Proc. 13th International Beam Instrumentation Conference,Beijing JACoW Publishing
ISBN: 978-3-95450-249-3 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2024-WEP20

THE PROJECT OF OPTICAL DIAGNOSTICS OF THE BEAM DIMENSIONS OF THE SKIF STORAGE RING WITH ULTRA-LOW EMITTANCE*

V. L. Dorokhov[†, 1], O. I. Meshkov[2], V.E. Boyarkina[1, 2]
Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, Russian Federation
[1]also at Synchrotron Radiation Facility - Siberian Circular Photon Source ”SKIF”,
Boreskov Institute of Catalysis of SB RAS, Kol’tsovo, Russian Federation
[2]also at Novosibirsk State University, Novosibirsk, Russian Federation

Abstract

The Siberian Circular Photon Source (SKIF), a fourth-generation synchrotron radiation (SR) source is being constructed in Russia. This installation has an ultra-low emittance, allowing for high beam intensity in various scientific and technological fields. A crucial aspect of SKIF is its availability of diagnostic instruments that measure the beam transverse dimensions. This will allow for minimizing the emittance during operation and comparing it with a calculated value. This comparison is critical for determining whether the physical setup meets the design specifications. In addition to measuring the transverse dimensions of the beam, it is also important to observe the behaviour of the longitudinal profile and measure its parameters with good accuracy. Since the calculated emittance of 75 pm · mrad corresponds to the beam sizes of less than 8 µm at the radiation output sites, a diagnostic complex was developed as a part of the working project, including a beam size monitor based on a double-slit interferometer. Observation and measurement of the longitudinal distribution of the beam will be carried out using mutually complementary devices, such as a streak camera and electron-optical dissector.

INTRODUCTION

The emerging Synchrotron Radiation Facility - Siberian Circular Photon Source ”SKIF” is a large accelerator complex. It contains a linear accelerator with an energy of 200 MeV, a booster synchrotron with a ring circumference of 158.7 m, a storage ring with a circumference of 476.14 m with 16 straight intervals and two transport channels: from linear accelerator to the booster and from booster to the storage ring (see Fig. 1).

The working energy of the SKIF main storage ring is 3 GeV. In this acceleration machine, the synchrotron radiation (SR) from bending magnets and ”insertion devices” - wigglers and undulators (which will be placed in straight-line intervals) will be generated.

In the common operating mode, there 500 electron bunches with a total current of 400 mA circulate in the main storage ring. For this purpose, injection is performed by 55 bunches with a charge of about 0.3 nC in each.

Table 1: Main ring specifications

Parameter	Unit	Value
General machine parameters		
Energy	GeV	3.0
Circumference	m	476.14
Current	mA	400
Rev. freq	MHz	0.6296
Rev. time	mks	1.588
ϵ_x	pm rad	75
σ_E/E		0.001
RF freq	MHz	357
Bunch length parameters		
U_{RF}	MV	0.77
U_0	keV	536
f_s	kHz	1.13
α		$7.6 \cdot 10^{-5}$
$\sigma_t(RMS)$	ps	17.5 (5.3 mm)

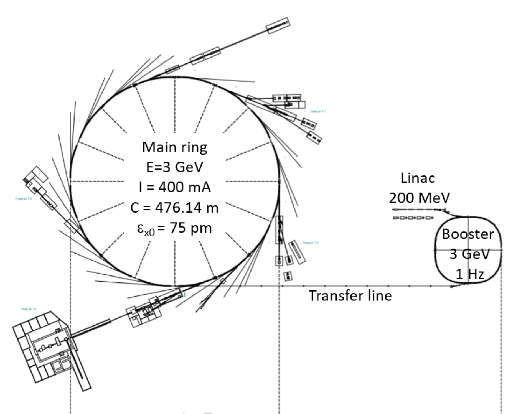

Figure 1: The common scheme of the Synchrotron Radiation Facility SKIF.

In addition, modes with one or several bunches distributed as required along the orbit are provided. That is why, control of the modulator of the injection complex gun allows obtaining one or several bunches in a train (within the envelope of 310 ns). In this case, the bunch intensity can be increased to

* work was supported by the Ministry of Science and Higher Education of the Russian Federation within the governmental order for SRF SKIF Boreskov Institute of Catalysis (project FWUR-2024-0041).
† V.L.Dorokhov@inp.nsk.su

ISBN: 978-3-95450-249-3 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2024-WEP20

1 nC. Some parameters related to the main storage ring of the SKIF are listed in Table 1.

Since SR is widely used as a diagnostic tool for measuring the transverse and longitudinal profile, three SR channels intended for diagnostics are designed and manufactured for the SKIF storage ring. There are two channels in the visible and near- ultraviolet (UV) ranges; the third uses the X-ray part of the SR spectrum. In this article, attention will be paid to the design of the visible radiation channels. The radiation from bending magnets we will discuss in this work, since only the SR output channels from the such magnets of the storage ring are allocated for optical diagnostics

SOURCE POINTS

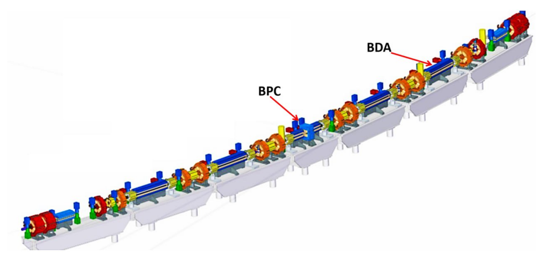

Figure 2: The superperiod of the SKIF main storage ring.

The magnetic structure of the SKIF storage ring consists of 16 superperiods built on five Multi-Bend Achromat (MBA) cells [1] (see Fig. 2) in which there are channels for the output of SR from two dipole magnets. The RF system is positioning in the two straight gaps. In addition, the remaining 14 straight gaps are dedicated for the installation of insertion devices for SR generation. The SR beamlines in each superperiod provide SR from two types magnets with a field of 2.1 T (BPC) and 0.55 T (BDA) respectively. The dipole magnet BPC serves to obtain a hard spectrum of SR and replaces (along with with two BDC magnets [1]) the BDA magnet in the central cell of each superperiod. Thus,

Table 2: Specifications of the dipole magnets of the SKIF main storage ring

Parameter	Unit	BDA	BPC
Length eff.	m	1.3	0.21
B	Tesla	0.55	2.05
Bending radius	m	18.07	4.87
E_{cr}	keV	3.29	12.57
λ_{cr}	nm	0.38	0.10
Power density	W/mA/mrad	0.06	0.24
Power	W	135	517
ψ_{rms}(525 nm)	mrad	1.36	2.12

out of 32 SR channels of SKIF dipole magnets, 16 provide radiation from the BPC and the same number provides radiation from the BDA. Several parameters of the BPC and BDA bending magnets are listed in Table 2, and Fig. 3 shows the radiation spectra from these magnets.

The SR is extracted from the center of the bending magnets and has an natural open angle, which depends on the radius of the trajectory curvature, as well as the wavelength of the SR. At a longer wavelength and/or a smaller radius of curvature, the SR will have a larger natural open angle [2] in accordance with

$$\psi_{rms} \approx 0.449 \cdot \left(\frac{\lambda}{\rho}\right)^{\frac{1}{3}} \quad (1)$$

where is a natural open angle of the sum of the σ- and π- polarization components, ρ is a curvature radius, λ is a wavelength of the SR. In the near-UV and visible regions, the number of photons is approximately twice as large for the weak magnet (see Fig. 3). However the SR vertical direction of the strong dipole is wider and the radiation power for the weak magnet is lower (see Fig. 4, Table 2). The expected

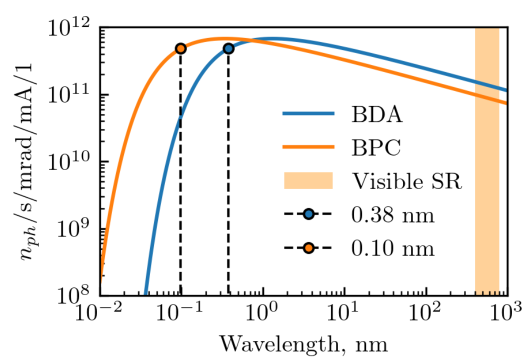

Figure 3: Spectral characteristics of radiation from the dipole magnets of the SKIF superperiod.

transverse dimensions of the beam at both emission points will be varied within the range of 8-30 μm depending on the settings of the storage ring magnetic system. When using visible range optics, the angular and spatial optical resolution in the vertical and horizontal directions, determined by the SR properties and the beam trajectory, do not allow using only projection optics to observe transverse distributions (they are limited by factors such as diffraction error, curvature error and depth-of-focus error).

According to [3], the resolution limit estimate for the two magnets at 525 nm wavelength yields a value close to 200 μm for BDA and 70 μm for BPC. Therefore, it is necessary to use a double-slit interferometer [4–6] and a beam size monitor based on the π-component of SR [7].

In terms of the amount of light, radiation density and thermal load on the first components of the optical path, the channel of the "weak" BDA magnet looks more attractive for use. It is worth noting that the direction of the SR from the "strong" BPC magnet is significantly wider, i.e. 1.36 mrad against 2.12 mrad. That can allow increasing the distance between the SR interferometer slits when measuring the vertical beam size. But at the same time the vacuum chamber of the SR beamlines limits the aperture of the horizontal

ISBN: 978-3-95450-249-3 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2024-WEP20

opening angle to the 5.4 mrad, and the vertical opening angle to the 3.6 mrad. Therefore, when choosing the places of

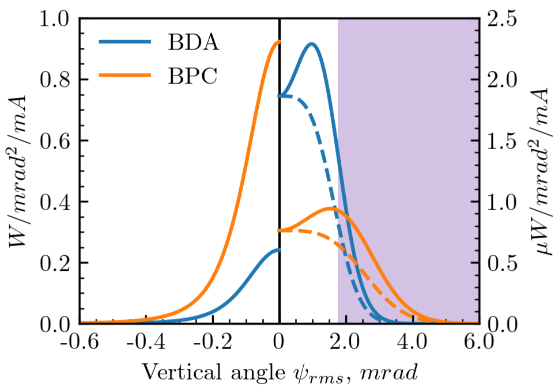

Figure 4: Angular distribution of the SR power density: left – general; right – in the range of 300-700 nm; the shaded area is limited by an absorber; the dotted line – σ-component of polarization.

radiation extraction for optical diagnostics, it was important to use the same configuration of SR beamlines as the users of SR. Consequently, to simplify the optical scheme and ease of maintenance, each of the SR output points solves serves its own purpose of measuring beam parameters. Light from the BDA point is designed for measuring the longitudinal intensity profile, and BPC will be used to measure the transverse dimensions of the beam.

DESCRIPTION OF THE OPTICAL DIAGNOSTIC STATION

Both types of the diagnostic systems are located inside the accelerator tunnel. BDA beamline will be used mainly to measure longitudinal distribution parameters such as beam length, bunch separation and beam filling patterns. Observation of the longitudinal bunch distribution will be performed using an electron-optical dissector [8–10] operating at a high harmonic of the beam revolution frequency. A streak camera designed for single measurements will be used to record the longitudinal charge distribution in bunches.

The radiation is directed to the streak camera using an insertion mirror, while the possibility of measuring the longitudinal profile using an electron-optical dissector can be preserved. It is assumed that the streak camera will be used for special experiments with the beam and will be placed in a protected room for a short time. To observe the behavior of the center-of-mass of the beam during injection, it is possible to install an additional gated camera with electron-optical amplification. This can be useful for tuning the beam injection. A digital camera will perform the high-quality observations of the transverse beam profile and control of the passage of radiation to the diagnostic station. The optical scheme for diagnostics of the longitudinal profile of the beam current is shown in Fig. 5.

After the first cooled mirror, located at a distance of 7 m from the source point and the vacuum window, the SR reflected by the mirror located in the atmosphere at a distance of 0.3 m from the window will be directed to the final station, where the experiments will be continued. The station is located at a distance of 5 m from the first mirror in the atmosphere and has an achromatic lens with a focal length of 1 meter at the input that builds an image on all detectors. The light is distributed among the detectors by a system of beam splitters and mirrors. And remotely controlled light attenuators adjust the intensity. In the SR output channel from

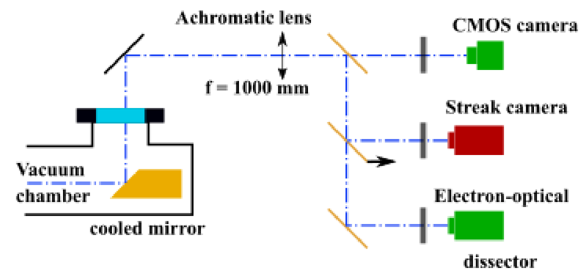

Figure 5: The scheme of the SKIF longitudinal optical diagnostic station.

the BDA magnet, the radiation power is ≈24 W/mrad with a total beam current of 400 mA. The most of this power falls on the region of X-ray radiation concentrated in a horizontal strip, the value of which is determined by the radiation direction (see Fig. 4). The base mirror, made of a copper cylinder with an aluminum coating with thich of 25 µm, is located at an angle of 45° to the vertical plane. Its total horizontal viewing angle is amount 5 mrad. To assess the effect of the thermal load on the mirror, the finite element modeling was performed. According to calculations, the maximum mirror temperature in the operating mode was 38°. Monitoring of the flow and temperature of the water that cooling the mirror is also provided.

As mentioned above, the calculated beam dimensions at the source point amount 8 µm. Based on this, to determine the transverse dimensions it is not enough to use projection optics in the visible wavelength range and it is necessary to shift to the region of wavelengths corresponding to X-rays. However, the use of X-ray optics and recording means of SR registration significantly complicates the design and its maintenance, and control. Therefore, to determine the transverse dimensions of the beam, as a first-priority diagnostic, an interferometric measurement method using SR in the visible and near-UV range will be used. This facility is relatively simple and does not require a large number of optical components.

Two interferometers reflecting SR are installed to measure the vertical and horizontal dimensions of the beam. The double slit will be located at a distance of 2.7 m from the source point. A focusing mirror with 1250 mm is used as an object-glass. A small off-axis diagonal mirror is provided to reduce the sizes of the interferometer. To limit the wavelength of the incoming light a set of bandpass filters with a passband of 25-35 nm for wavelengths of 550, 450, 350 and 300 nm will be used. The σ-polarization of the SR will be

ISBN: 978-3-95450-249-3 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2024-WEP20

selected using a polarizing filter. Figure 6 shows the scheme of the SR interferometers.

The resolution of a double-slit interferometer depends on the measurement error of visibility. With the expected value of this quantity of 0.01, it is desirable not to exceed 5% [11]. This can be achieved by increasing the distance between the slits in the diaphragm and/or decreasing the wavelength of light. A significant reduction in wavelength is complicated by the increase in the cost of components and the deterioration of the filter bandwidth. An increase in the distance between the slits can be limited by the direction of the SR or the beamline aperture.

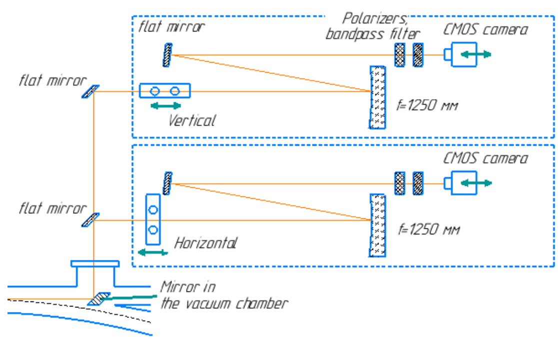

Figure 6: The scheme of the SKIF transverse optical diagnostic station.

In Fig. 7, the area shaded in orange colour corresponds to half of the visibility angle of the distance between the slits of the diaphragm from the source point. Thus the area for visibility of the interference pattern is less than 0.9 with a source size of 8 µm is shown. The lines in Fig. 7 demonstrate the dependence of the vertical opening of the SR direction angle via the wavelength. Since the characteristic beam

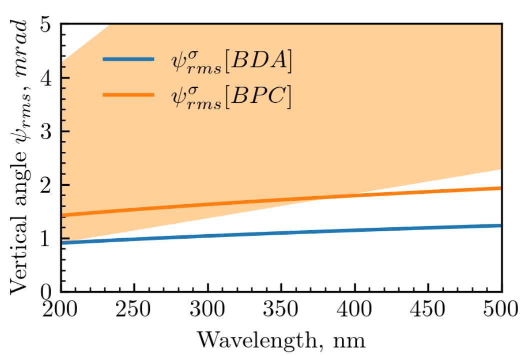

Figure 7: Vertical aperture of the SR via the wavelength for two bending magnets. Orange region is the desired location of the diaphragm slits.

angle for the BPC magnet lies closer to the desired region, it will be possible to obtain reliable results of vertical beam size measurements while simultaneously shifting to the near-UV region and increasing the distance between the interferometer diaphragm slits.

It is difficult to manufacture the first mirror in the vacuum chamber. To reduce the load on the mirror, it is assumed that it will be located after the cooled absorber, which transmits radiation into an aperture of 5.4 × 5.4 mrad. The mirror is supposed to be made of copper with an aluminum reflective coating and water cooling. It will have a slot with a vertical aperture of 2 mrad transmitting the hard part of the radiation.

CONCLUSION

The article presents a project of SR optical diagnostics in the visible and near-UV region for the main ring of SKIF accelerator. Two diagnostic types were designed, the first of which will observe the longitudinal distribution of charge in the beam, and the second will provide measurements of the transverse dimensions of the beam in the storage ring.

ACKNOWLEDGEMENTS

This work was supported by the Ministry of Science and Higher Education of the Russian Federation within the governmental order for SRF SKIF Boreskov Institute of Catalysis (project FWUR-2024-0041).

REFERENCES

[1] G. Baranov *et al.*, "Lattice optimization of a fourth-generation synchrotron radiation light source in Novosibirsk", *Phys. Rev. Accel. Beams*, vol. 24, no. 12, p. 120704, Dec. 2021. `doi:10.1103/physrevaccelbeams.24.120704`

[2] A. Hofmann, "The Physics of Synchrotron Radiation", Cambridge University Press, Cambridge, UK, 2004

[3] J. A. Clarke, "A Review of Optical Diagnostics Techniques for Beam Profile Measurements", in *Proc. EPAC'94*, London, UK, Jun.-Jul. 1994, pp. 1643-1646.

[4] T. Mitsuhashi, "Beam profile and size measurement by SR interferometers", in *Proc. Joint US–CERN–Japan–Russia School on Particle Accelerators*, May 1999, pp. 399–427. `doi:10.1142/9789812818003_0018`.

[5] T. Naito and T. Mitsuhashi, "Very small beam-size measurement by a reflective synchrotron radiation interferometer", *Phys. Rev. ST Accel. Beams*, vol. 9, no. 12, p. 122802, Dec. 2006. `doi:10.1103/physrevstab.9.122802`

[6] W. J. Corbett *et al.*," Transverse beam profiling and vertical emittance control with a double-slit stellar interferometer", in *Proc. IBIC'16*, Barcelona, Spain, Sep. 2016, pp. 236–239. `doi:10.18429/JACoW-IBIC2016-MOPG70`

[7] A. Anderson *et al.*, "Recent Results from the Electron Beam Profile Monitor at the Swiss Light Source", in *Proc. DIPAC'07*, Venice, Italy, May 2007, paper TUPB27, pp. 129-131.

[8] O. Meshkov, "New instrumentation for optical beam diagnostics", presented at Beam Tests and Commissioning of Low Emittance Rings, ARIES-ICFA Workshop, Karlsruhe, Germany, Feb. 2019, unpublished.

[9] S. V. Andreev *et al.*, "A Picosecond Electron-Optical Dissector for Detecting Synchrotron Radiation", *Instrum. Exp. Tech. and Experimental Techniques*, Vol. 62, No. 2, pp. 208-213, Apr. 2019. `doi:10.1134/s0020441219020027`

ISBN: 978-3-95450-249-3 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2024-WEP20

[10] D. Malyutin *et al.*, "The Optical Dissector Bunch Length Measurements at the Metrology Light Source", in *Proc. IBIC'17* Grand Rapids, MI, USA, Aug. 2017, P. 125-128. doi:10.18429/JACoW-IBIC2017-TU1AB3

[11] N. Samadi, X. Shi, L. Dallin, and D. Chapman, "Source size measurement options for low-emittance light sources", *Phys. Rev. Accel. Beams*, vol. 24, no. 11, Nov. 2021. doi:10.1103/physrevaccelbeams.24.119901