THE PROJECT OF KIRKPATRICK – BAEZ FOCUSING SYSTEM FOR BEAM DIAGNOSTICS ON THE SKIF

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Abstract

The Siberian Ring Radiation Source (SKIF) is an up-coming 4th-generation SR source under construction in Novosibirsk, Russia. The designed beam emittance for SKIF is 75 pm-rad, which corresponds to a beam size of 6 micrometers at the observation point within the dipole magnet. The transverse beam dimensions are essential parameters for tuning and reliable operation of the facility. The SKIF diagnostic suite includes a double-slit interferometer operating in the ultraviolet region of the spectrum. This device's spatial resolution should be sufficient to measure the radial size of the beam to an accuracy of 10 percent. These diagnostics will be used during the commissioning of SKIF and afterwards. Although an additional source of information on beam dimensions and dynamics would be desirable for assurance, taking into account the record designed value of beam emittance. The application of X-ray optics and the Kirkpatrick-Baez focusing system seem to be the most suitable options. The article discusses the project of this system, which will acquire X-rays from a SKIF dipole magnet

INTRODUCTION

The SKIF [1] is the 4-generation synchrotron light source designed by the Budker Institute of Nuclear Physics (BINP) with an energy of 3GeV. It is expected to be completed in 2024 and put into operation in 2025. magnetic structure of the SKIF is based on the modified mTME cell and consists 16 superperiods. Figure 1 presents the beam transverse dimensions within a single superperiod. A superperiod comprises four “soft” magnetic dipoles with a field strength of 0.55 T and four of “hard” magnetic dipoles with a field of 2.2 T. The synchrotron radiation (SR) of the beam emitted from these dipoles can be used for the beam diagnostics, specifically for measuring beam dimension. This paper will focus solely on the application of the SR from the “soft” mag-net. The critical energy in the SR spectrum emitted from this magnet is E_{cr} = 3 keV. Detailed information about the properties of the SR can be found in [2].

The well-known limitations of a spatial resolution are determined by the properties of SR [3]. These includes the diffraction limit: $\sigma_{df} \approx 0.25\sqrt[3]{\frac{\pi}{6}\lambda^2\rho}$; a visible segment of the beam trajectory: $\sigma_{arc} \approx \frac{1}{2}\sqrt[3]{\left(\frac{3}{4}\frac{\lambda}{\pi}\right)^2}\rho$; and a depth of field: $\sigma_{dp} \approx 2\sigma_{arc}$. A total restriction on the radial beam dimension is given by $\sigma_t^{rad} = \sqrt{\sigma_{df}^2 + \sigma_{arc}^2 + \sigma_{dp}^2}$. This limit for the vertical beam dimension is also given by $\sigma_t^{vert} = \sqrt{\sigma_{df}^2 + \sigma_{dp}^2}$, where λ - is the wavelength of the radiation, and ρ = 18.8 m is radius of curvature of the beam trajectory. These limitations make it impossible to measure transverse beam dimensions in the visible area of the SR using projection optics because $\sigma_t^{rad}, \sigma_t^{vert} \approx 70$ mkm if the light at wavelength λ = 550 nm from the “soft” magnet is applied for that.

It is possible to measure the transverse dimensions of a beam using double-slit interferometer [4] and this technique for the SKIF is discussed in [2, 5].

Nonetheless, the capacity to observe the beam transverse profile of the beam has some advantages when compared to acquiring an interferometric pattern. Thus, it becomes possible to investigate dynamics of a beam during injection and monitor a spectra of beam oscillations [6]. Because of that we aim to develop a method for diagnosing the transverse profile of a beam based on an optical projection system operating in the X-ray range, utilizing multilayer mirrors [7]. The shift to the soft X-ray region significantly reduces the limitations for $\sigma_t^{rad}, \sigma_t^{vert} \approx 2.5$ mkm if a radiation with an energy of *E* = 400 eV is employed.

The optical system should be capable of providing a magnification of about ×5 in order to enlarge the dimensions of the captured beam image to several tens of micrometers. This will allow for a reliable digitization of the beam image. There are two well-known optical systems which are used for similar purposes: the Kirkpatrick-Baez focusing system [8-10] and the Schwarzschild objective [11-13]. Their key characteristics under specific conditions of the SKIF are outlined below.

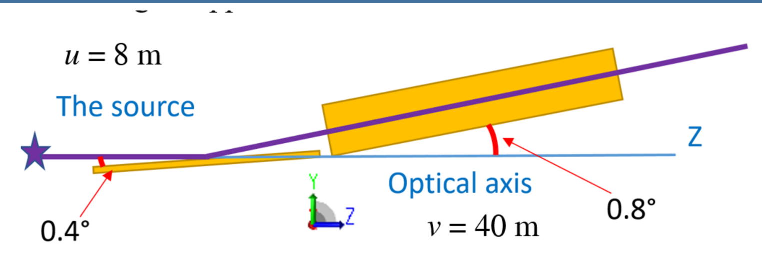

Figure 3: The optical scheme of the KB system used for simulations (not in scale).

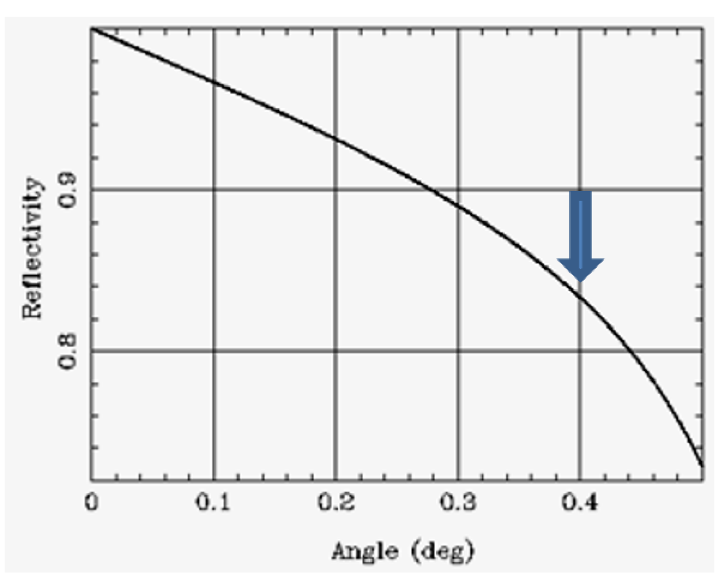

Figure 4: The relationship between the reflection coefficient of a platinum surface and the angle of incident of X-ray photons at an energy of 8052 eV.

The layout of the KB system which have been used for simulations is presented in Fig. 3. The dimensions of the mirrors at 20×60 mm² are sufficient to completely accept the SR shower with a divergence of 1.5 mrad. The final version of the dimensions of the mirrors will be determined after simulations of the thermal load under the SR flux. Considering the reliable testing of the mirrors during manufacturing, a wavelength of $\lambda = 1.54\,A$ ($E \approx 8$ keV) has been selected. The tests will be performed with an X-ray tube using a copper cathode.

The advantage of a KB system is the high reflection coefficient of the mirrors due to the small of incidence of the radiation. We have chosen platinum as the coated sur-face of the mirrors. The dependency of the reflection coefficient on the angle of incidence for X-ray photons with an energy of 8052 eV is shown in the Fig. 4. As a result, the total reflection coefficient of the mirrors is approximately 0.7.

The detector for acquisition of the beam image

A conventional approach involves the use of a scintillator, which offers the benefit of optical magnification while maintaining a reasonable level of spatial resolution. [9, 18]. It is important to pay attention to the thickness and optical homogeneity of the scintillator crystal. The choice of a digital camera does not create a problem.

CONCLUSION

The possibility of using the Kirkpatrick-Baez mirror for transverse beam size measurements at the SKIF storage ring has been preliminarily studied. The optical system can provide a spatial resolution of 3 μm within the field of view of ± 250 μm. The choice of the final design of the KB system requires more accurate numerical simulations to determine the influence of surface imperfections and heat load from synchrotron radiation on the point spread function of the diagnostic system.

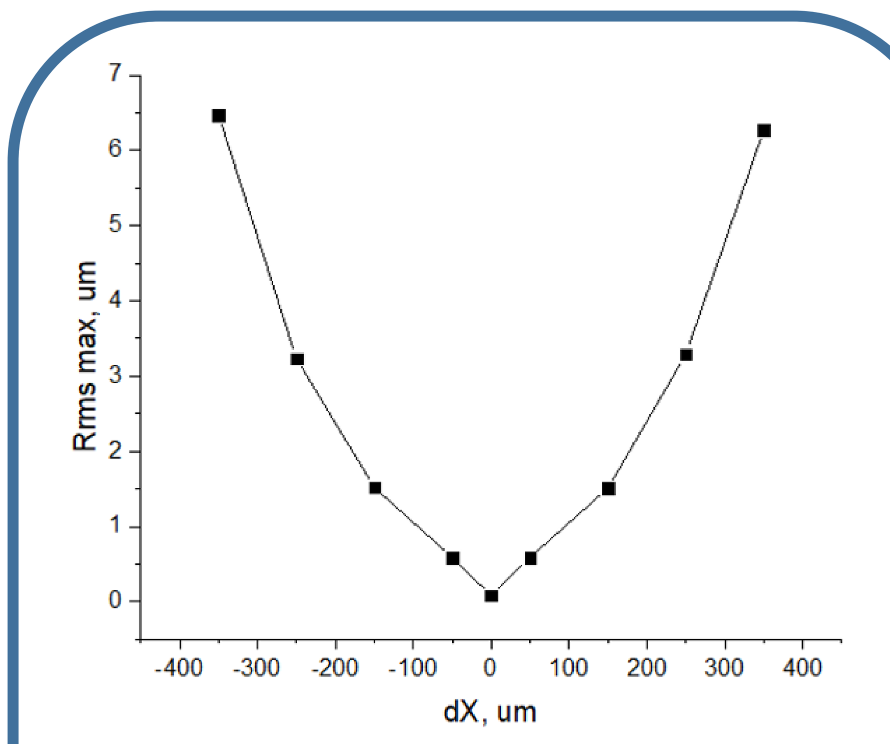

Figure 6: The spatial resolution of the KB system varies of the field of view.

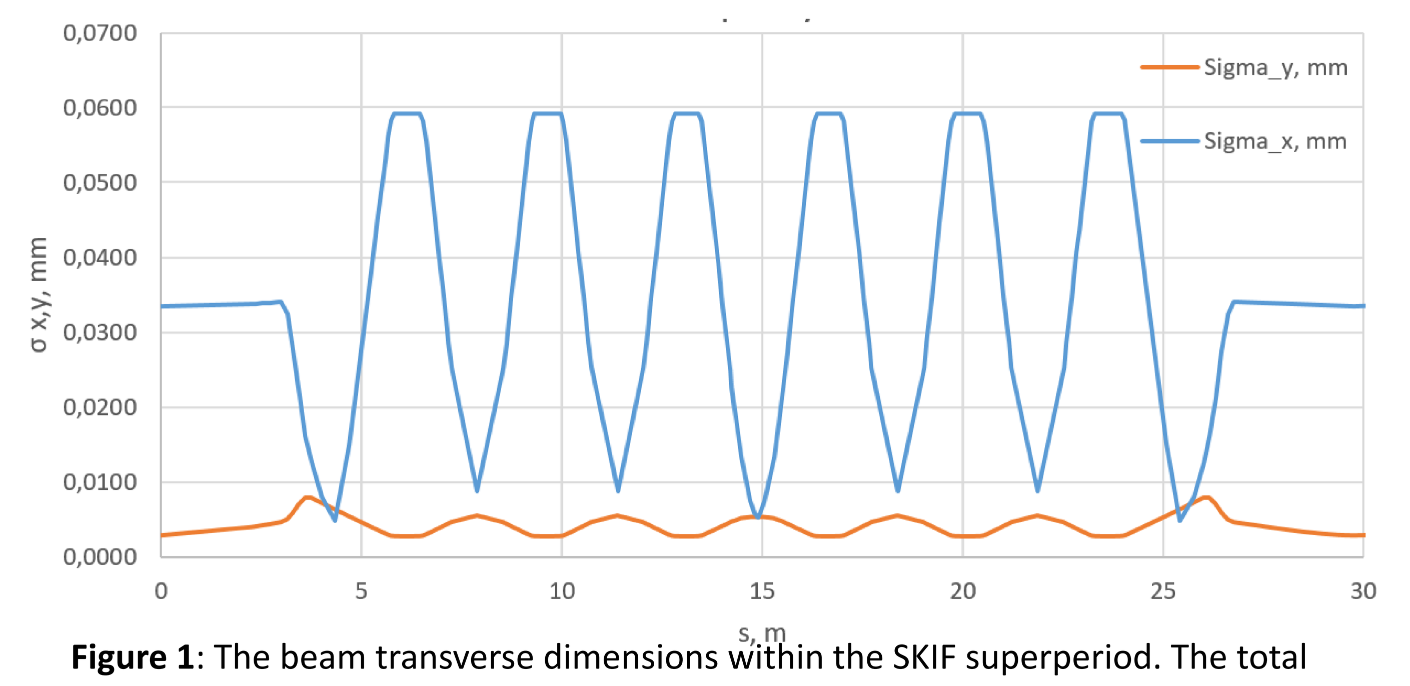

Figure 1: The beam transverse dimensions within the SKIF superperiod. The total magnetic structure of the SKIF has 16 superperiods.

KIRKPATRICK – BAEZ FOCUSING SYSTEM

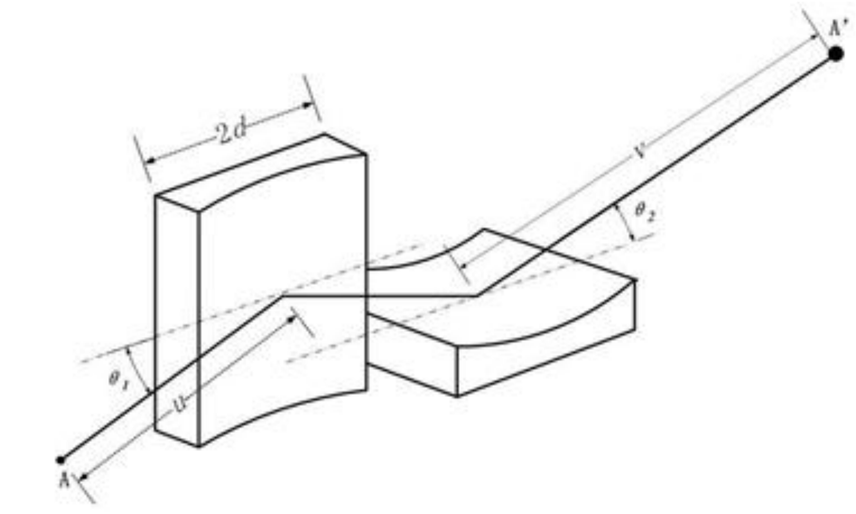

Figure 2: Upstream (blue) and downstream (red) losses distributions of the electron beam in the transfer line between the BINP facilities acquired by CBLM.

The analyse of the spatial resolution of the KB focusing system

The KB mirrors (Fig. 2) which we intend to use for beam imaging in the main storage ring of the SKIF are essentially analogous to a type of microscope described in [14, 15], albeit with an object distance *u* = 8000 mm. The imaging properties of the KB system are characterized by Coddington equations [8]:

$$\frac{1}{u} + \frac{1}{v + 2d} = \frac{2}{R \cdot \sin(\theta_1)}$$

$$\frac{1}{u + 2d} + \frac{1}{v} = \frac{2}{R \cdot \sin(\theta_2)}$$

The grazing incidence angle is θ_1 = 1.5 mrad in vertical and radial directions which is determines by the design of the beamline. With a magnification *M* = 5 we obtain *v* = 40 000 mm and a curvature radius of the mirrors is *R* = 4.44 km.

The simulations of a spatial resolution of the KB focusing system

The first simulations of the proposed KB system have revealed that the field of view is too small when the mirrors had a pure spherical surface. Therefore, the next simulations were conducted for asphericical mirrors. A map of the asphericity of the mirrors with a PV of 230 nm is shown in Fig. 5.

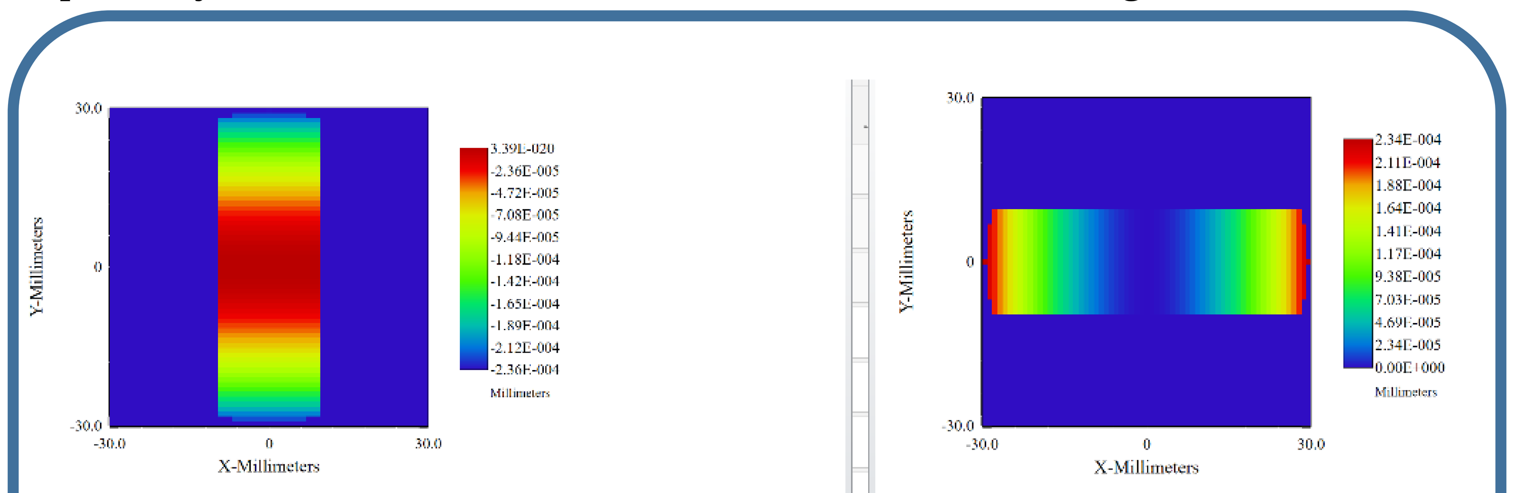

Figure 5: The map of the asphericity of the first mirror of the KB system with PV = 230 nm.

The Fig. 6 shows the relationship between the simulated spatial resolution of the KB mirrors and the field of view.

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