COMPACT HARD X-RAY SYNCHROTRON RADIATION SOURCE WITH SUPERCONDUCTING BENDING MAGNETS

E.I. Antokhin, A.A. Gvozdev, G.N.Kulipanov, P.V. Logachev, N.A. Mezentsev, V.E.Panchenko, A.V. Philipchenko, Y.V. Rakshun, A.V. Utkin, N.A. Vinokurov, K.V. Zolotarev*,
Budker Institute of Nuclear Physics, 630090, Novosibirsk, Russia

Abstract

Synchrotron radiation (SR) with relatively hard spectrum (up to 50 keV) is necessary for realization many modern X-ray analytical methods. These methods can be effectively used in industrial and medical applications, in universities and scientific centers. So, the task of developing of compact source of hard synchrotron radiation is very perspective. Budker INP has a big experience for developing and fabrication of high field superconducting insertion devices for different SR centers. In frame of this activity a superconducting bending magnet with field up to 9.6 T was fabricated for BESSY-II and commissioned in 2004. This magnet also became a prototype for compact hard SR source. A project of such storage ring is under developing in Budker INP now. This design fixed beam energy to 1.2 GeV, ring circumference about 56 m. Estimated horizontal equilibrium emittance will better near 10 nm. This report includes a detailed description of main parameters and magnetic structure of designed storage ring as well as preliminary design of injector system and beamline layout.

INTRODUCTION

Development of compact and low-cost SR sources of hard (up to 50 keV) X-rays is an actual task for further application of the advanced X-ray methods in industry, medical centers, hospitals, small scientific centers and universities. Application of superconductive bending magnets allows solving this task with relatively small electron beam energies in a storage ring. Economically, a high cost of the magnetic system of such a storage ring can be compensated by cheaper injector, RF and protection systems and abrupt decrease of expenses for construction of the infrastructure of the complex. Low beam energy simplifies reduction of the emittance value and permits increasing spectral brightness of the source as compared with a high-energy storage ring with a magnetic system of a similar type.

The concept of compact SR source using superconducting magnets has been realized in different projects (AURORA, NIJI-3, SXLS, Helios, Super-ALIS etc.) (see [1, 2]) in the 1990s. However, these projects were aimed at generation of VUV and soft X-rays, which did not allow using such installations for research in the hard X-ray region.

In 1992 a prototype of superconducting bending magnet with a working field of 6 Tesla was fabricated and successfully tested at Budker INP. It was decided to organize manufacture of such bending magnets for future creation of compact SR sources consisting of superconducting and conventional bending magnets [3, 4]. Unfortunately, these projects were not realized because of serious problems in Russian economics at that time.

In 2001 a project for design and fabrication of a 9 Tesla superconductive bending magnet (Superbend) was started in the framework of collaboration between Budker INP and BESSY. In 2003 the Superbend was successfully tested and a field of 9.37 Tesla was obtained. After some work to minimize heat inleak in the cryostat and to reduce liquid helium consumption, the magnet was successfully commissioned at the BESSY site. The maximal field value of 9.6 T was achieved in 2004 during site acceptance testes at BESSY [5].

The successful commissioning of the superconducting bending magnet confirmed reliability of the BINP technology and allowed creation of a compact SR source of hard X-rays on the basis of such magnets. This project was started at Budker INP in 2006.

Besides, Siberian Synchrotron Radiation Center (SSRC) at Budker INP unites a lot of SR users from Siberian Branch of Russian Academy of Science and from other organizations. SSRC has good experience in organization of large user communities, and has the infrastructure required for research [6]. But the main problem of SSRC is the absence of a specialized SR source. This project can be considered as a way of noticeable up-grade of this center. Thus, development of such compact and bright SR source is really a very actual task.

POSSIBLE SCHEME OF COMPACT STORAGE RING

To show realizability of all the above-mentioned ideas, a scheme of such a system was suggested. Main parameters of the complex are sumarized in Table 1 and general view is presented in Figure 1. The ring perimeter is 56 m, and a 17 × 22 m hall can accommodate such storage ring. This variant allows organization of as many as 18 channels for hard spectrum SR extraction and of a rather large amount of channels for the soft X-radiation.

*Zolotarev@inp.nsk.su

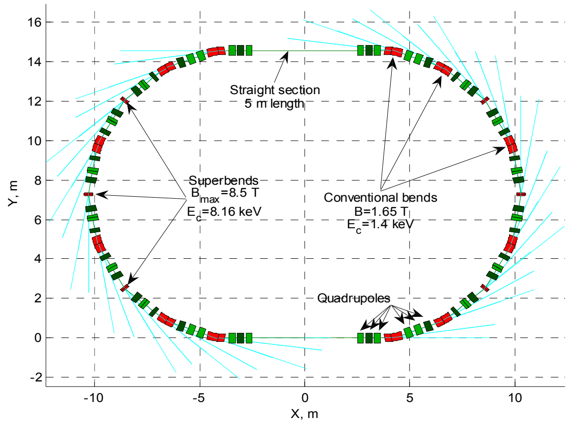

Figure 1: Possible schemes of compact SR source.

Table 1: Main parameters of a compact storage ring – SR source (requirements).

Parameter	Value
Electron energy	1.2 GeV
Critical energy of SR quanta	8.16 keV for SR from superconductive magnets (8.5 T) 1.6 keV for SR beams from normal magnets (1.65 T)
Number of bending magnets	6 superconductive magnets 12 conventional magnets
Number of SR beamline	18 with hard X-ray spectrum 6-10 with soft X-ray and VUV spectrum
Beam phase-space volume	10 nm·rad
Beam current	800 to 1000 mA
Beam lifetime	8 to 10 hours
Orbit perimeter	< 60 m
Size of a hall for the storage ring facility	17 × 22 m (without the space required for users' stations)

Fig.2 presents the optical functions of the suggested scheme. Magnets and quadrupole lenses are arranged in accordance with the theoretical minimal emittance (TME) lattice requirement, as far as it is possible for such compact lattice. The structure has a racetrack shape and consists of two arcs and two 5-m long straight sections. Each of the arcs includes 3 Superbends and 6 conventional bends. Bending angles in all the magnets are the same and equal 20º. The edge arc bends work as dispersion suspensors; they provide zero dispersion in the straight section. The Superbends are separated with conventional magnets, to prevent intersection of beamlines from a Superbend with the cryostat of next one.

The computed horizontal beam emittance is 11 nm rad. Thus, this facility can be classified like the most compact among the 3rd generation SR sources.

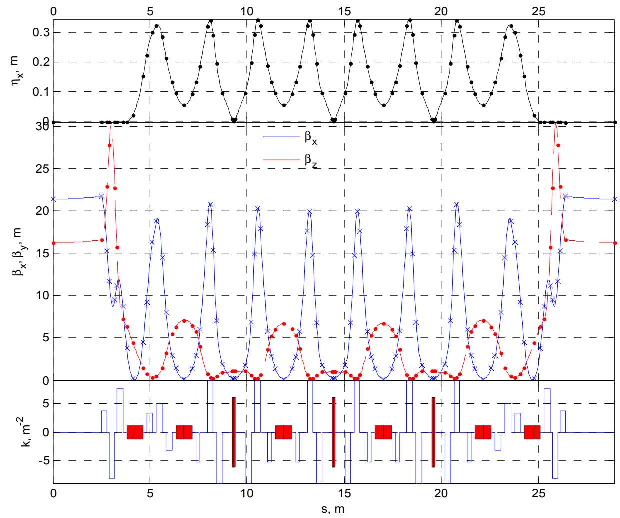

Figure 2: Optical functions in one superperiod of a compact SR source.

Of course, this design is only a first proposal and covers only the stage of linear optimization of lattice optics. A lot of problems of nonlinear beam dynamic are complicating implementation of this scheme. But this example shows the main direction for design optimization.

Since bending angles in the magnets are big enough, several beamlines can be extended from one magnet, three beamlines in this design. In this case, the central beamline takes SR from the center of the Superbend, where the magnetic field is maximal. The angle between neighbor beamlines is 5º, which provides enough space for users. Since the field at irradiation points in side channels is about 8 T, spectral parameters of SR of these beamlines do not differ much from those of the central one. The same angle was selected for beamlines from the normal conducting magnets.

BRIEF SUBSYSTEMS DESCRIPTION

Other subsystems of this facility can be built in accordance with standard Budker INP approaches and technologies. Most of these components already have working prototypes and thus can be used after small modifications.

The injector system will include a 150 MeV linac and a booster synchrotron for full energy (1.2 GeV) injection.

A special electron and positron source as an universal injector facility was created and commissioned at BINP [7]. The fist section of this facility can be used in the current project as an initial electron beam source. It contains two sections of the linear accelerator structure that can accelerate electron bunches up to 150 MeV. All parameters of this linac meet the booster injection requirement, so it was decided to use this system.

The booster takes the electron beam from the linac and accelerates it up to 1.2 GeV, for full energy injection into the main ring. The booster will be similar in design to the booster produced at BINP for Duke University (North Carolina, USA) [8].

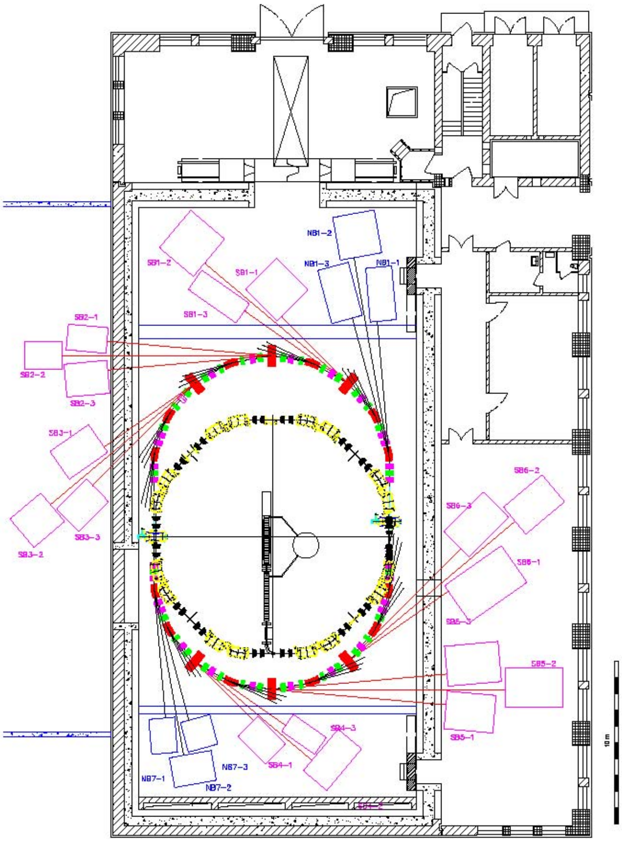

Figure 3: General layout of compact SR source facility, SR beamlines and experimental stations.

Standard RF cavities used at Budker INP, with high order mode suppression and a frequency of 180 MHz, will be installed in the booster and main ring. In spite of big dimensions of the system, relatively long bunches formed by this cavities will help to decrease intrabeam scattering and to increase the beam life time.

The facility will be located in an already existing building of Budker BINP. Figure 3 shows a possible layout of the injector system, storage ring, beamlines and experimental stations for users. A median plane of booster synchrotron and linac will be located in 1 m lower than mediam plane of main ring. This building is being reconstructed now. Some stations will be placed in a building extension to be created later.

Altogether 18 experimental stations will be installed on beamlines from the Superbends. They will use SR in the hard X-ray region. The most popular X-ray research techniques will be presented, XAFS, XRD, and XRF among them. Also 6 beamlines will use SR from the conventional bends. Thus, some research techniques in the soft X-ray and VUV regions will also be implemented.

CONCLUSIONS

Modern technology for fabrication of superconductive bending magnets can be effectively used to create a compact SR source with hard X-ray spectrum. The relatively small beam energy of such storage ring simplifies meeting a number of important requirements for biological protection, injection system and emittance minimization.

BINP has great experience in development and creation of different accelerators. All necessary technologies for fabrication of this facility and all components are also available. Thus, such compact SR source really can be created.

Since SSRC really needs a specialized SR source, the decision for development of such source was taken at BINP. This source should cover large part of SR user needs in the hard and soft X-ray ranges.

A detailed project of this source is under development now. Prototypes of some critical components can be fabricated next year.

It is possible to suppose that the facility will be commissioned in the end of 2010.

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