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

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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

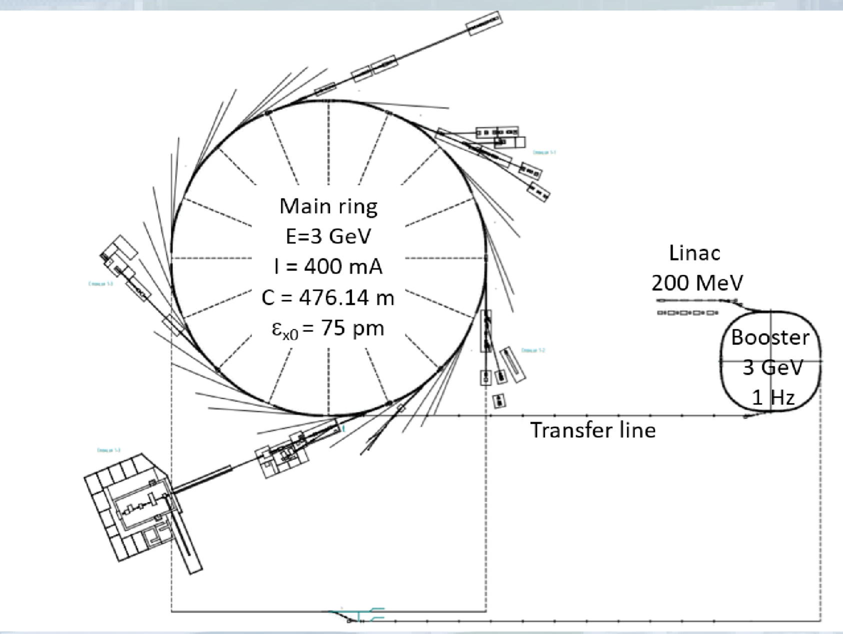

Fig. 1 The common scheme of the Synchrotron Radiation Facility SKIF.

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.

SOURCE POINTS

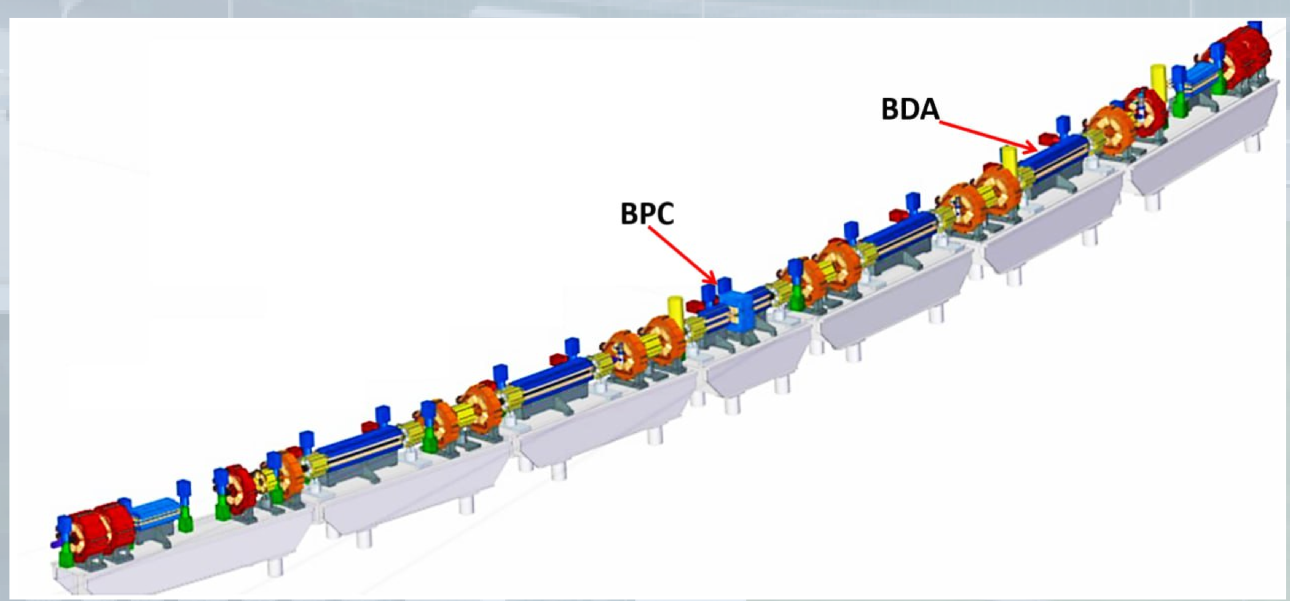

Fig. 2: The superperiod of the SKIF main storage ring.

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 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. Several parameters of the BPC and BDA bending magnets are listed in Table 1, and Figure 3 shows the radiation spectra from these magnets.

The expected 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.

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 [4,5,6] 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.

Tab. 1: Specifications of the dipole magnets of the main SKIF 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

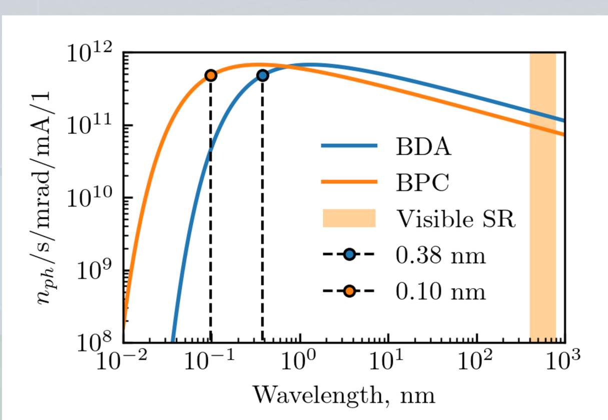

Fig. 3: Spectral characteristics of radiation from the dipole magnets of the SKIF superperiod.

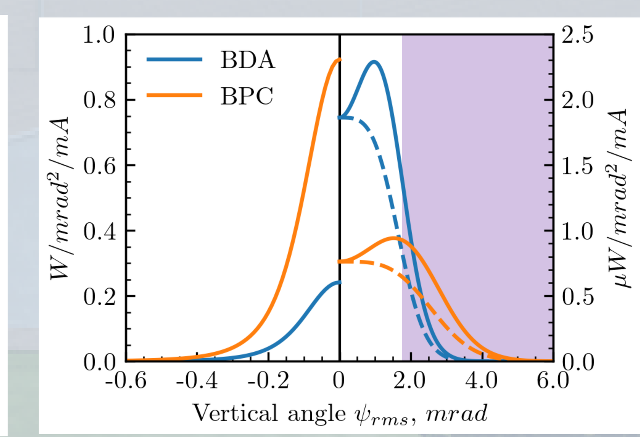

Fig. 4: Vertical power density.

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, 9 and 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 Figure 5.

After the first cooled mirror, located at a distance of 7 meters from the source point and the vacuum window, the SR reflected by the mirror located in the atmosphere at a distance of 30 centimeters 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 meters 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.

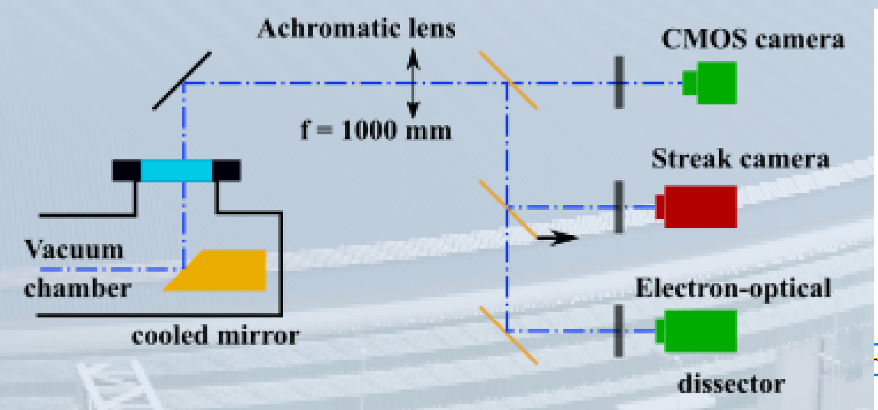

Fig. 5: Scheme of the longitudinal diagnostic channel.

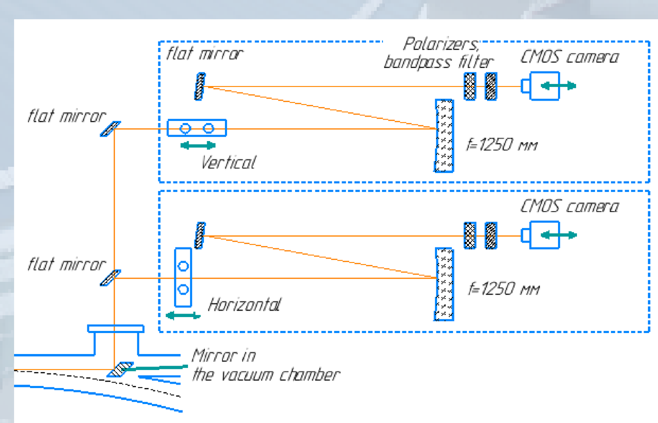

Fig. 6: Diagram of the transverse diagnostic channel.

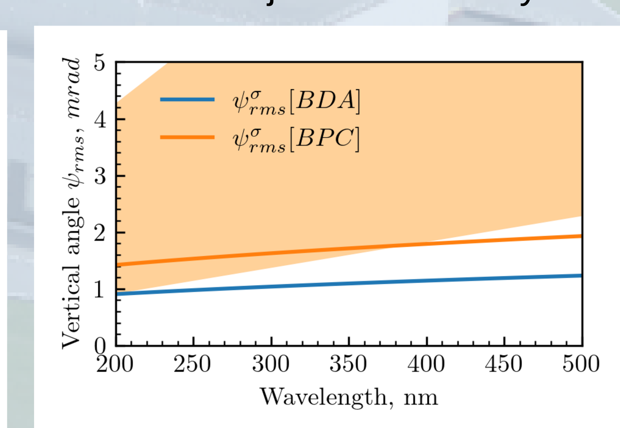

Fig. 7: Vertical aperture of the SR via the wavelength for two bending magnets. Orange region is the desired location of the diaphragm slits.

In the SR output channel from the BDA magnet, the radiation power is ~24 W/mrad with a total beam current of 400 mA. The most of this powe 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^{0}C. 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 meters 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 selected using a polarizing filter. The 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 a visibility of 0.9 to ensure a relative estimate better than 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.

In Figure 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 Figure 7 demonstrate the dependence of the vertical opening of the SR direction angle via the wavelength.

Since the characteristic beam angle for the BPC magnet lies closer to the desired region, it will be possible to obtain reliable results of epy 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

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