# PRESENT STATUS OF KEK PHOTON FACTORY AND FUTURE PROJECT

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*Abstract*

Two synchrotron radiation sources of KEK, the PF-ring and the PF-AR, have continued operation for about thirty years. The Photon Factory (PF) has SR users more than 3000 working on about 800 experiment proposals a year. We just proposed a construction of a new SR facility tentatively named KEK light source (KEK-LS). An extremely low-emittance storage ring based on the hybrid multi-bend achromatic (HMBA) lattice has been devised as a successor of the aged two rings. An outline of the KEK-LS project will be described in this paper.

## PRESENT STAUTUS AND DEVELOPMENT OF PF-RING AND PF-AR

The 2.5-GeV PF-ring and the 6.5-GeV PF-AR are continuing their user operation with various improvements. Scrap and build of the first generation undulators of the 1980s at the PF-ring are pushed forward year by year. Five new elliptically polarized undulators have been installed in these five years.

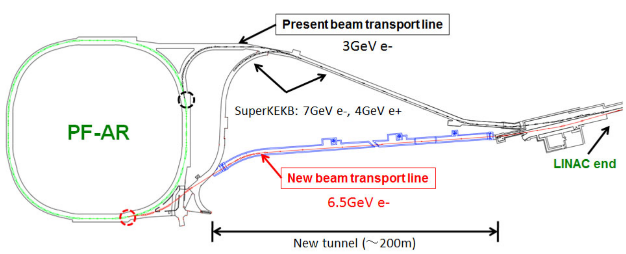


Figure 1. New full-energy beam transport line for PF-AR.

Installation of accelerator components for the new beam transport line (BT) for the PF-AR will start in this summer, and be completed by the end of 2016. The injection point for the storage ring will be moved and the pulse magnets using for the injection as kicker and septum magnets will be all replaced. After the 6.5-GeV full-energy injection for the PF-AR is realized, simultaneous top-up operations of the two SR sources and the continuous injection for the two main rings of the Super-KEKB will become possible. The Improvement of the PF-AR brings a profit on not only SR users but also on the Super-KEKB project, the physics run is planned to start from autumn 2017.

Operational statistics of the PF-ring and the PF-AR are shown in table 1 and table 2, respectively. The both rings keep stable operation with relatively long mean time between failures (MTBF) and a small failure rate about 1% or less. Unfortunately, the total operation time has the tendency to decrease in these several years. In the fiscal year 2014, it recorded the shortest hours without any major reconstruction work. The deficiencies in the budget and the remarkable rise of the electricity bill in Japan caused unfavorable circumstances.

Table 1: Operational statistics of the PF-ring

| Fiscal Year | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|
| Total operation time (h) | 4416 | 4176 | 3024 | 3888 |
| Scheduled user time (h) | 3792 | 3504 | 2317 | 3014 |
| Ratio of user time (%) | 85.9 | 83.9 | 76.6 | 77.5 |
| Number of failures | 23 | 22 | 15 | 23 |
| Total down time (h) | 37.6 | 52.1 | 11.4 | 14.4 |
| Failure rate (%) | 1.0 | 1.5 | 0.5 | 0.5 |
| MTBF (h) | 165 | 159 | 155 | 133 |
| Mean down time (h) | 1.6 | 2.4 | 0.8 | 0.6 |

Table 2: Operational statistics of the PF-AR

| Fiscal Year | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|
| Total operation time (h) | 4080 | 3912 | 2352 | 3336 |
| Scheduled user time (h) | 3672 | 3478 | 1992 | 2784 |
| Ratio of user time (%) | 90.0 | 88.9 | 88.9 | 83.5 |
| Number of failures | 33 | 47 | 22 | 18 |
| Total down time (h) | 29.7 | 99.6 | 37.0 | 31.0 |
| Failure rate (%) | 0.8 | 2.9 | 1.9 | 1.1 |
| MTBF (h) | 111 | 74 | 90 | 155 |
| Mean down time (h) | 0.9 | 2.1 | 1.7 | 1.7 |

## PROPOSAL OF KEK-LS PROJECT

We have made a proposal of constructing a new SR facility, tentatively called KEK light source (KEK-LS). An extremely low-emittance 3-GeV storage ring has been devised as the central facility of the KEK-LS, and it will replace both the PF-ring and PF-AR. The KEK-LS project is being discussed as the KEK's program implementation plan (PIP) aiming at the early realization.

The principal parameters of the KEK-LS are shown in Table 3. Most remarkable characteristic point of the KEK-LS is the low emittance as 0.13 nm rad realized by a

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compact size storage ring of a 570-m circumference. It is the natural horizontal emittance without considering any intra-beam scattering (IBS).

The KEK-LS has been designed based on the hybrid multi-bend achromatic (HMBA) lattice[1] originally devised at ESRF for their upgrade project of the 6-GeV storage ring[2]. They successfully realized 0.15 nm rad with 32 cells of the HMBA lattice keeping the configuration of the existing facility.

In our case for constructing a new 3 GeV ring, we started the design from 20 cells of the HMBA lattice. Not only the long straight sections of 5.6 m long, but also the short straight sections of 1.2 m long are prepared for undulator installation. The short section was inserted in the center of the unit cell by dividing the combined-functioned bending magnet into two pieces. So eight bending magnets consist the unit cell, it is a difference from the original seven bend achromat configuration of the ESRF upgrade.

Table 3: Principal parameters of KEK-LS

| | | |
|---|---|---|
| Energy | 3 GeV | |
| Circumference | 570 m | |
| No. long straight sections | 20 (1.2 m) | |
| No. short straight sections | 20 (5.6 m) | |
| No. of cells | 20 | |
| RF frequency | 500.1 MHz | |
| Harmonic number | 952 | |
| Radiation loss | 0.30 MeV/turn | |
| Betatron tune ($\nu_x$, $\nu_y$) | 45.58, 17.62 | |
| Damping time (x, y, z) [ms] | 29.25, 38.28, 22.63 | |
| Beam current [mA] | 0 | 500 |
| Hor. 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 |

We investigated how the emittance change depending on the number of cells and tried to design more compact ring with a smaller number of cells. We confirmed that a 16-cell version was feasible as the 3-GeV ring at a slightly inferior in the natural emittance of about 0.35 nm rad and the circumference of 440 m. Consequently, the 20-cell version was selected regarding the smallest emittance as the most important characteristic.

In Figure 2, it is shown the comparison of the world's low-emittance SR sources from the third generation to the latest MBA rings. The horizontal axis is the square of the energy divided by the cube of the circumference. The low-emittance rings are grouped by the lattice type in the drawing, and it is clear that the HMBA lattice can realize an extremely low emittance without the circumference goes too large. Figure 3 is a tentative bird's eye view drawing of the KEK-LS facility.

The maximum stored current is planned to be 500 mA, and the horizontal emittance affected by the IBS is estimated to be 0.31 nm rad when the 2.6% coupling is assumed.

Another characteristic point of the HMBA lattice is an ingenious device to keep a dynamic aperture. In the KEK-LS, the dedicated cell with a large horizontal beta function is prepared for the injection. The conventional injection scheme can be applied, and the stable top-up operation can be expected against to the relatively short Touschek lifetime.

The radiation loss of 0.3 MeV/turn is much smaller than that of 2.5 GeV PF-ring, 0.4 MeV/turn. The magnetic bore will be less than half of the PF-ring as mentioned later. Though the radiation loss of each undulator can be large as shown in Table 4, we estimated the electricity consumption of the KEK-LS is almost equal to the PF-ring.

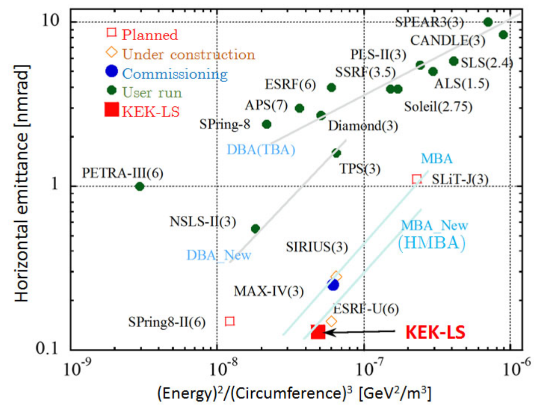


Figure 2. Comparison of the world's SR sources.

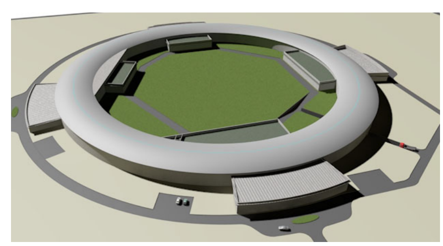

Figure 3. Bird's eye view of KEK-LS (tentative).

**Undulator brightness and coherent fraction**

The potential brightness of the KEK-LS estimated for several types of undulators listed in Table 3 is shown in Fig. 4. In the figure, the dashed lines show the brightness for the case without considering IBS effect and the solid lines considering the IBS effect. The vertical emittance is assumed to be 8 pm rad for both cases.

The undulator brightness almost approaches $10^{22}$ or exceeds $10^{22}$ in the soft X-ray to hard X-ray region of 1 keV to 10 keV. It is higher by two orders of magnitude than those of present 3rd generation light sources and by four orders from the PF-ring.

The emittance growth affected by the IBS can be suppressed with bunch lengthening using the higher harmonic cavity. The design of effective higher harmonic cavity and the suppression of emittance growth must be substantial subjects to make the best use of the low emittance of the HMBA lattice.

In Fig. 5, the coherent fraction of the KEK-LS was calculated for both assuming the undulators of the long and the short straight section. It is more than an order of magnitude larger than that of the typical third generation ring. The so-called diffraction limited photon energy for 0.13 nm rad is 0.78 keV. The coherent fraction of the long undulator at the diffraction limited energy is estimated to be about 25%.

### Magnet

For the strong focus to achieve the low emittance, the maximum field gradient of the quadrupoles is twice larger than the PF-ring and is estimated to be 50 T/m. To avoid the magnetic saturation in the cores, the bore diameter of quadrupole magnets is determined to be 3 cm.

The unit cell contains eight bending magnets, four of them are the longitudinal gradient bends and four of them are the transverse gradient or the combined-function bends. The mechanical design of these magnets are under consideration. The linear tapered configuration instead of the stepwise shape was proposed to realize the longitudinal gradient bend. The magnetic calculation in preparation for the trial manufacturing is underway.

### RF system

Normal conducting RF cavities of the frequency 500.1 MHz are assumed to be used. The number of RF cavities necessary for the KEK-LS under the full installation of undulators is four, and the total RF voltage is estimated to be 2 MV. To carefully avoid the coupled-bunch instability caused by the HOM is the substantial subject to design the RF cavities. The higher harmonic cavity is planned to be introduced for the improvement of the lifetime, brightness and the beam stability.

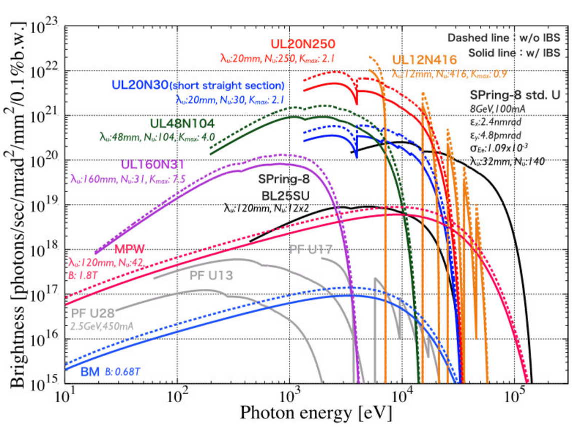


Figure 4. Brightness of undulators under consideration.

### Vacuum system

The vacuum system is required to deal with the concentrated SR power and to overcome small conductance because the diameter of beam duct is limited by the small magnetic bore. The effects of the impedance of the narrow vacuum components have to be carefully taken into consideration.

The space for the lumped vacuum pumps is limited in the normal cells, so the extensive installation of distributed pumping system is indispensable. The application of the NEG (non-evaporable getter) coating is under consideration.

Table 4: Undulator parameters prepared for calculation of the brightness

| | 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 |

### Beam Instrumentation

With the longer damping time and smaller revolution frequency, the beam instability suppression becomes a serious subject. In addition to the suppression of the impedance and HOM, it is estimated that the bunch by bunch feedback system is indispensable.

Typical electron beam sizes are 50 μm for the horizontal direction and 5 μm for the vertical. To secure the beam position stability, local mechanical vibration sources with higher frequency (e.g. air conditioner, vacuum or water pumps, chillers…) should be carefully isolated from the storage ring and beamlines. The magnetic girders which do not amplify the ground oscillation are essential. The fast and precise beam orbit feedback systems are also required.

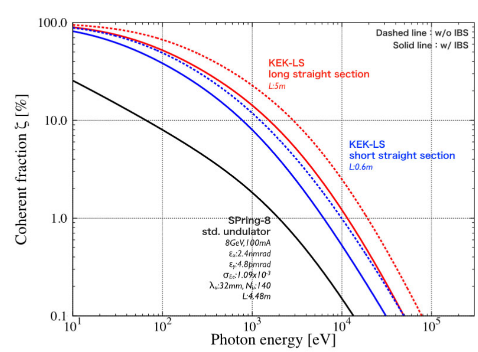


Figure 5. Coherent fraction of KEK-LS.

## SUMMARY

The Photon Factory has proposed the KEK-LS project with constructing the 3-GeV, 0.13-nm rad storage ring. The storage ring was designed based on the HMBA lattice and has the enough dynamic aperture enabling the conventional injection scheme. The potential brightness and the coherent fraction of the undulators are estimated to be at the highest level compared with the existing SR sources.

## REFERENCES

[1] K. Harada et al., "The HMBA lattice optimization for the new 3 GeV light source", in these proceedings, THPMB012.

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