SPring-8 Beam Performance

Development and Upgrades of the Storage Ring

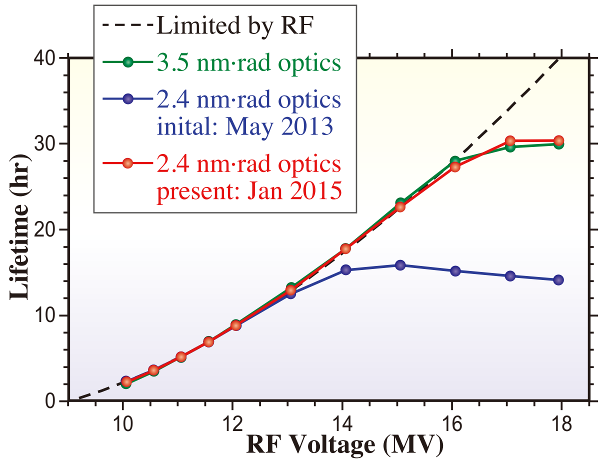

Fig. 1. Touschek lifetime as a function of RF accelerating voltage.

Improvement of Beam Lifetime by Adjusting Sextupole Magnets

At the present light source facilities, the top-up operation, where the electron beam is injected during user experiments to keep the stored current constant, is indispensable for precise experiments. Although the beam lifetime is no longer a critical issue for the present light sources due to the top-up operation, it is still important for radiation safety to extend the beam lifetime or to suppress the beam loss. The Touschek effect, which is the beam loss driven by the momentum change through the collision in the electron bunch, dominates the beam lifetime in the high brilliance light source ring. Since a scattered electron with large momentum deviation at a dispersive section starts to oscillate transversely, the momentum acceptance is restricted by the dynamic or physical acceptance as well as the RF acceptance [1-4]. To prevent the insertion devices, especially the in-vacuum undulators, from demagnetization, the reduction of the electron loss is crucial. Furthermore, when the top-up operation is halted due to a machine trouble in the injection, the long beam lifetime is effective in suppressing the rapid decrease of the stored current.

In May 2013, the emittance of the SPring-8 storage ring was improved from 3.5 to 2.4 nm·rad by changing the ring optics. At the same time, the momentum acceptance decreased from 3.2 to 2.4%, which led to the reduction in the Touschek beam lifetime by half. Figure 1 shows the measured Touschek lifetime as a function of the RF accelerating voltage. The dashed line represents the estimated Touschek lifetime under the assumption that the lifetime is limited only by the longitudinal momentum acceptance, i.e., the RF bucket height. For easy comparison of the momentum acceptance, the lifetime is normalized by the bunch volume. The measured lifetime is saturated above some RF accelerating voltage where the transverse dynamics rather than the RF bucket height determines the lifetime. In order to enlarge the momentum acceptance, we optimized the dispersion and the dynamic aperture by using sextupole magnets. As a result, the Touschek lifetime has been improved up to the previous level with larger emittance as shown in Fig. 1.

Development of a Ceramic Chamber Integrated with Pulsed Magnet

We are pushing forward the development of an air-core coil pulsed magnet that has an integrated structure of magnet coils with a ceramic vacuum chamber, aiming to reduce the gap size.

With a small gap, we can increase the magnetic field on the beam orbit. As a result of the increased magnetic field, the magnet length becomes shorter while keeping the kick angle the same. A narrow gap magnet reduces the coil inductance and, hence, the pulsed power supply load. As a result, a short pulse width with a high-repetition pulse is much more easily achievable while realizing the necessary kick angle.

In the structure we are developing, single-turn air-core coils are implanted along the longitudinal axis in the cylindrical 5-mm-thick ceramic chamber wall.

There are two technical advantages of applying this structure. The first is that the all-in-one structure makes the system simpler; three functionalities are included by implanting the coil in the ceramic chamber wall: (i) vacuum separation, (ii) the coils are held mechanically, and (iii) electrical insulation of the coils from the vacuum chamber. With this structure, magnet pole edges can be set close to the inner diameter of the chamber. Looking from the inside of the ceramic chamber, the pole edges are placed on the inside surface of the chamber and not bulge inward from the inner surface. Therefore, the pole edges are located close to the beam without disturbing the beam impedance.

The second is that the air-core coils are arranged around the circle on the inside surface of the ceramic to optimize the magnetic field strength and uniformity. There is no structural restriction in the arrangements of the coils or any complex coil-supporting structure. As a whole, a pulsed magnet will be built with an extremely simple component that does not bulge on the inside or toward the outside of the ceramic chamber.

The key technology in this magnet development is to implant the coil into the ceramic with a varying thermal expansion rate along the longitudinal axis. The development started with an implanting technique for the magnet coil in the ceramic chamber wall in 2012. A dipole-type prototype pulsed magnet was successfully manufactured with a bore radius of 30 mm and a magnetic length of 0.3 m in 2013 (Fig. 2). Figure 3 shows the aging setup with the vacuum pump and pulsed power supply. Continuous operation over 200 days from 2013 to 2014 was achieved without any failure under the condition of current excitation with a 20 kV/7.7 kA pulse with a 4 μsec width and a repetition of 1 Hz in a thermal cycle ranging from 30°C to 80°C, by using the dipole prototype, while maintaining the vacuum degree better than 10^{-6} Pa. The measured magnetic field strength and uniformity agreed with calculation results within 1%.

We are continuing the development to make the magnet installable in a storage ring as an accelerator device as the next step. The problem to be solved for the next step is to develop an inner coating to enable the flow of the wall current induced by the electron beam, which is necessary for matching the chamber impedance in order to avoid instabilities. The coating of the inside surface of the ceramic chamber should be the 2–3-μm-thick metal layer around the coil while maintaining the electrical insulation between the coils and metal layer. This technique will be expanded to multipole pulsed magnets, such as quadrupole or sextupole pulsed magnets and/or small radius pulsed magnets whose radius is 10 mm or smaller.

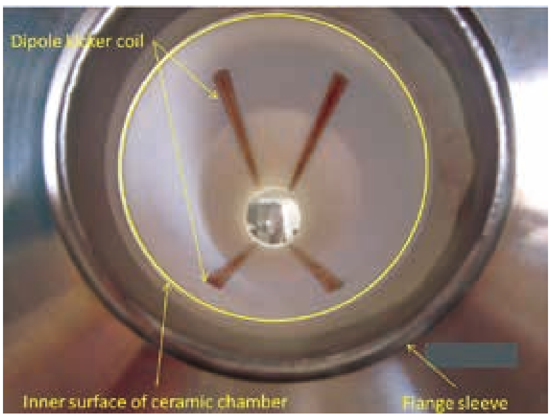

Fig. 2. Inside surface of the ceramic chamber in the dipole-type prototype magnet.

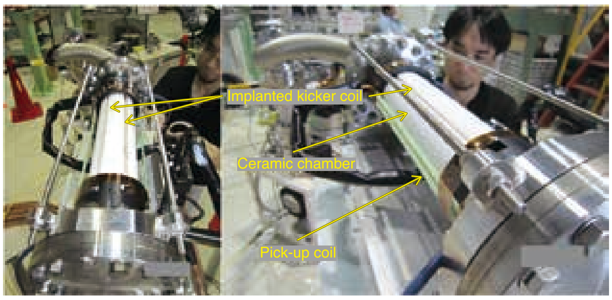

Fig. 3. Aging setup with vacuum pump and pulsed power supply.

New Magnet Alignment System Using Laser and Iris Diaphragms

The magnets on the common girders of the storage ring have a very tight alignment tolerance. For SPring-8, it is 50 μm in the beam transverse directions, while for SPring-8-II, which is at the planning stage, it will be 25 μm. To align these magnets, we have used a laser CCD-camera system and obtained reasonably good alignment results. The only shortcoming of the old system is the time-consuming measurement because great care must be taken when setting the camera's position to obtain good reproducibility at each measurement point. This alignment system should be replaced with a new one capable of high precision and high speed.

A new system that uses a laser and irises has been developed as shown schematically in Fig. 4. The system utilizes the Fraunhofer diffraction of a circular aperture (iris), known as an Airy pattern, and measures the distance between the centers of iris images to determine the distance between two irises.

The new laser alignment system is considered to solve the problem of camera setting and uses iris diaphragms as the targets [5]. At the point of measurement, the diaphragm closes to its minimum caliber, and then opens to its maximum caliber after measurement to let the laser beam pass.

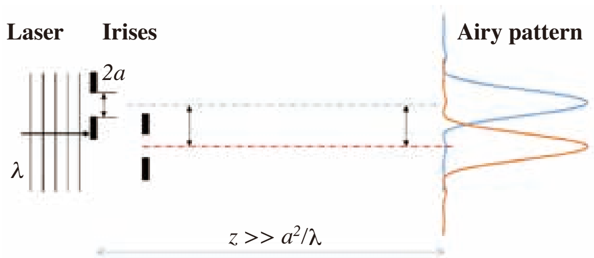

Fig. 4. Principle of the laser and iris alignment system.

We previously attempted a laser-iris system in 2006, as part of the SCSS (SPring-8 Compact SASE Source) project. In the previous system, a laser beam was introduced into the vacuum chamber. Retractable irises, having fixed apertures from 2 to 5 mm, were inserted into the chamber with compressed air cylinders and were used to measure the positions of the BPMs in sequence along the beamline. For this system, it is important to have good reproducibility of the iris center. Although the initial reproducibility achieved was better than 1 μm, the reproducibility gradually became worse due to friction and impact between the iris and BPM bodies.

The new system for the storage ring uses iris diaphragms as the targets. Commercial iris diaphragms were tested but did not meet the precision requirement. They usually have central reproducibility of a few micrometers, which is insufficient for our requirement. Therefore, we have developed a new diaphragm (Fig. 5). This device consists of 11 blades, a base plate, centering balls and an actuating ring driven with a gear. The rotation parts are very precise and smooth. The device has variable calibers from 1-12 mmϕ. The reproducibility of the diaphragm center was measured to be under ±1 μm in 100 trials. The iris diaphragms are used at 1-2 mmϕ calibers depending on the distance from the camera and are opened and closed with a remote controller.

The new laser alignment system is composed of a laser source, a CCD camera and four diaphragm targets (Fig. 6). The two end diaphragms are set on the reference points of a girder, and the two inner diaphragms are placed on the magnets in measurement. The total length of the design is 10 m.

The laser head consists of a 3.5 mW fiber-coupled diode laser of 0.635 μm wavelength, a collimator and a 6× beam expander. The output laser beam has a 5 mm diameter, which is adjusted to cover a 10 m measurement range. For an alignment tool, pointing stability of the laser is essential. The pointing stability was tested and found to be under ±2 μm (σ) in 8 m when the cooling water and air conditioner were stopped.

A Redlake Megaplus II ES4020 CCD camera is used. It has a small pixel size of 7.4×7.4 μm^2 and a large sensor size of 15×15 mm^2 with 2048×2048 pixel resolution. Images of 8 Mb are acquired at a frame rate of 15 fps through a CameraLink interface. For each frame, pixel values are summed in rows or columns to obtain one-dimensional intensity distributions of x and y. The centroid of an Airy disk is calculated at a clip level of above 13.5%. The camera system was verified to have a resolution better than 1 μm using a precise automatic stage.

The performance of the new laser alignment system was examined by 10 repeated measurements of the magnet positions on a common girder. It was verified that the system has a measurement uncertainty of ±10 μm (2σ) in a 8 m range, which even meets the requirement for the future accelerator of SPring-8-II.

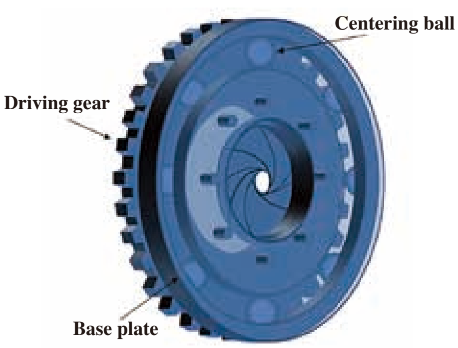

Fig. 5. Schematic of developed iris diaphragm.

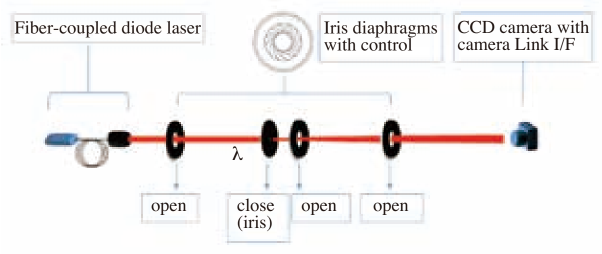

Fig. 6. Schematic of the iris diaphragm laser alignment system.

S. Goto*, M. Takao, C. Mitsuda and C. Zhang

SPring-8/JASRI

*E-mail: sgoto@spring8.or.jp

References

[1] M. Takao *et al*.: Proc. EPAC00 (2000) p. 1569.
[2] M. Takao *et al*.: Proc. 13th Symposium on Accelerator Science and Technology (2001) p. 316.
[3] H. Tanaka *et al*.: Proc. EPAC02 (2002) p. 1305.
[4] M. Takao *et al*.: Proc. 3nd Annual Meeting of Particle Accelerator Society of Japan and 31st Linear Accelerator Meeting in Japan) (2006), 898 (FP53).
[5] C. Zhang and S. Matsui: Proc. IWAA2012, Fermilab, USA (2012).