In-Vacuum Undulator Developed in Japan

Highly efficient production of the world's greatest synchrotron radiation

Achievements

- Realization of the world’s first in-vacuum undulator* to produce high-brilliance synchrotron radiation at SPring-8
- Production and export of in-vacuum undulators to countries including the United States, Australia, Switzerland, and Korea
- Application of in-vacuum undulators to the X-ray free electron laser (XFEL)**, an extremely intense new light, and successful oscillation of an X-ray laser at SACLA

R&D facility: RIKEN and others

*In-vacuum undulator: Synchrotron radiation is generated when an electron beam traveling nearly at the speed of light is bent using a magnet. This is achieved using an undulator. Magnets are placed outside the vacuum tank in conventional undulators. In contrast, magnets are placed inside the vacuum tank in in-vacuum undulators, enabling us to place the magnets closer to the electron beam to apply high-intensity magnetic fields. It is thus possible to generate high-brilliance X-rays in a highly efficient way.

**X-ray free electron laser (XFEL): A new laser in the X-ray region produced artificially. An accelerated high-quality electron beam injected into an in-vacuum undulator generates X-rays, and the interaction between the X-rays and the electrons in the in-vacuum undulator produces the XFEL. The XFEL is a billion times brighter than the X-rays of SPring-8 in specific ranges of wavelength. More detailed structures of materials, for example, the structures of proteins will hopefully be observed.

Mechanism of in-vacuum undulator

An electron beam is introduced between two rows of magnets, with the appearance of a harmonica, whose N and S poles are alternately aligned. The electron beam traveling in the magnetic fields periodically meanders, and synchrotron radiation is generated each time the beam direction changes. A high-brilliance light with a specific wavelength is produced by making the synchrotron radiations thus generated interfere with themselves.

Undulator for XFEL (Vacuum tank removed)

In-vacuum undulators manufactured in Japan have been exported since around 2000. Some undulators around the world have also been developed whose designs were based on these Japanese models.

Results

However, we had to wait for cutting-edge technology to be developed, such as the realization of a high degree of vacuum and a means of preventing the dissipation of magnetic forces, to put in-vacuum undulators into practice. A pilot in-vacuum undulator was developed at the High Energy Physics Laboratory (currently, High Energy Accelerator Research Organization) in Tsukuba, Ibaraki, in 1990. A full-scale in-vacuum modulator was also introduced at SPring-8, which has equipment for generating the world’s highest-level X-rays with short wavelengths and high brilliance. Currently, 27 undulators are running at SPring-8. One of these undulators is 25 m long, making it the world’s largest undulator, although most of them are 4.5 m long. In-vacuum undulators have also started to be used in medium-sized synchrotron radiation facilities because of their capability to generate X-rays even at low electron energy.

Japanese in-vacuum undulators playing active roles around the world

Undulators must be designed to have a short period length of a series of magnets to obtain short-wavelength high-brilliance X-rays. It is also necessary to narrow the vertical gap between magnets to achieve the magnetic field required. However, narrowing the vertical gap in conventional undulators is difficult because the vacuum tank is placed between magnets. In-vacuum undulators were developed to solve this problem. It is possible to narrow the vertical gap to as short as possible unless the electron beam is blocked, because a line of magnets is placed inside the vacuum tank in in-vacuum undulators.