of acquiring the photons emitted by the beam both with feedback on and with feedback off to evaluate their characteristics. A beam of photons having a spectrum between the visible and the near ultraviolet generated by a curving magnet will be propagated using a series of mirrors to an optical laboratory located in the experimental hall for its characterization. The acquisition system will consist of a dual time base Streak Camera (Fig. 4) for measuring the longitudinal profile of the beam.

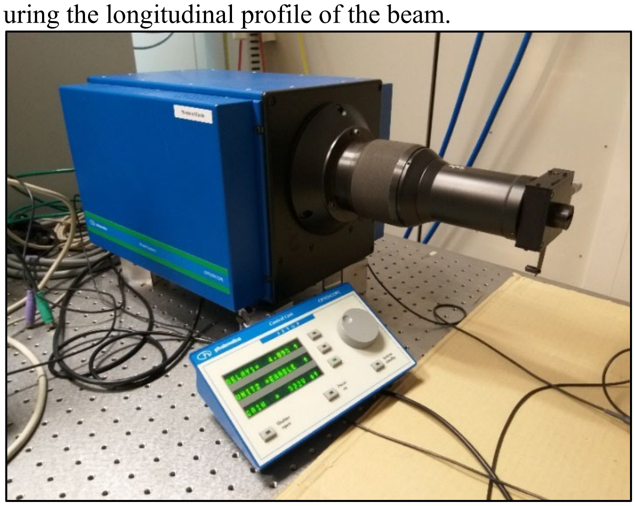

Figure 4: Dual Sweep Streak Camera System (Optronis).

This instrument, suitably synchronized to the timing system, may acquire the time intensity profile of the photon flux (i.e. of the electron beam) over a broad time scale intervals, from a single bunch to several machine turns. The transverse profile of the same photon beam transverse profile will be acquired by a camera to monitor the transverse stability of the beam to give a "visible" feedback of the machine status in the control room.

BEAM LOSS MONITORS

Another important diagnostic tool, for a safe and reliable operation of particle accelerators, is the beam loss monitor (BLM) system. During normal operation of the Storage Ring, beam losses are expected to be at a minimum level; higher losses indicate some anomaly. Losses monitoring can be of great help in reporting critical issues especially in the early stages of commissioning.

For Elettra 2.0, it is planned to use beam-loss sensors sensitive only to electrical charges and sensors sensitive to both charges and photons. Both sensor types use photodiodes as active elements: single in the second case, in pairs to form a coincidence detector in the first.

For coincidence sensors, the acquisition system will be based on event counting. For single sensors, the measurement of the reverse current intensity is proportional to the intensity of the incident radiation. The sensors will be distributed along the vacuum chamber in order to reconstruct a leakage map along the accelerator.

The control system collects data and analyses them in real time, memorizing anomalous situations and signaling these situations to the operator through warning and alarm messages.

At each insertion device (ID), some meters of the integrated dose will also be installed. Each ID will be equipped with a RadFET system equipped with 4 sensors placed at the beginning and at the end of the ID that will monitor the absorbed dose throughout the life of the device. This system developed for the FEL FERMI IDs will also be used for Elettra 2.0 [4].

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