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In-vacuum undulators of SPring-8

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Most of the SPring-8 insertion devices are in-vacuum undulators except for the soft X-ray devices and one elliptical wiggler. The standard-type SPring-8 in-vacuum undulator has a period of 32 mm and a minimum gap of 8 mm. The fundamental radiation energy ranges from 5.2 to 18.5 keV. Three standard in-vacuum undulators are already installed in the ring and are operating without any problems. The magnetic field correction, the vacuum system and the commissioning of the in-vacuum undulators are described in this paper.

Keywords: undulators; in-vacuum undulators; ultra-high vacuum.

1. Introduction

The main advantage of in-vacuum devices is that the gap size can be reduced unless the beam is perturbed. Therefore, a short magnetic period can be achieved using small-size magnet blocks, resulting in high-energy fundamental radiation (Kitamura, 1995). On the other hand, the undulator components must be designed carefully to attain an ultra-high vacuum ($\sim 10^{-9}$ Pa) and to minimize disturbance of the beam.

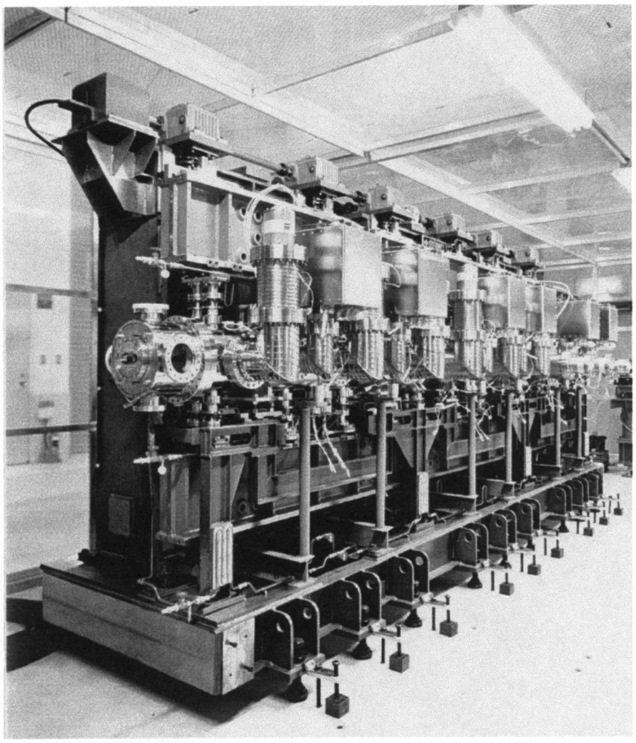

Figure 1
The standard SPring-8 in-vacuum undulator.

Table 1
Main parameters of the standard-type SPring-8 in-vacuum undulator.

Type	Pure permanent-magnet device
Length	4.5 m
Number of periods	140
Period length	32 mm
Minimum gap	8 mm
K_{max}	2.3

A photograph of a standard SPring-8 in-vacuum undulator is shown in Fig. 1 with a schematic cross section given in Fig. 2. In order to reduce the resistive wall impedance, the magnet surface is covered with a Cu-coated (10 μm) Ni (50 μm) sheet, and RF fingers are connected between the ends of the magnet arrays and the neighboring vacuum duct. The magnets and RF fingers are cooled by water during ring operation since they are almost thermally isolated in the vacuum (Hara *et al.*, 1998).

The main parameters of the standard-type SPring-8 in-vacuum undulator are given in Table 1. Each 4.5 m-long undulator consists of three 1.5 m segments. The mechanics, vacuum chambers and pumps of the in-vacuum undulators are all standardized for easy maintenance.

2. Magnetic field and end correction

As shims cannot be used for the in-vacuum undulators because of its rugged surface, small magnet chips are inserted into the back of the magnet holders for the field correction. Using this method, the residual first-field-integral variation with the undulator gap is

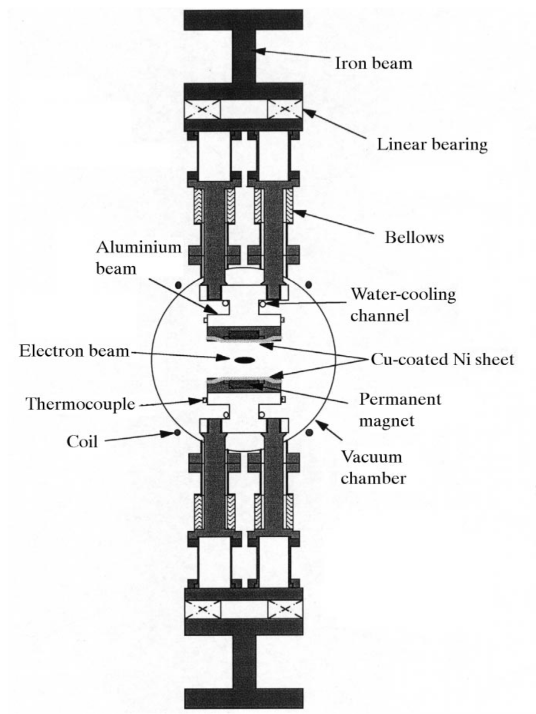

Figure 2
Cross section of the standard SPring-8 in-vacuum undulator.

corrected to within 100 G cm. The typical r.m.s. phase error (Walker, 1993) for an 8 mm gap is about 7°.

Many ideas and methods have been proposed to cancel the end effects of the undulator (Schlueter, 1994). For the standard SPring-8 in-vacuum undulators (pure-magnet type), the entrance and exit magnets are terminated by the configuration shown in Fig. 3. In addition to the end half-poles, other longitudinally magnetized blocks are installed at a separation of half a period. The size of the last magnet block (*d* in Fig. 3) is optimized so that the electron beam wiggles with respect to the undulator center. Hence the average electron-orbit displacement inside the undulator is zero, and the emitted photons are directed accurately to the beamline.

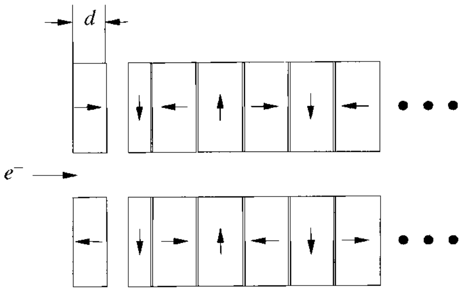

Figure 3
The configuration of the end-correction magnets for the SPring-8 in-vacuum undulators

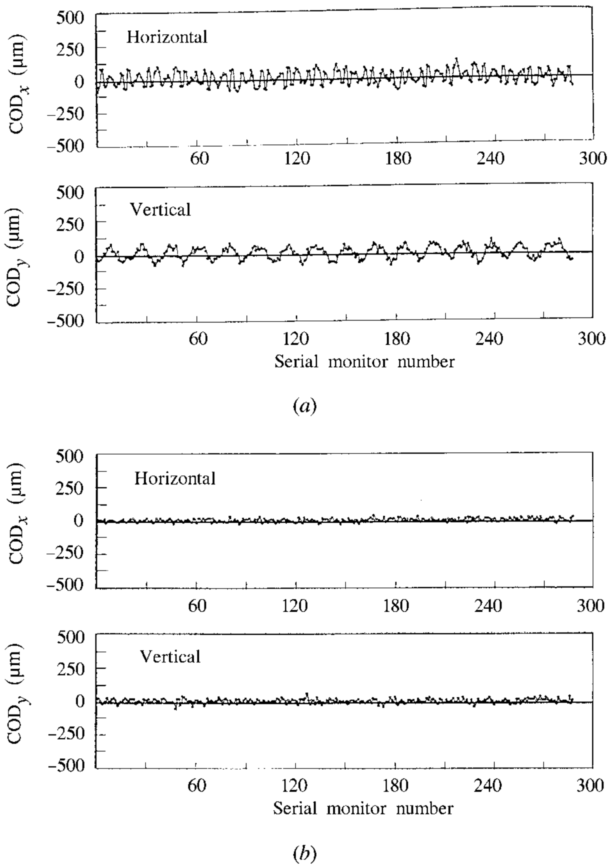

Figure 4
The horizontal and vertical beam-orbit displacement measured by 300 monitors around the ring; (*a*) without long-coil correction and (*b*) with long-coil correction.

3. The vacuum system

Six ion pumps (125 l s^{-1} × 6) and twelve NEG pumps (500 l s^{-1} × 12) are used in a standard-type SPring-8 in-vacuum undulator. The magnets are clamped mechanically in the holders and no glue is used. The surfaces of the magnet blocks are coated with 5 μm TiN to prevent outgas and oxidation.

Since the in-vacuum undulator is part of the storage ring, an ultra-high vacuum (~10^{-9} Pa) should be attained inside the undulator chamber. For this, bake-out is indispensable. However, special attention should be paid to the irreversible demagnetization of the undulator magnets at high temperature. At SPring-8, NdFeB magnets (NEOMAX-33UH, Sumitomo Special Metal Co.) are used. SmCo magnets have better characteristics at high temperature, but they are not strong enough for the mechanical clamp. The magnet and vacuum-chamber temperatures are controlled independently by cooling the magnets to 403 K with pressurized hot water, whereas the SUS (stainless steel) vacuum chamber is heated to around 473 K. All the magnets are prebaked at 418 K before installation into the undulator, and thus flux loss during bake-out can be avoided.

4. Commissioning of the in-vacuum undulators

The commissioning of three standard-type in-vacuum undulators has been completed at SPring-8 with a beam current up to 20 mA (500 bunches). The variation of the integrated field error with the undulator gap is canceled by long coils surrounding the undulator chamber. Fig. 4(*a*) shows the beam-orbit displacement without

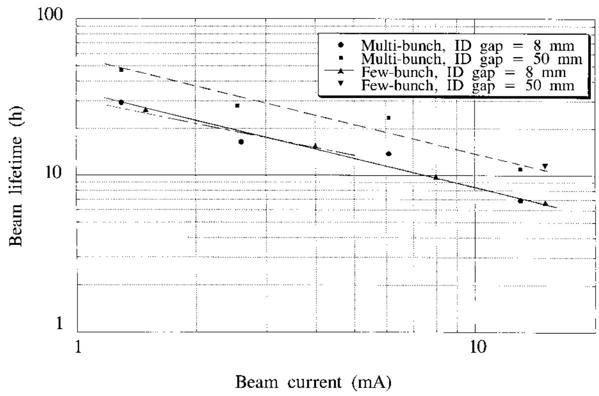

Figure 5
The beam lifetime change caused by the undulator gap.

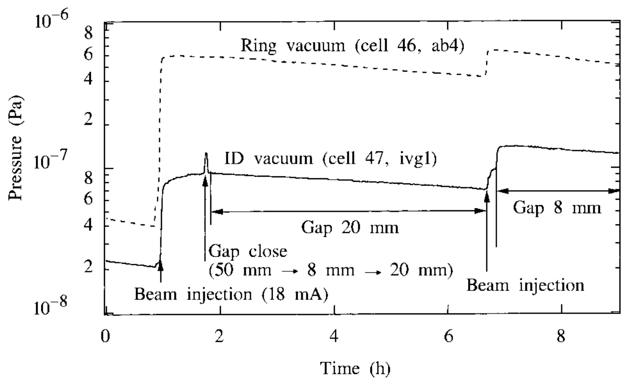

Figure 6
The undulator vacuum (ivg1) and the neighboring ring vacuum (ab4).

the long-coil correction when closing the undulator gap from 50 to 8 mm. The oscillation at the betatron frequency is clearly shown in Fig. 4(*a*). After the long-coil correction, such oscillations disappear and the beam displacement reduces to within the monitor resolution (Fig. 4*b*). The photon-beam position is measured by X-ray BPMs (beam-position monitors), and its displacement is corrected to within 10% of the beam size (Kitamura, 1998).

The lifetime degradation resulting from the small undulator gap is shown in Fig. 5. When the gap is closed to the minimum gap (8 mm), the lifetime decreases to two thirds of the initial value. However, this is due to the scattered electrons hitting the minimum aperture of the ring, *i.e.* the undulator gap, so it is not a cumulative effect with the number of undulators.

Fig. 6 compares the undulator vacuum (ivg1) and the neighboring ring vacuum (ab4). During the gap movement, the undulator vacuum goes up momentarily, but there is no problem concerning the vacuum.

The temperatures of the magnets and the RF fingers have been measured, but no temperature rise was observed with a beam current less than 20 mA.

5. Summary

Three standard-type SPring-8 in-vacuum undulators have been completed and installed in the ring. They are now in operation, and no serious problems have been encountered so far.

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