ISBN: 978-3-95450-204-2 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2019-MOAO03

OVERVIEW ON THE DIAGNOSTICS FOR EBS-ESRF

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Abstract

On December 2018 the ESRF was shut down and the 28 years old storage ring was entirely dismantled in the following months. A new storage ring, the Extremely Brilliant Source (EBS), that had been pre-assembled in 2017 and 2018, is presently being installed and the commissioning will start in December 2019. EBS will achieve a much reduced horizontal emittance, from 4 nm to 150 pm, and will also provide the x-ray users with a more coherent synchrotron radiation beam. In this paper, we present an overview of the diagnostics systems for this new storage ring.

INTRODUCTION

After one year to replace the full storage ring, the commissioning of the Extremely Brilliant Source (EBS) will start in December 2019 [1].

The full EBS upgrade process foresees also the upgrade, modernization and the adaptation of the diagnostics systems dedicated to monitor the electron beam characteristics with the utmost precision and resolution. Table 1 lists the components of the diagnostics system for EBS. A more detailed description of the individual systems will follow.

Table 1: Components of EBS Diagnostics

Quantity	Component
320	Beam Position Monitors (BPMs)
5	Striplines
2	Shakers
3	Special BPM blocks
6	Current Transformers (PCT, ICT, FCT)
128	Beam Loss Detectors (BLDs)
5	Emittance Monitors
1	Bunch Purity Monitor
1	Visible light beamline

BEAM POSITION MONITORS

A detailed review of the EBS BPM system can be found in [2]. The electronics has been extensively tested on the previous ESRF storage ring.

BPM Blocks

EBS will host 320 BPMs distributed as 10 per cell. Due to the shape of the vacuum chamber, the BPMs blocks are designed with two different geometries:

- Large (6 BPMs per cell) with a button diameter of 8 mm, a horizontal distance between buttons of 23 mm, and a vertical one of 13.34 mm;
- Small (4 BPMs per cell) with a button diameter of 6 mm, a horizontal distance between buttons of 12.5 mm, and a vertical one of 9.62 mm.

The compactness of the BPMs causes a reduction of the zone where the so called Delta over Sum (DoS) formula is accurate enough to calculate the beam position. This has been studied using BPMLab [3] which also provided suitable sets of 2D polynomials to extend the linear range of the beam position response.

Electronics

The BPMs will be read by a hybrid system composed by 6 Libera Brilliance and 4 Libera Spark per cell. Both of the electronics produce data-streams and buffers with identically synchronized sampling rates. The distribution of the electronics along a cell is presented in Fig. 1.

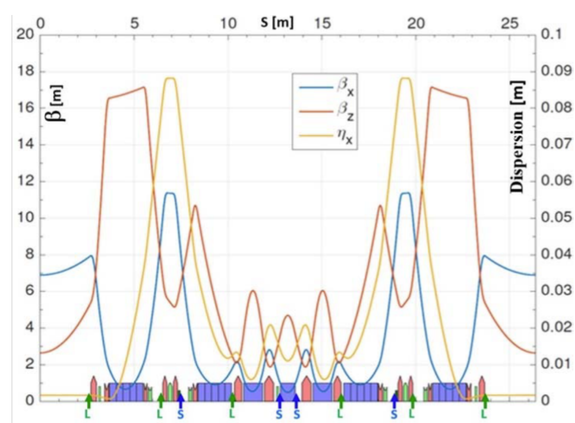

Figure 1: Distribution of the Libera Brilliance (L, green) and the Libera Spark (S, blue) along a cell.

All the BPMs will be used during machine operation for slow orbit acquisition and for orbit correction. The 192 BPMs equipped with Libera Brilliance will also provide position data at 10 kHz on an independent network for the Fast Orbit Feedback. Some of these latter BPMs (between 10 and 30) will also be used for machine interlock purposes.

Preparation and Implementation

After the installation of the blocks into the chambers, the button to button transmission has been measured using the Lamberson method [4] to estimate the offset induced by the difference in button sensitivity. The same measurement will be performed once the installation and the bake-out are completed in order to verify the behaviour of each block. A

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correction factor will be applied to the signals of each button to correct for their sensitivity.

A measurement of the mechanical offset of each BPM will be provided by the alignment group and will used to correct the beam position during the commissioning. The final BPM offset will be measured with beam based alignment as soon as there will be sufficient current and life time in the storage ring.

The measurement precision required for commissioning purpose is better than 100 µm. Acceptance tests and results obtained by preliminary tests with beam performed at the ESRF, show that the achieved measurement precision of the system for a 1 mA beam current is 50 µm [5].

FEEDBACK

The EBS storage ring will have a mixed slow and fast orbit feedback to reduce orbit perturbations and a multi-bunch feedback to avoid beam instabilities. A review of the slow and fast orbit feedback can be found in [6], while information on the bunch by bunch feedback are reported in [7].

Slow Orbit Correction

The slow orbit correction system will use 10 BPMs and 9 correctors per cell to get the closed orbit. The system will operate at a fraction of 1 Hz and will enhance the life time and beam coupling. Six correctors are integrated into the sextupoles via additional windings and three others are dedicated corrector magnets. The correction in computed using the usual SVD method.

Fast Orbit Feedback

The Fast Orbit Feedback will read the data from 192 BPMs equipped with Libera Brilliance at a 10 kHz rate and will provide the corrections through 96 fast dedicated corrector magnets. The orbit signal will be broadcasted on a dedicated Communication Controller protocol, 8 FPGA-based power supply controller boards will be used to compute the fast corrector settings via the SVD method and will apply them to the correctors by RS422 serial lines. The overall bandwidth of the correction will be around 100 Hz, the main limiting factor being the eddy currents in the vacuum chamber.

The Fast and the Slow Orbit Feedback are not independent and it is necessary to avoid that the fast corrections modify the average closed orbit. To do so the close orbit calculated by the slow orbit correction and will be used as a set point for the fast orbit feedback [6].

The Fast Orbit feedback will be able to correct the perturbation related with mechanical vibration up to 50 Hz which is enough to cope with the first girder resonance mode.

Multi-Bunch Feedback

EBS has been designed to avoid the need of active multi-bunch feedback both on the transverse and the longitudinal plane: HOM-damped cavities will be used to avoid longitudinal instabilities and the storage ring will operate at high chromaticity to achieve high lifetime. However, only 6 month are foreseen for commissioning (3 for the storage ring and 3 for beamlines) and problems related with ion instabilities during the vacuum conditioning might appear. For this reason, EBS will have, from day one, two operative transverse multi-bunch feedback systems. A longitudinal feedback is also ready to be installed in case of need.

A full upgrade of the transverse multi-bunch feedback has been carried out in 2017: a system developed by Diamond Light Source [8] has been successfully integrated and commissioned on the previous ESRF storage ring and will be installed in EBS.

Corrections will be applied through a horizontal and vertical stripline and another pair of striplines will be installed in the storage ring and used as a spare.

Among the capabilities of the multi-bunch feedback system, the most interesting features for EBS are the tune measurement of specific bunches, the possibility to perform drive-damp experiments to obtain information on the machine impedance, and the bunch cleaning. This last capability will be used only in case of need, since the main cleaning will be performed in the booster to avoid perturbation after injection for users [9].

ELECTROMAGNETICS DEVICES

In EBS several special pickups will be used to excite or retrieve the RF signal from the beam. A stripline is used to measure the filling pattern and four others are dedicated to the multi-bunch feedback. The technical drawing of the horizontal stripline implemented in EBS is presented in Fig. 2.

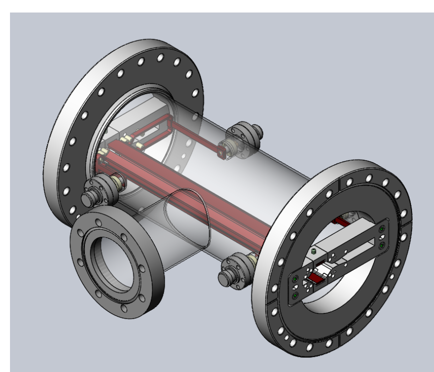

Figure 2: EBS horizontal stripline.

Two shakers are also present: these devices have a bandwidth of 1 MHz, which is smaller with respect to the one of the striplines, but provide stronger excitation. They will be used for the tune monitor [10], injection damping [11], beam blow up and beam studies purposes.

Two additional 20-buttons chambers will also be present in EBS allowing to obtain RF-signals from the beam in case of need. Four buttons will be used as position measurement for the tune monitor, another four for the phase monitor for RF diagnostics. Further buttons can be used for HOM detection or for machine studies.

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Another 16-button chamber will be located in the injection zone to measure the beam position and angle in the injection bump. Due to the non-linearity of the BPM blocks, it was difficult to have a unique BPM block able to measure the position of the beam for both orbits with sufficient precision. The 16 buttons are shared between two locations, and for each location two BPM blocks measure the position of the beam for both the normal, and the bumped orbit. Each BPM block is centered around the expected orbit.

BUNCH PURITY AND FILLING PATTERN

An avalanche photo diode is used to perform time correlated single photon counting to measure the bunch purity. The photo-diode will collect photons coming from the scattered x-ray synchrotron radiation. The experimental setup will remain the same used for the previous ESRF storage ring [12], and it is able to achieve a dynamic range of 10^7. The bunch purity will be usually measured after each injection to decide if cleaning in the storage ring is needed to remove the spurious bunches.

The bunch purity measurement has a high dynamic range but it takes several minutes and the photo-diode might be damaged by long exposure to x-rays. For this reason, the routine measurement of the filling pattern will be performed by reading the signal from a stripline to a 12 bit oscilloscope and by applying a dedicated data analysis [13]. This method achieves a dynamic range better than 10^3 which is not enough for bunch purity but is suitable for beam monitoring and to identify the less populated bunches to be selectively refilled during top-up.

CURRENT MONITORS

Six current monitors will be installed in the EBS storage ring. Three Bergoz Parametric Current Transformers (PCTs, also called DC-Current Transformer) will read the continuous beam current. Two Integrated Current Transformers (ICTs) will be used to measure the current in a single bunch when operating in timing mode (for example 7/8 of the storage ring filled and a single bunch of 8 mA in the gap). Finally a Fast Current Transformer (FCT) will be used to monitor the filling pattern. All these current transformers and the readout electronics, apart from one PCT, have been recuperated from the previous ESRF storage ring.

The mechanical implementation of the Current Monitors and the insertion of electrically isolating ceramic gaps have been optimized to minimize the effect on the machine impedance. In order to allow the circulation of the image current interrupted by the ceramics, copper return current blades are installed around the transformers. A copper shielding around the ICTs and the FCT will protect the storage ring equipment from RF-radiation emitted through these gaps. A ventilation system will avoid overheating of the ICTs and the FCT due to RF-radiation trapped within the closed shielding, forming an RF cavities. The ICT and PCT full mechanical layout is presented in Fig. 3.

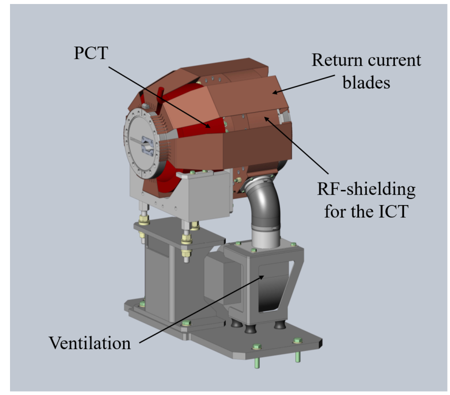

Figure 3: Mechanical layout of the ensemble ICT and PCT.

BEAM LOSS MONITORS

The Beam Loss Monitor (BLM) system is composed of 128 photomultiplier-scintillator based Beam Loss Detectors (BLDs) (4 per cell) which are powered and controlled by 32 Libera BLM electronics (1 per cell). More details can be found in [14].

The BLDs are calibrated with respect to each other but no absolute dose can be measured. The system is capable of delivering information on both fast and slow losses. During the beam decay, the signal produced by the losses is read over a large impedance and integrated over 400 ms. The system will provide data at a 1 Hz rate and will be used to identify unexpected behaviours related with insertion device moving or unexpected bad vacuum conditions. The slow data will also be used to optimize the storage ring lifetime during machine tuning.

During injection, when more losses are produced, the impedance of the electronics is switched to 50 Ohm and the signal is integrated over 4 turns. The BLM system will read losses at 4 Hz which is the injection rate. In this way data will not saturate and will be useful to observe possible problems that might appear in this period.

Finally the BLM system is also able to measure losses on an almost bunch-by-bunch scale.

The system has been commissioned during the last year of operation of the previous storage ring and a lots of data has been stored. This will provide a useful comparison on the losses level between ESRF and future EBS. This information will be of great importance especially in the vicinity of the in-vacuum insertion devices.

EMITTANCE MONITORS

Five x-ray ports will be available for measuring the beam emittance and will also allow to measure the energy spread. Each of these ports will be equipped with a pinhole to measure the beam size. The emittance will be calculated by using the lattice functions provided by beam theory.

Among the five emittance monitors, two of them will take light from the first segment of the first dipole of the cell (DL1A_5), while three will have their source on the last combined dipole-quadrupole magnet (DQ1D), as depicted

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in Fig. 4. Special crotch absorbers were designed to transmit 0.5 mrad and 0.6 mrad of radiation horizontally for the DL1A_5 and DQ1D respectively.

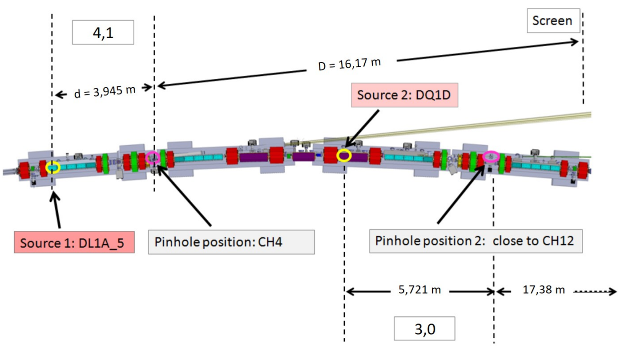

Figure 4: Source points and positions of the pinholes and the detector.

The characteristics of the source points and the foreseen magnification values are collected in Table 2. Using different source points with different dispersion values allows to measure the energy spread of the beam. The considerably higher value of the vertical β-function of the DL1A_5 source point makes this the preferred location to measure the vertical emittance.

Table 2: Characteristics of the Pinhole Sources and Foreseen Magnification

	B [T]	β_x [m]	β_y [m]	η [m]	M
DL1A_5	0.62	1.59	16.64	0.0007	4.1
DQ1D	0.55	1.442	3.844	0.01302	3.0

The horizontal and the vertical emittances for different coupling values and the related beam sizes are listed in Table 3, for two different locations.

Table 3: Horizontal and Vertical Emittances and Beam Sizes

	Hor.	Vert.		
		$C = 4\%$	$C = 1\%$	$C = 0.1\%$
ε	150 pm	5 pm	1.3 pm	0.13 pm
σ_{DL1A_5}	15 µm	9 µm	4.7 µm	1.5 µm
σ_{DQ1D}	19 µm	4 µm	2.2 µm	0.7 µm

The pinholes will be square apertures formed by crossed tungsten bars. The choice of a square aperture of 10 µm per side is necessary to resolve the small horizontal and vertical beam sizes (see Table 3) at the expense of photon flux. The location of the pinhole and the observation point will provide a magnification of 4.1 a the DL1A_5, and of 3 at the DQ1D and a resolution of 5 and 6 µm respectively. For the DL1A_5 it will be possible to resolve the vertical beam size during standard operation (4% coupling). To measure the beam size at lower coupling, other techniques such as diffraction or the use of x-ray lenses are under investigation [15].

Because of the compactness of EBS, in the case of the DL1A_5 source point, one of the storage ring vacuum chambers had to be modified to accommodate the pinhole as close as possible to the source. No modifications were needed in the DQ1D case. The pinhole will be located in air and the x-rays will be extracted through a 2 mm cooled aluminum window. The thickness of the window has been chosen to maximize the transmitted power and minimize the radiation dose created in air. Calculations show that the power transmitted will be 25 W/mrad for the DL1A_5 and 19 W/mrad for the DQ1D source, while the radiation dose deposited within 10 cm from the Al window will be 500 kGy/s and 330 kGy/s. The results are lower with respect to the maximum radiation dose obtained in the previous ESRF storage ring.

VISIBLE LIGHT BEAMLINE

A visible light beamline will be operative at EBS mainly to perform bunch length measurements using a Hamamatsu C10910 streak camera. The beamline, already present at the ESRF, had to be adapted to the different demands of the new storage ring layout. The source point position is in fact different from the previous one and a new hole in the storage shielding wall had to be drilled. In order to minimize the passage of unwanted radiation, the hole is situated 0.7 m below the electron orbit plane. A periscope system composed of two motorized mirrors has been designed to guide the light through the storage ring tunnel wall to the optical hutch and another mirror will deflect it to the optical table.

The radiation will come from the entrance of the first longitudinal gradient bending magnet (DL1A_5), where the magnetic field is the highest (0.62 T). An in-vacuum mirror oriented at 42° with respect to the synchrotron radiation beam will extract the light to the periscope trough a view-port. The mirror will select only the upper part of the radiation and its temperature is continuously monitored by two thermocouples. However, the in-vacuum mirror is water cooled and can be inserted and used as a ”full-mirror” when operating at very low current for machine studies.

FUTURE DEVELOPMENTS

Extremely small sources and x-ray beamlines are pushing on the synchrotron radiation beam position stability requirements. For this reason, having photon BPMs integrated to the closed orbit loop control system could be of great interest for EBS. Future developments in this direction are foreseen.

Also, a full x-ray beamline dedicated to insertion device tests and beam diagnostics is foreseen to perform beam tests and to allow the study and the development of new detectors.

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OUTLOOK

The diagnostics elements for EBS have been presented. The commissioning will start in December 2019 and most of these systems have to be ready from day one of the restart. A complete test of electronics, hardware and software is now ongoing to guarantee good performance of all the diagnostics systems.

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