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ScienceDirect

Physics Procedia 84 (2016) 40 – 46

Physics Procedia

International Conference "Synchrotron and Free electron laser Radiation: generation and application", SFR-2016, 4-8 July 2016, Novosibirsk, Russia

Progress in the design and related studies on the High Energy Photon Source

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Abstract

The High Energy Photon Source (HEPS), a kilometer-scale diffraction-limited storage ring light source, with a beam energy of 6 GeV and a natural emittance of a few tens of pm.rad, is to be built in Beijing and now is under design. In this paper we will report the progress in the design and related physical studies on the HEPS, covering issues of storage lattice design and optimization, resonance effect evaluation, booster design, injection design, collective effect study, error study, etc.

Peer-review under responsibility of the organizing committee of SFR-2016.

Keywords: High Energy Photon Source; diffraction-limited storage ring; physical studies

1. Introduction

Early in 2008, a kilometer-scale storage ring light source with a beam energy of 6 GeV, originally called Beijing Advanced Photon Source and now named High Energy Photon Source (HEPS), was proposed to be built in Beijing [Jiang et al. (2012)]. Extensive efforts have been made on the lattice design and relevant studies of this project. The basic lattice structure of the HEPS storage ring has been continuously evolved, from DBA, standard 7BA, TBA, standard 7BA with high-gradient quadrupoles to the 'hybrid' 7BA with high-gradient quadrupoles, while with the goal emittance decreased from about 1 nm.rad to a few tens of pm.rad, approaching the diffraction limit of hard X-rays. Presently, a 'hybrid' 7BA design with a natural emittance of 60 pm.rad was reached [Xu et al. (2016)]. Most

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Peer-review under responsibility of the organizing committee of SFR-2016.
doi:10.1016/j.phpro.2016.11.008

recently, we received a funding of about 50 million dollars to construct the test facility of the HEPS, with 1/3 of the budget for accelerator R&D studies. The aim is to test and verify the availability of the advanced hardware technologies dedicated to the ultralow-emittance design, for instances the small-aperture magnet and vacuum systems. At the same time, lattice design and optimization and other related physical studies are going on, with the aim to make an optimum and complete design for the HEPS, provide practical parameter suggestions for different hardware systems, and give tolerance budget for various machine imperfections. In the following, we will give a bird view of the progress and the status of the physical studies on the HEPS project, covering issues of lattice design and optimization, resonance effect evaluation, injection design, RF parameter choice, collective effects, tolerance study and insertion devices. It is worthy to note here that these issues are coupled and jointly determine the overall performance of the light source. They are introduced separately here just for clearance and convenience of readers.

2. Present HEPS lattice design and related physical studies

2.1. Lattice design for the main ring and the booster

The HEPS project consists of a 300 MeV linac, a booster and the main ring.

The present design of the main ring is based on the so-called 'hybrid' MBA concept, which was first proposed for the ESRF upgrade project [Farvacque et al. (2013)]. This design has 48 identical 7BAs, with a natural emittance of 59.4 pm.rad and a circumference of 1295.6 m [Jiao (2016)]. The main parameters of the ring are listed in Table 1 and the layout and optical functions of a single 7BA are shown in Fig. 1. Each 7BA is about 27 m, with a 6-m straight section for insertion devices (IDs). In each 7BA, high-gradient (up to 80 T/m) quadrupoles were located neighboring the inner three combined-function dipoles to achieve an ultralow emittance as well as a compact layout. Four outer dipoles with longitudinal gradients were used to create two dispersion bumps with all the sextupoles placed therein for an efficient chromatic correction. Totally six sextupoles were used in each 7BA and grouped in three families. Between each pair of sextupoles, a $-\boldsymbol{I}$ transportation, with phase advance at or close to $(2n+1)\pi$ (where n is an integer) in both the x and y planes, was designed to cancel most of the nonlinearities induced by sextupoles. A family of octupoles was also placed in the dispersion bumps and used to reduce the detuning terms. Among these multipoles, two sextupole families are used for chromaticity correction, with two free knobs left for nonlinear optimization. Through optimization of the multipole strengths, it was feasible to obtain an 'effective' momentum acceptance (MA) of ~3% and an 'effective' dynamic aperture (DA) of ~2.5 mm in x and ~3.5 mm in y plane. Different from the MA and DA defined in a conventional sense, the 'effective' DA and MA are defined so that within which not only the motions remain stable after tracking over a few thousand turns, but also the tune footprint is bounded by the integer resonances (IRs) and half integer resonances (HIRs) that are nearest to the working point. Such a definition allows a quick and reasonable estimation of the practical ring acceptance (the ring acceptance in the presence of machine imperfections) with only the bare lattice (see Sec. 2.2).

The small DA does not meet the requirement of off-axis injection. To solve this problem, we are considering on-axis longitudinal injection schemes, which will be introduced in Sec. 2.4. At the same time, based on the present main ring design with 48 identical hybrid 7BAs, we are exploring possible designs suitable for off-axis injection by replacing two nominal ID sections with high-beta sections dedicated to off-axis injection. To restore the lattice periodicity, the two 7BAs neighboring the high-beta section are designed to a $2n\pi$ transfer line, within which no sextupole will be used. In this way, the on-momentum DA for injection can be enlarged by the square root of the amplification of the beta function. Nevertheless, the $2n\pi$ phase advance does not hold any more for a nonzero momentum deviation. This leads to a reduced MA and difficulty in MA optimization. To solve this problem, the multipoles are grouped into more groups and re-optimized with stochastic methods. The optimization is under way.

We are now simultaneously considering three optional booster designs. One design shares the same tunnel as the main ring, with a basic lattice structure of 12BA. This design has a circumference slightly smaller than that of the main ring, and can promise an emittance of about 2 nm.rad at 6 GeV. The other two designs assume that the booster is located in a separate tunnel, with circumference of one third of that of the main ring. One design consists of four 15BAs, with combined-function dipoles with horizontally defocusing gradients and a natural emittance of about 4 nm.rad at 6 GeV. Another design is similar to the NSLS-II booster design [Kiselev (2014)], which uses mainly dipoles combined with focusing or defocusing gradients as well as the sextupole gradients, and predicts a natural