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BEAM DIAGNOSTICS SYSTEMS FOR SIRIUS LIGHT SOURCE

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Abstract

This paper gives an overview of Sirius diagnostics systems under commissioning or in planning phase. It includes beam position monitors for electron and photon beams, visible and X-ray synchrotron light monitors, transverse profile monitors, streak camera, beam loss monitors, current monitors, charge monitors, tune and filling pattern measurements. The paper focuses on the specification of the beam diagnostics systems and their motivation, parts selection, accompanying data acquisition systems, control software capabilities and development status.

INTRODUCTION

The Sirius light source facility is based on a 518 m circumference 5BA 3 GeV electron storage ring (SR), designed to achieve a bare lattice emittance of 0.25 nm·rad [1]. The machine is under construction at LNLS, in Campinas, Brazil. Machine installation is expected to start at the end of 2017 and beam commissioning in the middle of 2018.

The injector is composed of a 497 m circumference full energy booster synchrotron (BO) installed in the same tunnel as the SR, with a 3.5 nm·rad emittance at 3 GeV, a 150 MeV LINAC supplied by SINAP, LINAC-to-booster (LTB) and booster-to-storage ring (BTS) transfer lines.

The LINAC operates in single and multi-bunch modes, with 1 ns / 1 nC and 150 ns / 3 nC pulse length / charge, respectively. Maximum repetition rate is 10 Hz, but booster cycling will occur at 2 Hz.

The SR and BO rings operate at 500 MHz and have harmonic numbers 864 and 828, respectively. The LINAC operates at the 6th RF frequency harmonic (3 GHz). All of the instrumentation has been designed to allow injection in multi, single or hybrid bunch modes.

For brevity, LINAC diagnostics are not covered herein.

SIRIUS DIAGNOSTICS

In order to monitor the quality of the electron and photon beams, several diagnostics equipment will be installed along the accelerators and transfer lines. Parameters like bunch charge, transverse and longitudinal profiles, beam orbit, tunes, beam emittance and beam loss, the injection efficiency and beam stability will be constantly monitored. Table 1 briefly shows the main beam diagnostics devices of the accelerator complex.

Table 1: Summary of Beam Diagnostics Components

	Linac	LTB	BO	BTS	SR
DCCT			1		2
FCT		1		1	
ICT	2	2		2	
Beam Flag	5	6	3	6	
Horizontal Slit		1			
Vertical Slit		1			
Button BPM			50		160
Stripline BPM	3	6		5	
Front-End Photon BPM					80
Filling Pattern Monitor					1
Horizontal scraper					1 pair
Vertical scraper					1 pair
Tune shaker			1		2
Tune pick-up			1		1
Bunch-by-Bunch kicker					2
Bunch-by-Bunch BPM					1
X-ray port					2
Visible light port					1
Streak camera					1
Beam Loss Monitor		tbd	tbd	tbd	
Gas Bremsstrahlung Monitor					tbd

Flags

In total 19 fluorescent screens (or beam flags) will be used in the commissioning phase and for general troubleshooting. In the transfer lines the fluorescent screens will be installed together with 6 cm stripline BPMs in order to provide beam profile measurements and non-destructive beam position measurements in the same location.

The booster fluorescent screens are installed right after the injection point, a few meters apart from each other, in order to monitor the position and angle of the injected beam.

Cerium-doped Yttrium Aluminium Garnet (YAG:Ce) 0.1 mm thick screens, produced by Crytur, were selected for the flags. The screen is placed inside a bellows, which can be moved to intercept the beam.

The bellows is attached to a Huber 5101.20 X1 linear translation stage moved by a Vexta PK-266-02B stepper motor. The linear stage also contains a rotary encoder provided by Huber. This allows the usage of more than one screen, as the motor can move the bellows with micrometer precision, enough to place one of the available screens in the correct position to intercept the beam. The current approach is to use a YAG:Ce screen to intercept the beam and an additional screen with markers to calibrate the optics.

The stepper motor is driven by a single-axis Galil DMC-30017 controller. An IOC [2], communicating with the controller through Ethernet, is used to integrate the motion controller to the accelerator control system via EPICS [3].

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The screen plane is tilted 45 ° relative to the beam axis, so that the produced beam image can be seen through a vacuum chamber side window. The camera used is a Basler acA1300-75gm featuring a CMOS sensor and Gigabit Ethernet interface. A 45 ° mirror allows the camera to see into the side window. The camera is powered by Power-over-Ethernet (PoE) so that it can be remotely restarted through a PoE switch. The aravisGigE EPICS IOC [4] is used to attach the camera to the control system.

The transfer lines' fluorescent screens assembly is illustrated in Fig.1.

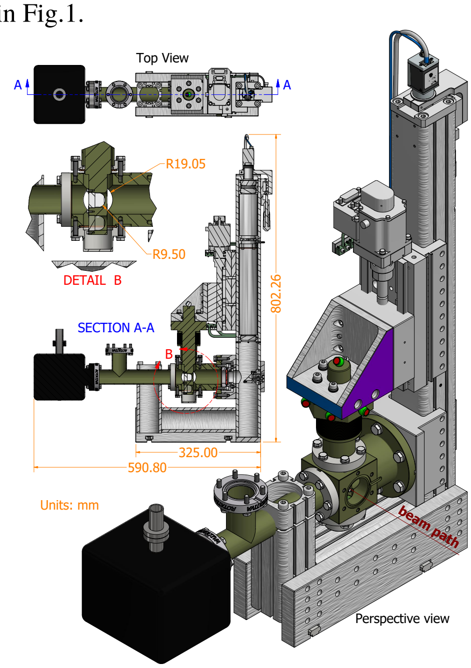

Figure 1: Mechanical project of the beam flags.

Injection Efficiency

After the commissioning phase Sirius will operate in top-up mode, which requires a stable operation of the whole injection system. In order to quantify the transmission of electrons from one accelerator to another, charge and current sensors are employed.

Integrating Current Transformers (ICT) [5] are installed at the exit of the electron gun, at the end of the LINAC and at the beginning and end of both transfer lines. The signals from the ICT transducer are processed by Bergoz BCM analog electronics [6] and further digitized by Keithley DMM7510 7½-digit multimeter [7]. The multimeter also allows for fast sampling at 1 MS/s, which is useful for troubleshooting.

Parametric current transformers, commonly known as DCCTs [8], are employed in the BO and SR to measure the circulating beam currents. The Bergoz New Parametric Current Transformer (NPCT) and its accompanying electronics was chosen. The analog DC signals generated by the NPCT electronics are digitized by the Keithley DMM7510 multimeter, the same instrument used on ICTs.

A common IOC has been developed to integrate the ICTs and DCCTs to the accelerator control system via EPICS [9]. Different modes of operation and parameters are set according to the instrument in use. Hence both the pulsed signals generated by the ICT electronics and slow varying voltages output by DCCTs are digitized by the same instrument controlled by a common software. It reduces the control software development and maintenance effort.

All devices, BCMs, NPCTs and digitizers are connected to the Sirius timing system [10], which provides acquisition triggers synchronized with the beam and adjustable delays.

Beam Slits and Scrapers

Tantalum horizontal and vertical beam slits will be installed in the LTB transfer line to delimit the portion of the beam that goes to the booster. In the storage ring, a pair of horizontal and vertical beam scrapers will serve various purposes, such as protection for insertion devices, beam loss control and diagnostics/physics machine studies.

Differently from the linear motion of the flags and the slits, the scrapers' plungers were designed under a concept of rotary motion – but still using linear actuators – hence providing smooth transitions throughout the beam image current path [11]. Figure 2 presents the mechanics of the prototypes of the beam slits and the scrapers, which are very similar to the mechanics of the beam flags, improving design reuse and reducing the diversity of the ordered parts. The scrapers use a Vexta PK-223PB stepper motor, a Huber 5101.07 X1 linear translation stage and the same rotary encoder as the beam flags. The slits use the same stepper motor as the scrapers, a Huber 5101.10 X1 linear translation stage with an absolute position Renishaw encoder.

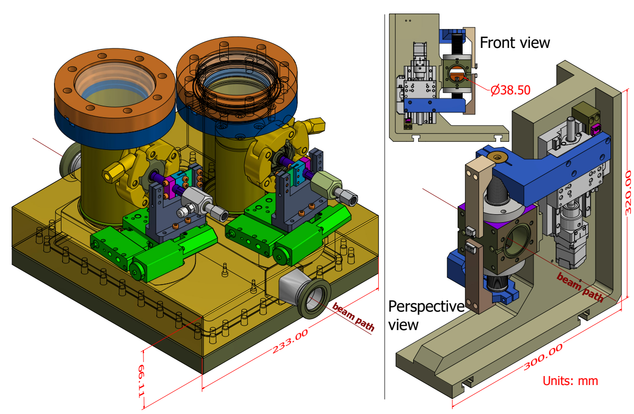

Figure 2: Horizontal scraper (left) – where some parts were set transparent – and vertical beam slits (right) mechanical assemblies. Vertical scraper and horizontal slits will follow the same concepts and structures shown.

Button BPM Sensors

After having prototyped several design ideas, the mechanical aspects of the SR button BPMs among the ones raised in [12] were defined. Regarding the choice of materials, a non-magnetic solution was selected: Ti_4Al_6V alloy body and housing, Mo button and Al_2O_3 ceramics, allowing satisfactory vacuum insulation through housing/body welding and housing/ceramics/button brazing. Geometry design

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changes were mainly carried out in the body in order to keep the electrical center steady for even button heat load due to wake losses. Uneven loads, as studied in [13], are expected to be prevented by sorting the buttons.

SR BPM model is currently under production. Its parts are being machined by Brazilian companies and the assembly (brazing and welding) performed in-house. BO design has followed the same materials configuration from the SR model, although it had several geometry aspects simplified and is still at prototyping stage. Figure 3 depicts the referred mechanical projects.

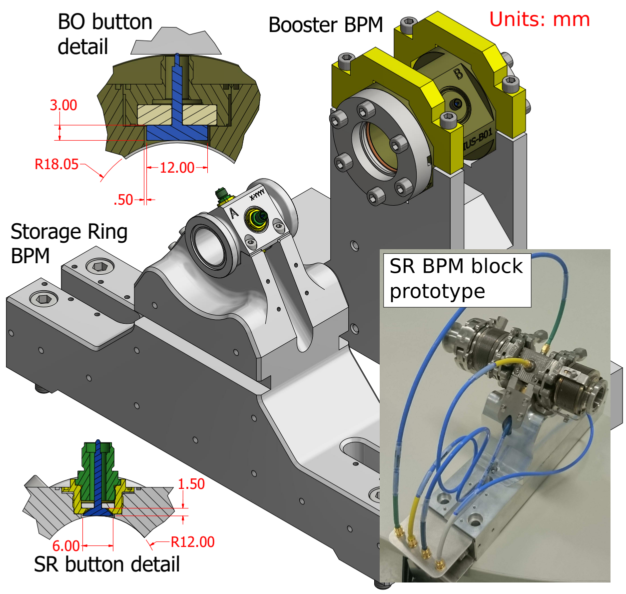

Figure 3: SR and BO BPM mechanical projects.

BPM Electronics

The in-house developed open source BPM electronics [14–16] is under final testing at LNLS. A fully populated rack comprising 13 RF BPM and 4 photon BPM electronics is assembled for performing short- and long-term beam position measurement stability tests as well as for debugging software and gateware components.

The procurement of the data acquisition subsystem (MicroTCA.4 crate, FPGA boards, ADC mezzanine cards) and RF front-end electronics has been made. The procurement of commercial components such as cables, racks, Ethernet switches is in the final stage of preparation. A local contractor has been hired to fully test and assemble the 20 BPM racks for the Sirius storage ring and booster. An additional rack with transfer line BPMs will be assembled by LNLS personnel. The complete system installation is foreseen for the first semester of 2018.

Striplines

Sirius stripline designs took into account the following aspects: pick-up (PU) or actuator (kicker/shaker) behavior, operation frequency and bandwidth, crosstalk between strips, line impedance matching and, only for the SR, beam impedance mitigation [11, 13]. Striplines for generic purposes were also designed and all models are currently in prototyping stage. Figure 4 shows BO stripline models and Fig. 5 SR ones. Their characteristics are detailed in Table 2.

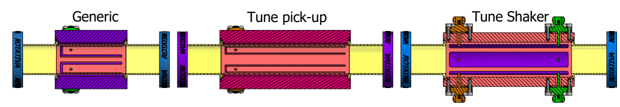

Figure 4: Side section view of the booster striplines mechanical design.

Table 2: Geometry Parameters of BO and SR Striplines: Strip Angular Aperture, Number of Strips per Assembly, Short-circuited (SC) Upstream End and Electrical Length

Stripline type	Strip aperture	# of strips	SC?	Elec. length
BO Tune PU	30°	4	yes	$\lambda/4$
BO Tune Shaker	90°	4	no	$\lambda/4$
BO Generic	45°	4	yes	$\lambda/8$
SR Tune PU	30°	4	yes	$\lambda/4$
SR Tune Shaker	90°	2	no	$\lambda/4$
SR BbB Kicker	90°	2	no	$\lambda/2.3$
SR Generic 1	40°	4	yes	$\lambda/8$
SR Generic 2	40°	4	yes	$\lambda/4$

The BbB stripline kicker had its electrical length reduced from the ideal $\lambda/2$ value due to physical space limitations. Another aspect worth noting is that every stripline actuator will be respectively aligned with the vertical and horizontal planes. The pick-ups follow the traditional 45°-rotated orientation in order to avoid damage and/or false readings from synchrotron radiation incidence, with the exception of the transfer lines – not present in Table 2 – where the UVX storage ring stripline BPMs spare units [17] will be used, with axis aligned orientation.

Bunch-by-Bunch Feedback System

The BbB system chain consists of a button BPM as pick-up, a front-back-end (FBE) unit and three iGp12 processors from Dimtel [18]. For the transverse plane, the feedback signals are directly amplified by AR amplifiers 75A400 to drive the stripline kicker. The longitudinal feedback signal is upconverted in the FBE unit and then amplified by Mini-Circuits ZT-102 amplifiers before reaching the overloaded cavity kicker. The amplifiers are the present units for the

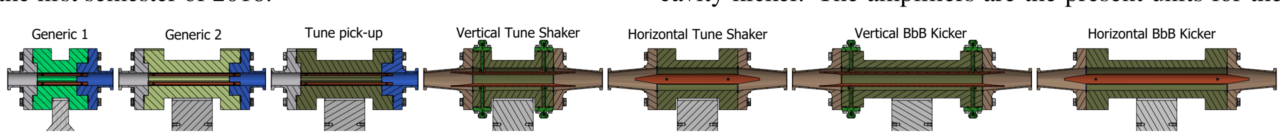

Figure 5: Side section view of the storage ring striplines mechanical design.

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UVX storage ring and their use in Sirius will need to be reviewed due to power limitations.

Longitudinal feedback system was not initially planned for the initial Sirius user operation phases [19, 20], but the plan changed since its use was found to possibly be needed during Sirius commissioning and first users' phase, where Petra-III 7-cell cavities will be used in the storage ring.

Tune System

The BO and SR tune measurement systems will employ stripline kickers for beam excitation and stripline BPMs followed by broadband horizontal and vertical beam position measurements using hybrid couplers. Three different excitation/measurement techniques will be employed:

- Noise excitation + real-time spectrum analyzer: a band-limited white noise signal generated by an Agilent 33521A arbitrary waveform generator passively mixed with a carrier signal from a R&S SMB100A signal generator. The beam position signals are acquired by a Tektronix RSA603A real-time spectrum analyzer. The instruments and peak search algorithm are integrated to the accelerator control system via EPICS IOCs [21, 22].
- Spectrum analyzer: the tracking generator feature of the R&S FSL3 spectrum analyzer is used. The instrument and peak search are integrated to EPICS [23].
- Tune tracking: the PLL-based iGp12 tune tracking feature [24] of the BbB system. EPICS integration is readily available.

The combination of different instruments and techniques to measure the betatron tunes is part of a strategy to balance ease of use during commissioning, speed of measurement and mitigation of disturbances when operating for users. For instance, the use of a noise excitation aimed at fast measurements (< 10 ms sample rate) during booster ramps with tune resolution of 10^{-2}. Contrarily, the use of a standard spectrum analyzer in sweep mode with long averaging was chosen for achieving a high precision measurement (< 10^{-4}) during commissioning and first months of operation of the SR, besides providing an intuitive interface to operators and machine physicists. The long-term solution planned is to use the PLL-based iGp12 tune tracking feature for exciting and tracking only one bunch of the beam. This minimizes emittance disturbance caused by betatron tunes excitation.

For the first two systems, the excitation power will be provided by AR 50W1000D amplifiers, thus allowing operation in the 50 MHz to 1 GHz frequency range with up to 48 dBm excitation power. The EPICS IOC responsible for controlling the amplifiers is currently under development [25]. A MOXA CN2650I-16 Ethernet to RS-232 converter is used to interface the amplifier with the accelerator's control system.

X-ray and Visible Light Diagnostics

Two X-ray beamlines will provide emittance and energy spread measurements in the storage ring. An optical beamline will extract visible light for longitudinal beam profile and other measurements. A cost-effective solution was chosen for the streak camera: the Hamamatsu instrument model C5680, currently operating in the UVX storage ring at 199 MHz (476 MHz / 4) with 2 ps RMS resolution, will be modified by the vendor to operate at 125 MHz.

Beam Loss and Gas Bremsstrahlung Monitors

Gas Bremsstrahlung monitors based on the BPW34 pin diode and accompanying analog electronics are under development at LNLS and aim at providing data about the vacuum pressure by detecting the gamma-ray emission cone along the SR. Commercial BLMs with differential outputs [26] will also be employed at the Sirius transfer lines, BO and in some parts of the SR where there is room for installation. The analog signal conditioning circuitry as well as the data acquisition instrumentation, currently in development by the LNLS Instrumentation and Controls groups, will interface with the EPICS control system directly. This approach will provide a modular system allowing quick changes in the placement of sensor heads of both sensors.

CONCLUSION

The Sirius beam diagnostics solution has been summarized. Most of the detailed designs are finished and the systems with a high level of complexity or with a high number of components are in advanced production stages, but a few of them are still under development, notedly SR beam scrapers, transfer line slits and the flag to be installed downstream of the SR injection septum. A large part of the production is carried out by local companies, including the BPM sensors, a critical part of the SR. Currently, the biggest concern is the limited time available for testing the systems prior to the installation.

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