MAIN BEAM LINES AT THE PHOTON FACTORY 2.5 GeV STORAGE RING

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ABSTRACT

Main beam lines which have been successfully in operation at the Photon Factory storage ring are described. Each line consists of an acoustic delay line, a fast closing value, a beam shutter, an absorber, vacuum components, SiC mirrors and/or Be windows, and is kept at an ultra high vacuum. The performance of the elements is presented in relation to the last two years operating experience.

INTRODUCTION

Since the achievement of the first stored beam in the Photon Factory storage ring in March 1982, eight beam lines have become operational[1]. They were designed to provide experimental stations with both vacuum ultraviolet (VUV) and X-ray parts of synchrotron radiation (SR) for investigations in many fields of science and technology. Table 1 summarizes the beam lines.

Table 1

Beam lines being operational at the Photon Factory

Beam line	Source	Experimental spectral region
BL-1	normal bending magnet	VUV and soft X-ray
BL-2	permanent magnet undulator	soft X-ray
BL-4	normal bending magnet	X-ray
BL-10	"	"
BL-11	"	VUV and soft X-ray
BL-12	"	VUV
BL-14	superconducting vertical wiggler	hard X-ray
BL-15	normal bending magnet	X-ray

Except in BL-2, SR from the storage ring is split into several branch beams, which are transported to various types of monochromators. We shall call the part of the whole beam line, from an exit port of the ring doughnut to the beam splitting section, a main beam line[2]. Due to a variety of monochromators and experimental apparatus, main beam lines on SR facilities have to meet a unique set of requirements.

In this report the hardware configuration and performance are described on the basis of design considerations and the last two years operating experience.

GENERAL DESCRIPTION

For the design of main beam lines the following requirements must be taken into account: 1) protection of the storage ring from sudden vacuum failures which may occur in the experimental beam lines, 2) personnel protection against radiation hazards, 3) protection of valves and shutters from overheating due to any exposure to SR, 4) vacuum connection between an ultra high vacuum (UHV) of the storage ring and a variety of pressures of experimental apparatus, 5) sufficient SR divergence to make several experiments simultaneously, 6) measures against degradation of optical elements and 7) remote control systems operating the hardware components. An example of the Photon Factory main beam line is shown in Fig. 1.

Protective Devices

An acoustic delay line (ADL), a fast closing valve (FCV) and a pneumatic valve constitute a vacuum protection system. The ADL is a stainless steel tube loaded with an array of conical diaphragms each having a rectangular aperture to delay the rapid propagation of a pressure wave front caused by possible downstream

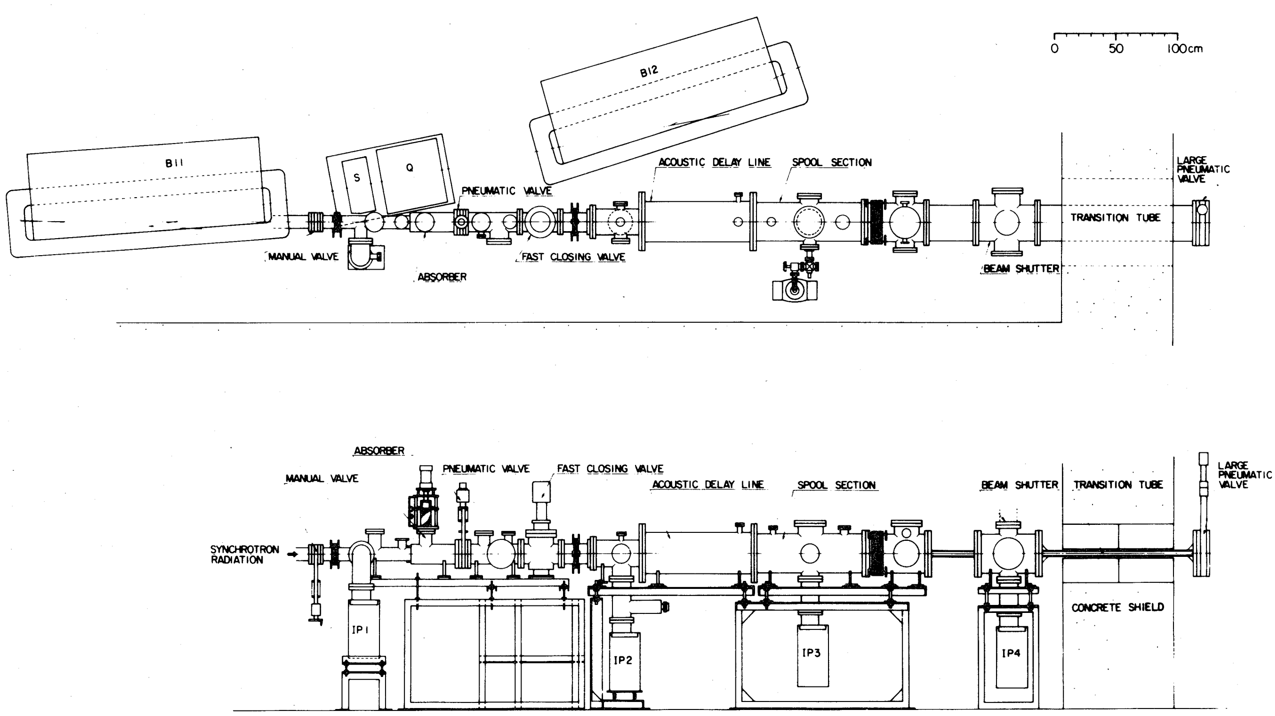

Fig. 1 Layout of the Photon Factory main beam line.

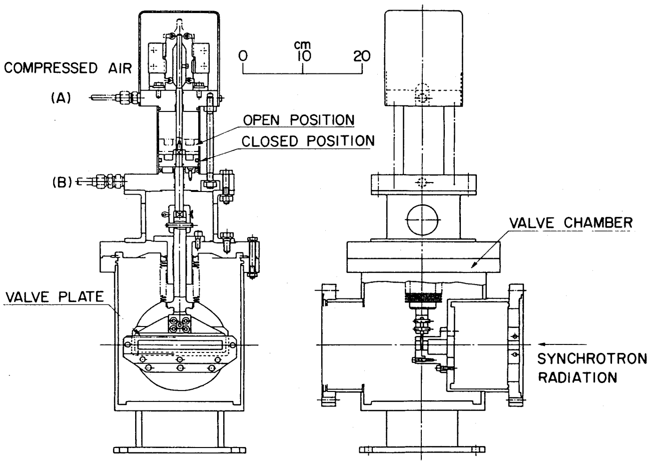

Fig. 2 Cross sectional diagram of the fast closing valve.

vacuum accidents. The transit (delay) time in the ADL was measured to be the order of 100 msec for a pressure front of 1×10^{-3} Torr. An assembly drawing of the FCV is shown in Fig. 2. The driving force is obtained by a pneumatic actuator instead of a spring mechanism. Closing the valve is accomplished by rapid release of the compressed air from the lower part of the cylinder using an electromagnetic cock with a signal from a 1 ℓ/s ion pump placed downstream. The closing time was measured to be about 40 msec, which is shorter than the delay time of the ADL. Since the FCV merely forms a high impedance to the inrushing gas, a pneumatic UHV valve is to be sealed off just after the FCV is closed. A safety beam shutter, which is made of a stainless steel block 40 cm thick and is driven by a hydrostatic pressure cylinder, stops high energy radiation caused by beam loss during injection. Whenever the valves and beam shutter are to be closed, a light absorber which is placed upstream intercepts SR to protect them from any exposure to SR. Since it receives the high power of SR, it is made of a copper rod directly cooled with water flowing through the inside and is driven pneumatically. These protection components are sequentially remote controlled with an interlock system[3].

Vacuum and SR Divergence

The vacuum of the main beam line must be kept at the same order ($\sim 10^{-10}$ Torr) as that of the storage ring. Four 110 ℓ/s triode ion pumps and two titanium sublimation pumps are installed for the main pumping. A 170 ℓ/s turbomolecular pump is used for rough pumping during bakeout. A manual valve, which is normally kept open, is necessary for venting the main beam line without breaking the ring vacuum.

The main beam lines from normal bending magnets extract 40 mrad horizontal divergence SR at the exit port of the storage ring. Since many masks and diaphragms are inserted in the main beam lines, SR of 30 mrad in horizontal aperture is supplied to the experimental areas. The wiggler line supplies hard X-rays of 9 mrad in vertical divergence while the undulator line provides 0.7 mmϕ divergence radition through pinholes.

Beam Deflection Mirror

In the VUV beam lines SR is divided among 3 or 4 branch beams and is then sent to monochromators by beam deflection mirrors. Since the direction and height of the SR beam may change, depending on the operating condition of the storage ring, the mirror adjusters have to allow rotational and translational adjustability while under vacuum. Remote control systems are required for the adjustments of mirrors distant from the experimental stations. The first mirrors which receive the intense SR beam must withstand the high power without thermal distortion or surface degradation. Chemical vapor deposited (CVD) silicon carbide (SiC) has been undergoing evaluation as a candidate mirror and mirror substrate material for SR beam lines because of its high resistance to thermal distortion and radiation damage. CVD-SiC has other desirable qualities.

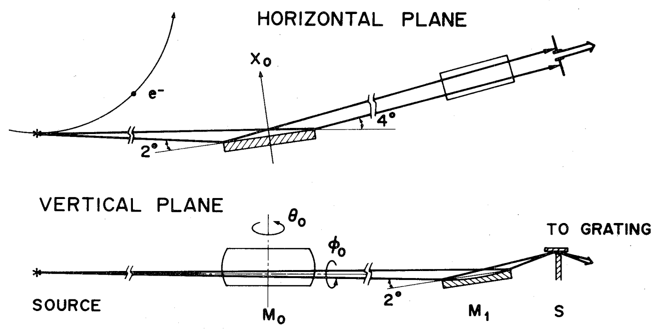

Fig. 3 Optical arrangement of the grasshopper branch line on BL-11.

Figure 3 shows the optical arrangement of the branch line to a grasshopper monochromator on BL-11[4]. A Pt-coated flat SiC mirror is used for a horizontal beam deflector M_0. The adjustments for the θ_0, ϕ_0 and x_0 motions of the mirror are achieved with pulse motors remotely controlled from the experimental station. The grazing incidence angle of 2° requires a mirror as long as 40 cm to receive 1.3 mrad horizontal divergence radiation. The mirror blank was produced by overcoating a high quality graphite substrate with well grown CVD-SiC 500 μm thick in order to fabricate a large mirror. The CVD-SiC surface was polished to an optical finish by the diamond lapping. Non-coated SiC mirrors are used for non-grazing incidence deflectors on the lines for normal-incidence monochromators.

Beryllium Window

In the X-ray beam lines, beryllium windows are attached at the downstream termination of each main beam line to pass X-ray components of SR to the experimental stations. In order to tolerate both the heat load due to SR and the pressure difference between the UHV main beam line and the experimental apparatus, a double-beryllium window type was adopted. Each beryllium foil is 0.3 mm in thickness for the wiggler line and is 0.2 mm thick for the lines from normal bending magnets. Joining a thin beryllium foil to a copper frame was done by the electron beam braze-welding.

Figure 4 shows schematically the arrangement of the Be windows for the wiggler line. This configuration was chosen on the basis of the calculation for the transmitted intensity of X-rays and for the thermal stess in the beryllium foils[5,6]. An upstream window faces a UHV environment and stands the heat load. In the case of the wiggler line, the power density is as high as 200 watts per 1 mrad vertical divergence with the 6 T wiggler operating at 2.5 GeV and 500 mA. To reduce the thermal load imposed on the upstream window, a beryllium heat absorber 1 mm thick is inserted upstream from the window. The middle section between two windows is pumped to $10^{-8} \sim 10^{-7}$ Torr with an 8 ℓ/s ion pump. A beam pipe from the downstream window to the experimental apparatus is evacuated to $10^{-3} \sim 10^{-2}$ Torr to protect the beryllium foil from oxidization and to avoid absorption of X-rays by air. The downstream window is only exposed to the small thermal load because the heat absorber and upstream window absorb most of the VUV and soft X-ray components of SR. The window frames and heat absorber holder are water cooled to reduce the temperature of the beryllium foils.

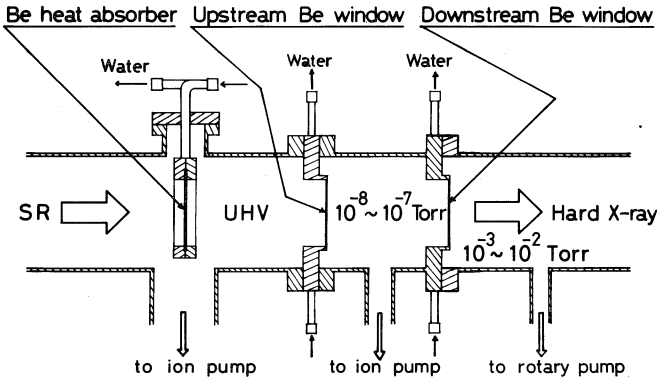

Fig. 4 Schematic of the Be window configuration for the vertical wiggler line.

OPERATING EXPERIENCE

At the time of the first test operation of the storage ring in February to March 1982, a single main beam line (BL-11) was available and it was used for beam monitoring. In order to observe the visible light of SR, a small SiC mirror was mounted in a beam-splitting chamber just outside the shielding wall. A single-type beryllium window was also attached to the same vessel to make a preliminary X-ray experiment. The visible light reflected from the mirror was monitored by a photomultiplier tube as well as a TV camera. Figure 5 shows an output signal of the photomultiplier at the initial stage of the test operation. About 20 peaks corresponding to every turn of decaying electrons were clearly observed. Signals from the photomultiplier proved to be quite useful in giving information on the accumulation of electrons. The beryllium window was found to transmit X-rays intense enough to take a Laue pattern with a silicon single crystal within a short time even at 1.7 GeV and 10 mA.

User experiments have been made since June 1982. An average base pressure of 5×10^{-10} Torr has been attained for each main beam line by baking at a temperature of 250°C for about 30 hours. The protective devices have shown excellent performance for the last two years. Figure 6 shows a photograph of the Pt-coated SiC mirror which has been used on the grasshopper line. The mirror showed visible evidence for hydrocarbon contamination after one year in the intense SR beam. The two stripes were produced as a result of reuse of the mirror with both sides interchanged. Renewal of the reflecting surface resulted in a drastic improvement in the monochromator throughput. Temperature rise of a beryllium window frame on BL-10 was measured to be only 20 degrees at 2.5 GeV and 180 mA. Figure 7 shows a photograph of the beryllium window assemblies which have been used on BL-4. The downstream beryllium foils were found to be slightly oxidized after one year under SR exposure.

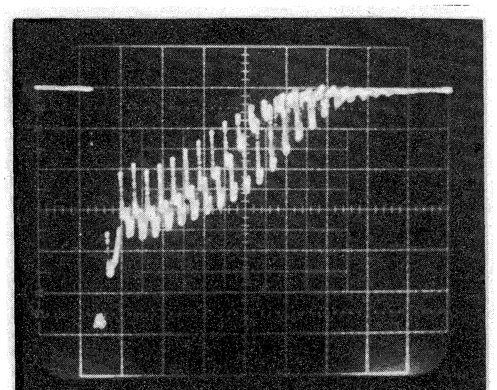

Fig. 5 Output signal of a photomultiplier detecting SR from decaying electrons. The horizontal scale is 2 μs/div.

Fig. 6 Pt-coated SiC mirror having been used on the grasshopper line. It has a size of $40 \times 17 \times 4$ cm^3.

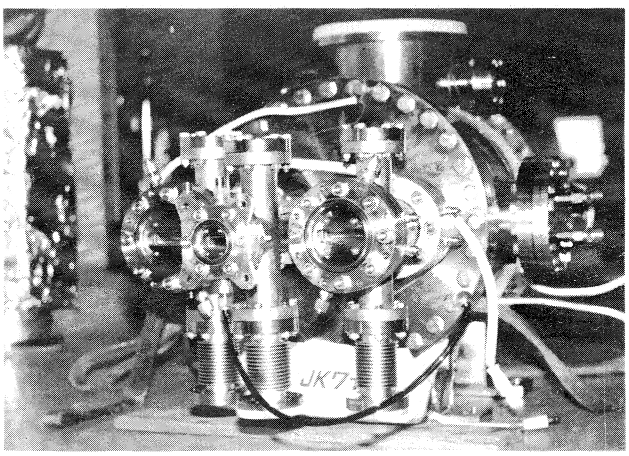

Fig. 7 Be window assemblies having been used on BL-4. The downstream windows are seen.

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