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Operational evaluation of ultrahigh-vacuum protection systems for intense-photon-flux wiggler beamlines

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The ultrahigh-vacuum (UHV) protection system at the 2.5 GeV synchrotron radiation source (positron storage ring) at the Photon Factory allows the intense-photon-flux wiggler beamlines to operate safely during synchrotron radiation experiments for a long time. There are six high-power wiggler/undulator beamlines that provide intense photon-flux beams to the experimental hall. In the case of a possible instantaneous vacuum failure at the experimental hall, the intense photon-flux radiation from the wiggler could cause a meltdown of the titanium-alloy fast-closing valve. The authors have developed a UHV protection system. Upon a vacuum failure, the protection system can dump the positron beam by turning off the RF power in the four RF klystrons (150 kW maximum), and then initiate a blade closure of the fast-closing valve. In this paper, the operational performance of the vacuum protection system for the intense-photon-flux wiggler beamlines is evaluated and discussed regarding the actual vacuum deterioration downstream of a beamline at the experimental hall.

Keywords: ultrahigh-vacuum protection systems; wigglers; undulators; fast-closing valves.

1. Introduction

There are six high-power wiggler/undulator beamlines (BL-2, BL-13, BL-14, BL-16, BL-19 and BL-28) and 16 normal bending-magnet beamlines installed around the 2.5 GeV positron storage ring at the Photon Factory at the High Energy Accelerator Research Organization (KEK). The six high-power wiggler/undulator beamlines are simultaneously in operation, producing very intense synchrotron radiation beams. The high-power beamlines are distributed along the long circumference of the storage ring. These beamlines feed synchrotron radiation to the experimental hall where experiments such as surface physics, X-ray lithography, microscopy and crystal structure analyses are simultaneously carried out.

The pressures in the storage ring and the beamlines are maintained at a UHV of less than 10^{-10} torr. However, there have been some vacuum failures downstream of the VUV (vacuum ultraviolet) branch lines (Kanaya, 1993). The vacuum failures have been caused by a rupture of an experimental vacuum chamber or vacuum components, resulting in an instantaneous gas leakage upstream of the beamline. Such a failure could result in fatal damage to the components of the storage ring, including the vacuum chambers, beam-position monitors, pressure gauges and the doughnut.

In order to protect the UHV of the storage ring against an instantaneous vacuum failure, fast-closing-valve systems (FCV) (Kanaya *et al.*, 1989) have been installed in the wiggler/undulator beamlines as well as in the normal bending-magnet beamlines. The FCV system can close a guillotine blade (1.2 mm-thick titanium alloy) in $\sim$0.01 s.

On the other hand, however, the FCV cannot protect the storage ring vacuum for the wiggler/undulator beamlines, since the wiggler/undulator can produce synchrotron radiation with a high power density, two orders of magnitude higher than that obtained with a bending-magnet source (Kanaya *et al.*, 1990; Kitamura, 1993; Avery, 1984; Brown *et al.*, 1983). For example, a wiggler at beamline BL-16 has a maximum power density of 8.26 kW cm^{-2} of the wiggler radiation at a beam current of 500 mA for the FCV blade located 10 m from the source point. At such a high-power wiggler beamline, the impingement of an intense photon flux on the closing blade of the FCV causes a meltdown within 0.1 s after exposing the blade to the radiation. There has been no protection system that allows many high-power wiggler/undulator beamlines simultaneously to protect the UHV of the synchrotron radiation source from an instantaneous fatal vacuum failure. To avoid such a case, the authors have built a dedicated vacuum protection system for the high-power wiggler/undulator beamlines. In this paper, the operational performance of the UHV protection system for such high-power wiggler/undulator beamlines is evaluated with respect to the actual vacuum deterioration.

2. System description

Fig. 1 shows a schematic diagram of the UHV protection system. In order to ensure that the blade can avoid intercepting intense radiation, the protection system allows any high-power beamline to instantaneously turn off the beam upon detecting a vacuum failure by switching off the RF power in the four remote RF cavities. In the storage ring there are four RF stations for beam acceleration, each of which consists of a klystron (500 MHz, 180 kW maximum), a single-cell cavity, and low-level electronics. Each beamline is controlled by the beamline control system, which is a distributed computer control system using micro-computers and an optical fibre network (Kanaya, 1984). The beamline has an FCV and a vacuum detector, which are inter-connected to the beamline control system.

The FCV has a thin guillotine blade made of titanium. The closing time of the FCV is 11 ms. Each beamline control system is connected to four RF klystrons using a high-speed optical transmitter and receiver with a transmission rate of 76 Mbit s^{-1}. The length of each optical fibre link is 250 m. The pressure signal of the vacuum detector is continuously transmitted to the FCV system to ensure that the pressure in the beamline is within the UHV region. The vacuum signal is compared with an over-pressure trip point of 5×10^{-4} torr. Upon detecting any vacuum deterioration, the protection system initiates a cut-off signal, thereby requesting the RF klystrons to turn off the RF power.

After the RF power is removed, the RF system transmits to the FCV control system, thereby allowing the FCV control system to initiate blade closure in order to block the inrushing gas. Upon completion of the absorber closure, the beamline control system finally closes the backup vacuum valve (Kanaya, 1998). The total response time measured between a vacuum failure and the closure of the FCV blade is 12 ms.

3. Preventive action against fatal vacuum deterioration

In April 1996, an instantaneous vacuum deterioration actually occurred at beamline BL-19 at the experimental hall during normal operation of the synchrotron radiation source for experiments. The vacuum failure was caused by a metal rod accidentally hitting a ceramic insulator for the high-voltage electrodes of an ion-pump downstream of the beamline, causing a crack in the ceramic insulator. As a result, it caused a breakage of the vacuum seal of the ion pump. Atmospheric pressure immediately rushed into the beamline through the crack in the ceramic insulator. The pressure in the beamline reached close to atmospheric pressure, and was then induced towards the storage ring.

The protection system could detect the pressure rise downstream of the beamline before the inrushing gas reached the storage ring. Upon detecting the vacuum deterioration, the protection system immediately transmitted a signal to the RF klystron system through a high-speed optical link. This signal notified the RF klystrons that the RF power should be removed. Simultaneously, the vacuum protection system automatically solicited the computer of the beamline control system to initiate a closure of the water-cooled absorber. The absorber then started moving to intercept the intense photon flux beam from the insertion device upstream of the beamline. It takes approximately 1 s for the absorber to close. From the viewpoint of keeping UHV, closure of the absorber does not contribute to completely sealing the beamline. However, it allows two backup vacuum valves to seal the beamline after the absorber has intercepted an intense photon flux.

Note that the FCV has the role of providing high impedance against the inrushing gas, rather than completely sealing off the beamline, making it possible to prevent the inrushing gas from entering the storage ring. Thus, while the FCV is blocking the inrushing gas, the absorber and the backup vacuum valves can obtain enough time to seal off the beamline completely.

After the initiation by the beamline control system, the RF power in the klystrons could be removed, forcing the positron beam to lose its energy, and to dump within 100 μs. The signal 'RF-POWER-DOWN' was called back to the vacuum protection system within 2 μs after removing the RF power. As a result, the stored beam was dumped. Upon receiving an acknowledgment signal, the protection system allowed the FCV system to initiate its blade, since there was no intense synchrotron radiation beam. The FCV could close its blade within 11 ms after initiation.

A computer of the on-line database system automatically recorded traces of the vacuum deterioration, showing that the pressure in the beamline reached almost atmospheric pressure. Two ion pumps with an exhausting capacity of $500\,\mathrm{l\,s^{-1}}$ were

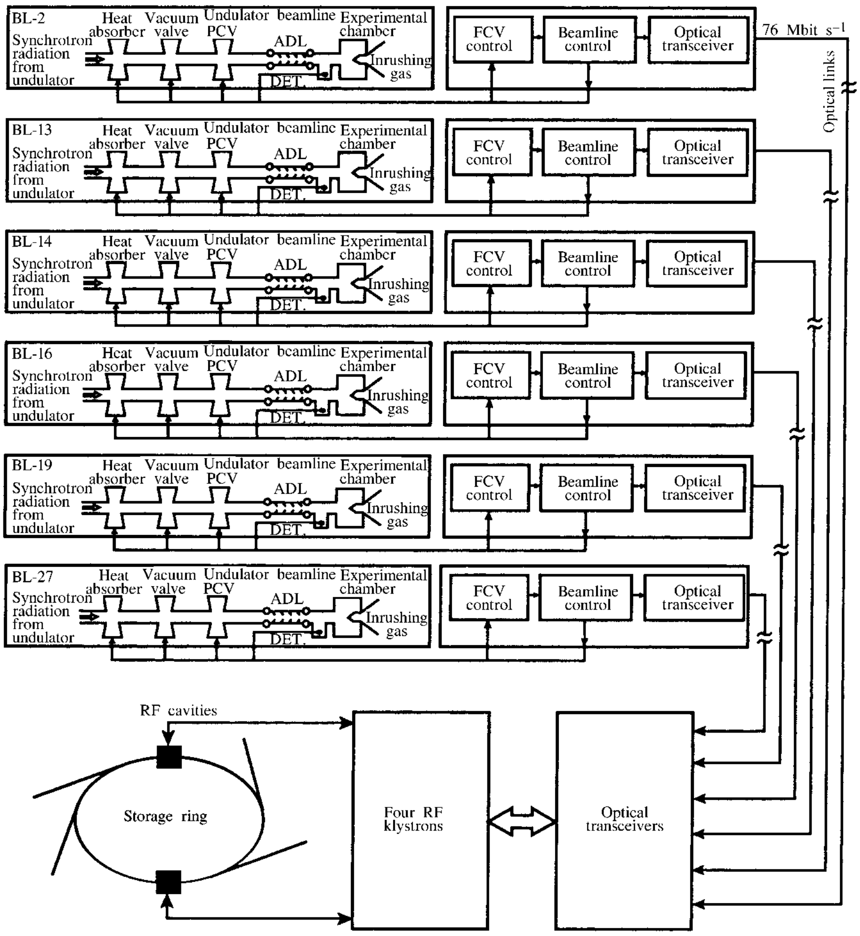

Figure 1
Block diagram of the ultrahigh-vacuum protection system for the intense-photon-flux wiggler beamline.

tripped off due to the atmospheric pressure, which exceeded their normal operational condition. Despite the fatal pressure rise downstream of the beamline, the pressure in the storage ring was found to be successfully maintained below 1.0×10^{-10} torr, causing no damage to the components of the synchrotron radiation source at all. A positron beam was injected into the storage ring again after approximately a 1 h inspection, and synchrotron radiation experiments took place again 1 h after the serious vacuum accident, though beamline BL-19 has been shutdown.

4. Conclusions

A UHV protection system for the six high-power wiggler/undulator beamlines has been implemented for the 2.5 GeV synchrotron radiation source. The protection system has high-speed optical-communication links to interconnect these six wiggler/undulator beamlines and the four RF klystrons. The actual operation for an actual instantaneous vacuum failure at the beamline proved that the protection system successfully functioned to protect the UHV of the storage ring as well as the components. If there was no UHV protection system, the synchrotron radiation and beamlines would have been filled with atmospheric pressure, causing a long-term shutdown. Our experience showed that the UHV protection system is important for synchrotron radiation sources with many insertion devices that produce an intense photon flux to the experiment hall. The protection system has been contributing to the long-term synchrotron radiation operation at the Photon Factory.

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References

Avery, R. T. (1984). *Nucl. Instrum. Methods*, **222**, 146–158.
Brown, G., Halbach, K., Harris, J. & Winick, H. (1983). *Nucl. Instrum. Methods*, **208**, 65–77.
Kanaya, N. (1984). *IEEE Trans. Nucl. Sci.* **31**, 957–962.
Kanaya, N. (1993). *Photon Factory Activity Report 1992*, R-16–17. KEK, 1–1 Oho, Tsukuba 305, Japan.
Kanaya, N. (1998). In preparation.
Kanaya, N., Sakanaka, S., Sato, S., Koide, T. & Asaoka, S. (1990). *IEEE Trans. Nucl. Sci.* **37**, 2–6.
Kanaya, N., Sato, S., Asaoka, S., Nakajima, K., Hayashi, S. & Kurita, S. (1989). *IEEE Trans. Nucl. Sci.* **36**, 1391–1395.
Kitamura, H. (1993). *Photon Factory Activity Report 1992.* KEK, 1–1 Oho, Tsukuba 305, Japan.