Proc. 13th International Beam Instrumentation Conference,Beijing JACoW Publishing
ISBN: 978-3-95450-249-3 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2024-WEP05

DIAGNOSTICS VISIBLE BEAMLINE AT SESAME STORAGE RING

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Abstract

Visible light range of Synchrotron radiation is a versatile diagnostics tool for accelerator studies and measurements. SESAME's storage ring has a dedicated diagnostics visible light beamline from 6.5-degree beam port of bending magnet source point. The beamline will host in future a time-correlated single photon counting unit to measure the bunch filling pattern, fast gated camera and a streak camera for longitudinal diagnostics. Recently, the beamline has been extended to be operational from outside the tunnel (dedicated hutch) to allow more flexible studies with direct source imaging and a double-slit interferometry for beam size measurement and study transverse instabilities. In this paper we give an overview of the design of the beamline, modifications and present first results.

INTRODUCTION

The SESAME Storage Ring (SR) is a 2.5 GeV, 133.2 m circumference composed of 8 DBA cells with dispersion in all straight sections (8*4.4 m and 8*2.4 m). It offers a maximum capacity of 25 beamlines, phase 1 current up to 300 mA and Emittance 26 nm.rad [1]. The designed parameters of the storage ring are presented in Table 1.

The visible diagnostics beamline (VDBL) was initially installed and commissioned in the SESAME Storage Ring (SR) during the accelerator's commissioning phase. At that time, it was located inside the tunnel, which posed significant challenges due to the limited space and difficulty in controlling the environment. However, this summer, the beamline was relocated outside the tunnel into a dedicated hutch. This move provides more flexibility for conducting studies, managing the optical system, and accommodating additional equipment in the future. The VDBL is designed to measure the transverse beam profile and monitor the emittance and stability throughout the beam decay.

BEAMLINE SETUP

From the outset, the design was intended to be simple and cost-effective. As a result, the system was compactly installed in cell 14 inside the tunnel, positioned vertically in front of the viewport. The measurement and monitoring of the transverse beam profile were conducted using direct beam imaging for both planes. However, due to the limited vertical resolution caused by diffraction from a crotch absorber in the vacuum chamber, the vertical beam size was measured using double slit interferometry [2].

The beamline accommodated both measurement methods by utilizing a motorized filter wheel, which housed the double slits and neutral density filters. Since the beamline was installed inside the tunnel, all calibration and optimization of the optical lenses and other components were performed in the lab before being transferred to the tunnel. This setup made calibration and fine focusing more challenging.

Table 1: Storage Ring Main Parameters

Energy (GeV)	2.5
Circumference (m)	133.2
RF Frequency (MHz)	499.654
Betatron tunes Q_X / Q_Y	7.23 / 6.19
Horizontal emittance ε_x (nm.rad)	26
Momentum compaction factor	0.0083
Circulating Current(mA)	300
Energy loss per turn (keV)	603

The New Setup

The new setup introduces some adjustments to the layout of the vacuum components inside the tunnel, making it more compact and modifying certain girders. The same in-vacuum mirror is used, with a design originally borrowed from the ANKA light source (now KARA), but with modified cooling circuit in order to handle our full future beam current of 400 mA. All FEA (Finite Element Analysis) have been conducted on the mirror, as shown in Fig. 1.

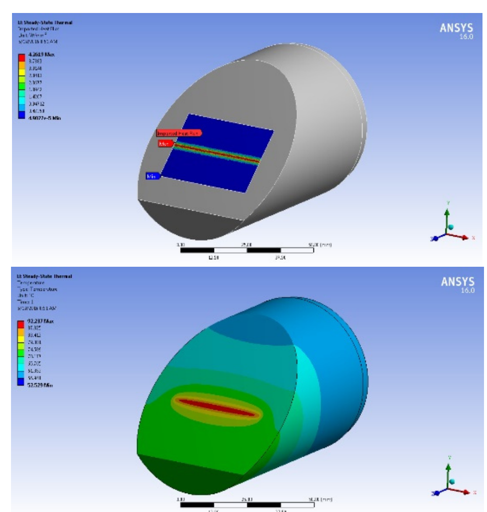

Figure 1: VDBL in-vacuum mirror FEA analyses, showing power at the mirror (up) and temperature distribution (down).

The mirror is a water-cooled OFHC (Oxygen-Free High Conductivity) copper block, brazed onto a CF63 stainless steel flange, and coated with aluminium optimized for the visible light range. This design achieves over 90% reflection efficiency at 500 nm, with quarter-wavelength flatness and surface roughness of less than 20 nm. The mirror is installed in a CF63 cube vacuum box, which is mounted on

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an aluminium plate. In the original design, the plate was supported by three stepper motors to control the system's orientation. However, this setup caused issues with controlling the reflection angle and achieving fine alignment. To resolve this, the mirror was fixed in place after precisely using a laser tracker. The mirror reflects visible light through a CF63 bonded fused silica viewport which has excellent optical properties.

Layout

The source point for the VDBL is a bending magnet located in cell 14. Figure 2 presents a schematic diagram of the beamline, which is situated opposite the transfer line between the booster and the storage ring. This transfer line contains several fluorescent screens (FS). The safety group expressed concerns about the potential radiation exposure in the diagnostics hutch during the use of these FS, as well as during various operational modes of the machine, including injection, ramping, normal operation, sudden loss, and FS usage. To address these concerns, radiation loss studies were conducted using FLUKA [3]. As illustrated in Fig.3a the interaction between gas bremsstrahlung-generated radiation inside the bending magnet and the FS at the exit height is clearly depicted. Additionally, Fig. 3b provides a visualization of the interaction of X-rays at the same height. The results indicate that the hutch remains safe under all modes of operation.

The VDBL design is simple, utilizing available in-house components. Synchrotron light is extracted by a water-cooled, in-vacuum copper mirror, which then reflects the light to the hutch through three in-air mirrors. These mirrors are 2-inch circular, flat fused silica mirrors, coated for the visible range and featuring λ/10 surface flatness. They are mounted at a 45° angle in kinematic mirror mounts, allowing for precise tip and tilt adjustments using knobs. The entire optical setup, including cages and elements, is sourced from Thorlabs [4].

Mirror 1 (M1) is positioned 3.7 meters away from the source point and reflects the visible light 90° downward toward Mirror 2 (M2). M2 then reflects the light 90° from the 6.5° beamline port toward the right shielding wall, causing the beam to flip. The shielding wall is 1 meter thick with a 10 cm core opening, positioned 35 cm above the ground. The light then reaches Mirror 3 (M3), followed by Mirror 4 (M4), before arriving at its final destination on the optical table. The total optical path length to the table is approximately 8 meters.

The optical table is equipped with a beam splitter, mirrors, and filters to direct the beam towards two cameras, one for direct imaging and the other for a double slit interferometer used to measure horizontal and vertical beam sizes. Additionally, the setup allows for the use of other mirrors or splitters for future measurements, such as bunch length measurement and filling pattern analysis. The schematic of the optical table is shown in Fig. 3.

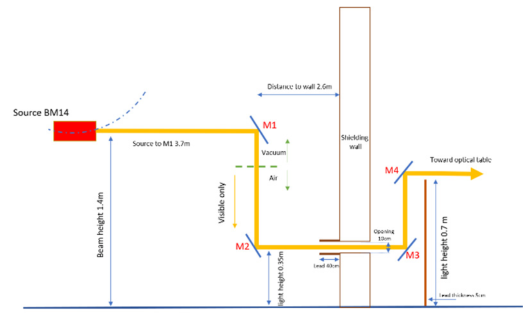

Figure 2: Schematic layout for visible diagnostics beamline from inside to outside tunnel.

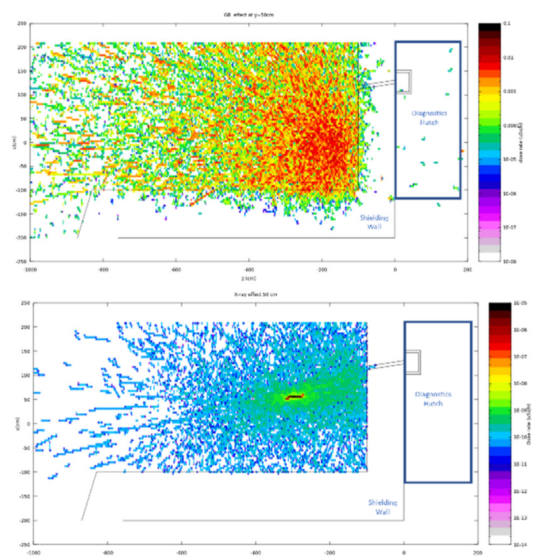

Figure 3: FLUKA simulation showing interaction between gas bremsstrahlung-generated radiation inside the bending magnet(up), and visualization of the interaction of X-rays while FS in (down).

BEAM SIZE MEASUREMENT SETUP

The VDBL includes an imaging system to capture the electron beam profile and a Young's double slit interferometer to measure beam sizes. The measurement principle is thoroughly explained in Ref. [5]. In summary, it relies on the interferogram produced by monochromatic and polarized synchrotron light after it passes through a double slit. When these two beamlets are focused onto a CCD camera, the electron beam size can be determined from the visibility of the interferogram, which reflects the complex degree of spatial coherence of the photons [6].

At the image plane, and considering that the two slits are illuminated with the same intensity, the light distribution that comes out when using slits is:

$$I(x) = I_o sinc^2\left(\frac{2\pi w}{\lambda d}x + \varphi_s\right)\left[1 + V\cos\left(\frac{2\pi D}{\lambda d}x + \varphi_c\right)\right] \quad (1)$$

where I_0 is the intensity of the interferogram, λ is the light wavelength, w is the slit width, d is the distance

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between the slits and the camera sensor and D is the separation between slits. φ_s and φ_c are relative phases.

When using pinholes instead of slits [7], the envelope of the interferogram is given by the Fourier transform of the shape of the aperture generating the interference. In the Mitsuhashi formula [4] the envelope is parametrized by a *sinc(x)*, being this the Fourier transform of a rectangle. In the case of pinhole, the resulting function is a Bessel function of the first type J_1 and the formula for the interferogram becomes [7]:

$$I = I_o \left\{ \frac{J_1\left(\frac{2\pi a x}{\lambda f}\right)}{\left(\frac{2\pi a x}{\lambda f}\right)} \right\}^2 \times \left\{ 1 + V \cos\left(\frac{2\pi D x}{\lambda f}\right) \right\} \quad (2)$$

where a is half diameter of the pinhole, f is the focal distance of the optical system used. The visibility V is related to the complex degree of coherence, and it is inferred as:

$$V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \quad (3)$$

where I_{max} and I_{min} are the maximum and minimum intensity at the interference fringe. For a point-like source, $V = 1$, but an extended source smears out the interference fringe. This allows the calculation of the beam size by:

$$\sigma = \frac{\lambda L}{\pi D} \sqrt{0.5 \ln\left(\frac{1}{V}\right)} \quad (4)$$

where L is the distance between the source point and the double slit system.

The double slit system is placed on the optical table, at a distance of 9m from the source point. After passing through a 550nm band pass filter and a linear polarizer, the two light beamlets are focused onto the CCD camera using varifocal objective lens.

Preliminary results of commissioning of the VDBL were recently conducted, yielding promising initial results. The electron beam size in the storage ring was successfully measured using a synchrotron radiation interferometer as will explained next.

Vertical Beam Size

The interferogram image of the vertical beam using 4mm separation distance between holes, along with its fitting, is shown in Fig. 4. After fitting the data and applying Eq. 4, a beam size of 81.22 µm was obtained, which is close to the 80.82 µm measured by the pinhole camera. However, the reproducibility of the measurement varied with different settings, particularly the camera's exposure time.

At low exposure times, the measured beam size appeared smaller than expected or could not be accurately fitted. Conversely, at higher exposure times, the measured beam size was larger than the theoretical value, likely due to the summation of several shifted interferograms during the longer acquisition period, which affected the contrast. Additionally, a vibration was observed in the image, potentially caused by the water-cooled mirror and/or the fact that the entire beamline mirrors are in air, making them susceptible to air turbulence.

Synchrotron radiation was not vertically homogeneous, and the footprint of the light reaching the VDBL could be affected by Fraunhofer diffraction [7]. As a result, the light intensity distribution of the radiation at the position of the double slit is unequal between the two slits, and this intensity imbalance must be considered [8]. To account for this imbalance, the visibility, as given in Eq. 4, must be adjusted as following:

$$\gamma = \frac{I_1 + I_2}{2\sqrt{I_1 I_2}} \times V \quad (5)$$

where I_1 and I_2 are the intensities at each single slit of the double slit. Multiple measurements were conducted with different slit separations; however, the results remained consistent. To improve the accuracy of beam size measurements using the interferometer technique, an alternative approach involves scanning the distance between the pinholes, D [7] has been used. This distance is the Fourier conjugate of the beam size, and by applying Eq. 4, we can derive the following relationship:

$$V = e^{-2\pi \frac{\sigma^2 D^2}{\lambda^2 L^2}} \quad (6)$$

Considering the visibility as a function of D the expected result is a Gaussian. Fitting the results letting the beam size as a free parameter, it was possible to obtain σ. Figure 5 shows the visibility as a function of the distance between the pinholes. The resulted beam size is closer to theory but still bigger than what should be. The expected visibility for 81µm beam size is plotted in Fig. 5 however with a shift can be seen in the curve.

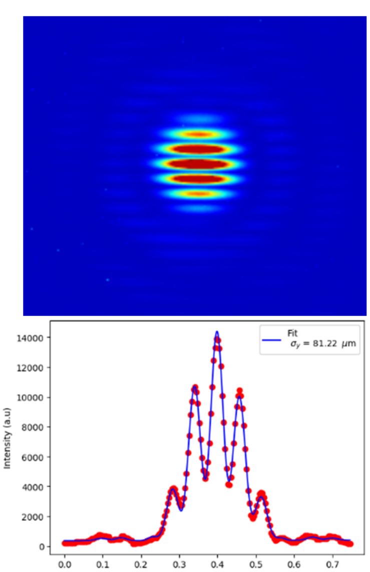

Figure 4: Vertical Interferogram with fitting using 4mm slit separation.

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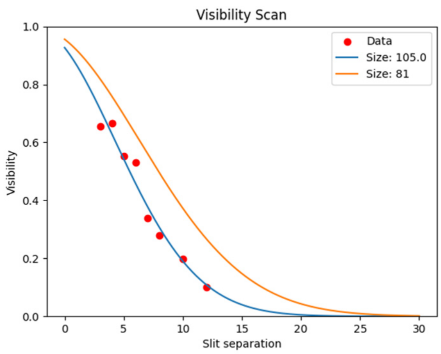

Figure 5: Visibility as a function of the distance between pinholes, blue is the measured and orange is the simulated.

Horizontal Beam Size

Several measurements were conducted using different slit separations. For each separation distance D, multiple data acquisitions were performed. The initial results showed good agreement with the theoretical value of the horizontal beam size, as well as with measurements from the pinhole camera (approximately 232 µm). Furthermore, visibility was calculated as a function of the pinhole distance by scanning the separations, and the results were consistent. An example of an image with the corresponding interferogram is illustrated in Fig. 6.

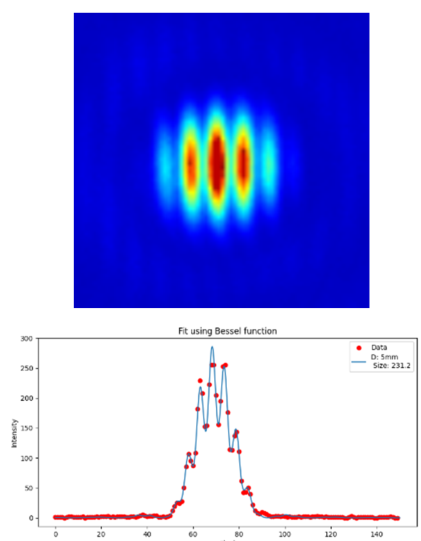

Figure 6: Horizontal Interferogram image (up) with fitting using 5mm slit separation (middle) and visibility as a function of the distance between pinholes (down).

CONCLUSION

This paper presents the design and layout upgrades of the Visible Diagnostics Beamline (VDBL) for the SESAME Storage Ring (SR). The successful installation and ongoing commissioning have enabled the measurement of beam size. To achieve reliable beam size measurements using the SR interferometer, several upgrades to the beamline are necessary. The quality of the light reaching the beamline must be thoroughly studied and significantly improved. Additionally, factors such as air flux and vibrations from the tunnel to the beamline must be carefully examined to ensure accurate and stable vertical beam size measurements. Further theoretical and practical studies, as well as additional upgrades and beam studies, such as bunch length measurement, are planned for in the near future.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to everyone who contributed to the design and installation through discussions and suggestions. Special thanks go to O. Kailani for his significant work on the previous beamline layout, the safety group for their assistance with simulations, calculations, and the core opening in the wall, and to trainees M. Telfah and A. Ibrahim for their excellent work in analysing the interferometer data and assisting with the optical table setup.

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