CONCEPT OF A NEW GENERATION SYNCHROTRON RADIATION FACILITY KEK LIGHT SOURCE

T. Honda[1†] for the KEK-LS design team
High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki, Japan
[1] also at SOKENDAI (The Graduate University for Advanced Studies), Tsukuba, Ibaraki, Japan

Abstract

A concept a 3-GeV quasi diffraction-limited synchrotron radiation source, KEK Light Source (KEK-LS), will be presented. The low emittance storage ring has been designed based on the Hybrid Multi-Bend Achromatic (HMBA) lattice, which was originally developed at the ESRF-EBS project [1]. We have modified it to insert a short straight section at the center of the unit cell. Five-meter in-vacuum undulator possibly produces the brightest SR at the soft to hard X-ray range. The short straight section will be used for installing a short undulator with sufficient x-ray brightness. The diffraction limit wavelength of the KEK-LS is around 0.5 keV, and a high coherent fraction is provided for the whole photon energy range from 100 eV to 15 keV.

INTRODUCTION

KEK has proposed a new SR facility based on 3-GeV extremely low emittance storage ring, KEK Light Source (KEK-LS) [2, 3, 4]. Principal parameters of the KEK-LS are summarized in Table 1.

The target of photon energy is assumed from 100 eV to 15 keV. A spatial resolution of 10 nm and an energy resolution of 10 meV will be aimed at the SR beamlines. As responding to the demands, a mid-size storage ring having a low emittance of the order of 0.1 nm rad has been designed applying a modified HMBA [1] lattice or a Double Quadruple Bend (DQBA) Achromatic lattice. The circumference of 570 m consists of twenty cells. Each cell can accommodate two undulator beamlines, and a bending beamline of the critical energy 4 keV is also available. The capacity to provide a variety of beamlines meeting the user's demand is essential as a successor of the two SR sources of KEK, PF-ring, and PF-AR.

Table 1: Principal Parameters of the KEK-LS

Energy	3 GeV	
Circumference	570.7 m	
No. of short straight section	20 (5.6 m)	
No. of long straight section	20 (1.2 m)	
No. of cells	20	
RF frequency	500.07 MHz	
Harmonic number	952	
Radiation loss per turn	0.298 MeV	
Momentum compaction	2.20 x 10^{-4}	
Betatron tune (ν_x, ν_y)	45.58, 17.62	
Damping time (x, y, z) [ms]	29.25, 38.28, 22.63	
Beam current [mA]	0	500
Horizontal emittance [nm rad]	0.13	0.31
Coupling [%]	-	2.6
Vertical emittance [pm rad]	-	8.2
Touschek lifetime [h]	-	1.8
Bunch length [ps]	9.1	11.1
Energy spread [x 10^{-4}]	6.42	8.22

There are many proposals for new generation light sources with an application of the MBA or HMBA. The extremely low emittance rings below 100 pm rad have been proposed as the APS upgrade [5] and the ALS upgrade [6] with an on-axis swap-out injection scheme. On the other hand, the KEK-LS is proposed as one of the world lowest emittance rings compatible with the conventional off-axis injection. We aimed to complete the development in a short period by keeping compatibility with the off-axis injection.

CONCEPTUAL DESIGN

Brightness and Coherent Fraction

The potential brightness of the KEK-LS estimated for several types of undulators listed in Table 2 is shown in Fig. 1. In the figure, the dashed lines show the brightness without considering the intra-beam scattering (IBS) effect and the solid lines considering the IBS effect. The vertical emittance is assumed to be 8 pm rad or 2.6% coupling for both cases. The maximum brightness almost approaches 10^{22} in the region of 1 keV to 10 keV.

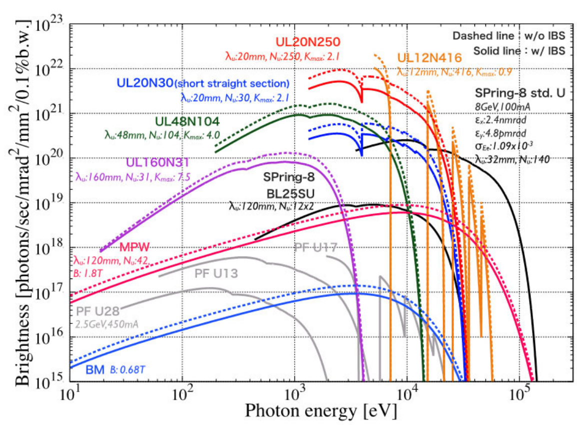

Figure 1: Brightness of undulators of KEK-LS.

The emittance growth due to the IBS effect halved the undulator brightness. The mitigation of the IBS effect is a key factor to optimize the brightness. The extension of the bunch length using harmonic cavity is thought to be es-

† tohru.honda@kek.jp

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sential. Application of cryogenic undulators (CPMU) or superconducting undulators (SCU) is under considering to improve the undulators brightness with saving the magnetic length.

High coherent fraction is a useful merit of the KEK-LS as shown in Fig. 2. The so-called diffraction limited photon energy for 0.31 nm rad is 0.32 keV. The coherent fraction at the diffraction limit was estimated to be 30 %. Even in the hard X-ray region, a fraction one-order higher than the existent 3rd generation ring is available.

Table 2: Undulator Parameters

	U12	U20S	U20L	U48	U160
Period (mm)	12	20	20	48	160
No. of Periods	416	30	250	104	31
Total Length (m)	5	0.6	5	5	5
Min. gap (mm)	4	4	4	12	12
K_{max}	0.9	2.1	2.1	4.0	7.5
Rad. Power (kW)	9.1	2.2	18.2	11.5	3.5

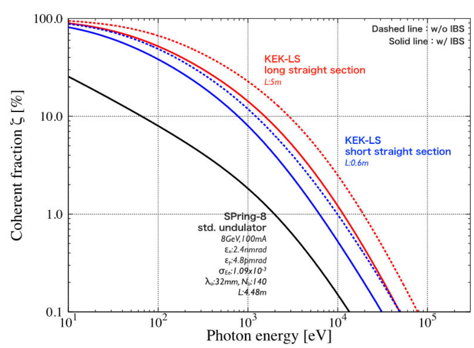

Figure 2: Coherent fraction of KEK-LS.

Lattice and Magnet System

The unit cell has been designed as a modified hybrid multi-bend achromatic (HMBA) lattice which can be called as double quadruple-bend achromat (DQBA). The HMBA lattice originally developed by the ESRF-EBS project [1] has flexibility in design, so we could modify the lattice without compromising its compatibility of a low emittance and a wide dynamic aperture [2].

The injection cell which broke the symmetry of the ring has been carefully designed and was successfully realize a sufficient horizontal aperture of about 15 mm with a high beta function. The efficient and stable off-axis injection would be expected.

The unit cell constitutes of eight bending magnets, four of them were longitudinal gradient bends (LGB), and the other four were combined bends as shown in Fig. 3. We are developing a 3D simulation of the LGB as shown in Fig. 4. The LGB fields ranging from 0.2 T to 0.3 T was produced by dividing into five steps in the prototype design.

Based on the maximum strength of the quadrupole magnet estimated as 60 T/m, the bore diameter of the quadrupole was determined at 30 mm. The strength of the sextupole magnets was suppressed at rather low value form 1200 T/m^2 to 1700 T/m^2, there was no difficulty to design at the same bore diameter.

The present version of DQBA lattice has a finite energy dispersion function, η, in the two straight sections. It was rather small as 25 mm or 20 mm, but the synchrotron radiation integral I_5 calculated by the ID field and the residual η had non-negligible contribution to the emittance growth. If we tried to apply a multi-pole wiggler (MPW) type device with high magnetic field, the emittance growth would be remarkable.

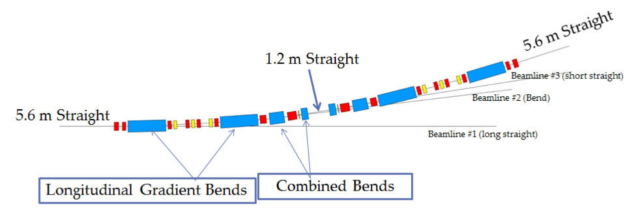

Figure 3: The layout of the DQBA unit cell.

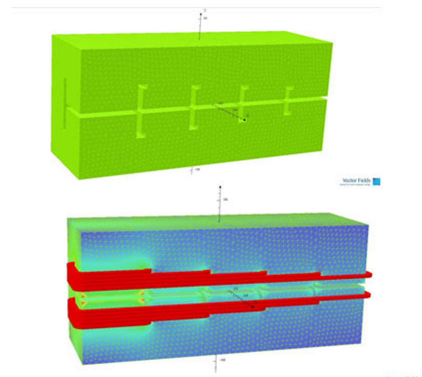

Figure 4: A prototype design of the longitudinal gradient bend for the 3D field simulation. The shape of the core and the coil design.

To solve this issue, we are making a perfect achromatic DQBA lattice [3]. At the same time, the length of the short straight section is tried to extend to 1.6 m to keep sufficient space for the transition components of the in-vacuum undulators. For the perfect achromatic lattice, the emittance is decreased by a radiation loss of IDs, and the MPW can work as a damping wiggler. We continue trying to find an optimized solution to achieve the highest undulator brightness.

RF System

The RF system has been planned based on a normal conducting (NC) cavity. The RF frequency was determined at 500.1 MHz same as the existent PF ring. A harmonic cavity system to expand the bunch length was thought to be essential from the early stage of the commissioning. The third harmonic cavity operated with the TM020 resonant mode [7] has been designed.

We confirmed that the partially damped cavity design of the PF ring was almost free from the coupled bunch instability, and was available for the KEK-LS with a care of a particular HOM mode. It could be a backup plan to minimize the development time and cost. The number of the RF cavities necessary for the KEK-LS is five. The existent model is too large to accommodate five cavities in a single straight section. We are going to develop a full damped cavity at a compact size.

The performance of the NC third harmonic cavity was studied [8, 9]. The TM020 cavity having high unloaded-Q and low R/Q was suitable for the third harmonic cavity and both the bunch lengthening performance and the transient beam loading effect was as good as those of the SC cavity.

Vacuum Pressure Simulation

According to the bore diameter of the Q magnet, the inner diameter of the beam path was assumed at 25 mm. The primary material of the beam duct was supposed to Cu-OFS (silver-bearing oxygen-free copper).

We simulated the improvement of the vacuum pressure during the accelerator commissioning on the assumption that the inner surface of the circular beam duct was fully coated by NEG (non-evaporable getter) films.

The gas yield of the photo-stimulated desorption of the NEG coating was deduced from our experiments conducted at the PF ring beamline collaborated with CERN. Two orders of lower yield than that of the non-coated OFHC surface was observed on the well activated NEG-coating.

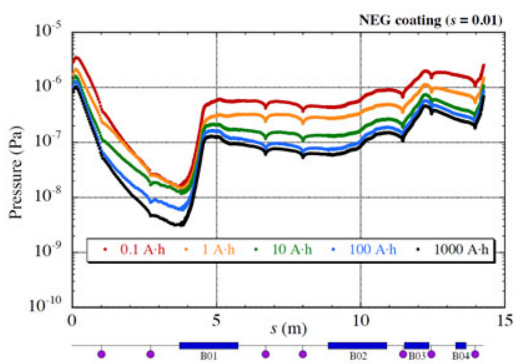

Figure 5: Vacuum pressure simulation for the KEK-LS using SynRad+ and MolFlow+ [10].

The vacuum pressure simulation using MolFlow+ with SynRad+ [10] are shown in Fig. 5. The initial pressure at a small integrated current of 0.1 Ah was sufficiently low; it would contribute facilitating a storage of high current. And it reached at the order of 10^{-7} Pa, the target pressure of the KEK-LS, in the integrated current 1000 Ah equivalent with the one-year operation. The pumping using the NEG coating was thought to be valid for the KEK-LS vacuum system with a limited conductance of the thin beam duct.

We deduced from the simulation that the gas load from the non-coated area possibly deteriorated the vacuum pressure even if it was only 10% of the total area. A simulation based on the detailed component design will be necessary to determine the vacuum pumping design.

Impedance Issues

The resistive wall impedance of the long narrow gap undulators as the U20L in the table 2 could cause a serious problem on the beam instability. The estimation of the longitudinal and the transverse impedance was conducted first [11]. The heating power due to the longitudinal impedance could cope with an efficient water cooling for magnets. The beam instability caused by the transverse impedance could be suppressed using the bunch-by-bunch feedback system even in the worst case that the long narrow gap undulators would be fully installed in all sections. The design study of the transverse feedback kicker has confirmed to generate a sufficient kick voltage to achieve the required damping time.

The resistive wall impedance of the NEG coating on the copper duct was evaluated [11]. As long as the thickness of the NEG coating kept the standard value of 1 µm, its influence to the longitudinal impedance was negligible. But attention should be paid to the steep increase of heating power when the thickness of the coating growth.

The heating power of the circular copper duct of 25 mm I.D. was estimated as 5 W/m. It would not become a problem, but the cooling of the beam duct should be considered.

SUMMARY

We have proposed a new generation synchrotron radiation source; KEK-LS. The highest brightness and the good coherent fraction will be provided for the VUV, soft and hard X-ray range. As the lattice design accomplished both the low emittance and the enough dynamic aperture, the KEK-LS would be realized with a short period development.

Though it should be paid attention to the impedance issue including the resistive wall impedance mainly caused by the narrow gap undulators, it would be controllable to satisfy the specification of the KEK-LS.

We are going to proceed the further optimization of the undulator brightness. The DQBA lattice is being improved to the perfectly achromatic version [3]. The design of the third harmonic cavity has been developed [8, 9] to achieve a sufficient mitigation the IBS effect.

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