STATUS OF THE VACUUM SYSTEM
IN THE PHOTON FACTORY ELECTRON STORAGE RING

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INTRODUCTION

The improvement of the beam lifetime performance is a main objective in the electron storage ring dedicated to synchrotron radiation sources because a stable intensity of synchrotron radiation (SR) is necessary for carrying out optical experiments, and the lifetime above 10 hrs is usually required. It is well-known that the minimum pressure in a normal electron storage ring with a relatively large aperture of the vacuum chamber is aimed at the lower range of 10^{-9} Torr. However, in the case of the ring designed to have a large number of insertion devices called wiggler or undulator with a low emittance beam[1], the situation for the vacuum system is different. The low emittance beam promises a high brightness of the radiation from the insertion devices as well as a long quantum lifetime[2] even with a small aperture, which is desirable for them to operate with a narrow gap height. On the other hand, the lifetime associated with the scattering by residual gases[3] is not made longer by reducing the emittance and depends strongly upon the width of the aperture. Thus, the pressure in such a special ring with a small aperture should be reduced to the lower range of 10^{-10} Torr being much lower than that in a conventional SR source.

The 2.5 GeV electron storage ring in Photon Factory (PF), which has been operating since May 1982, is designed to provide SR sources of X-ray and VUV regions and has 6 long straight sections available for special insertion devices. The cleaning of the vacuum system against photo-desorption (PD) was made by self-cleaning during the first running of the ring. However, the rate of PD was not made lowered so much by self-cleaning of the time-integrated beam current of 10 Ahrs, and the resulting pressure at the beam current of 100 mA was 1×10^{-7} Torr with the beam lifetime being 0.5 hr at that current. Therefore, we adopted argon glow discharge cleaning (ArGDC)[4] aimed at the reduction of PD as well as increased the total pumping speed in the vacuum system by introducing many Ti sublimation pumps in September 1982, and the resulting pressure at 100 mA decreased down to 1×10^{-9} Torr by an additional self-cleaning of 70 Ahrs. At present, the ring is operating at 100 mA in the lower pressure range of 10^{-10} Torr, and the beam lifetime at that current exceeds 20 hrs even with the undulator[5] which limits the vertical aperture within 18 mm.

In the present paper, we describe the recent performances of the vacuum system in the Photon Factory ring and some problems encountered during its operation.

VACUUM SYSTEM OF THE PF RING

The total pumping speed of the vacuum system of the PF ring, which had been 1×10^4 ℓ/s prepared in the initial design of the system, was increased up to 3.6×10^4 ℓ/s by introducing many Ti sublimation pumps in September 1982 just before ArGDC. Figure 1 shows the schematic illustration of the present vacuum system. The vacuum ducts forming the system with a circumference of 187 m are made of aluminum alloy (6063T) and 304 stainless steel[6]. As shown in Fig. 1, 55 pumping ports are distributed in the system and each of them, except for a few cases, is provided with a combination

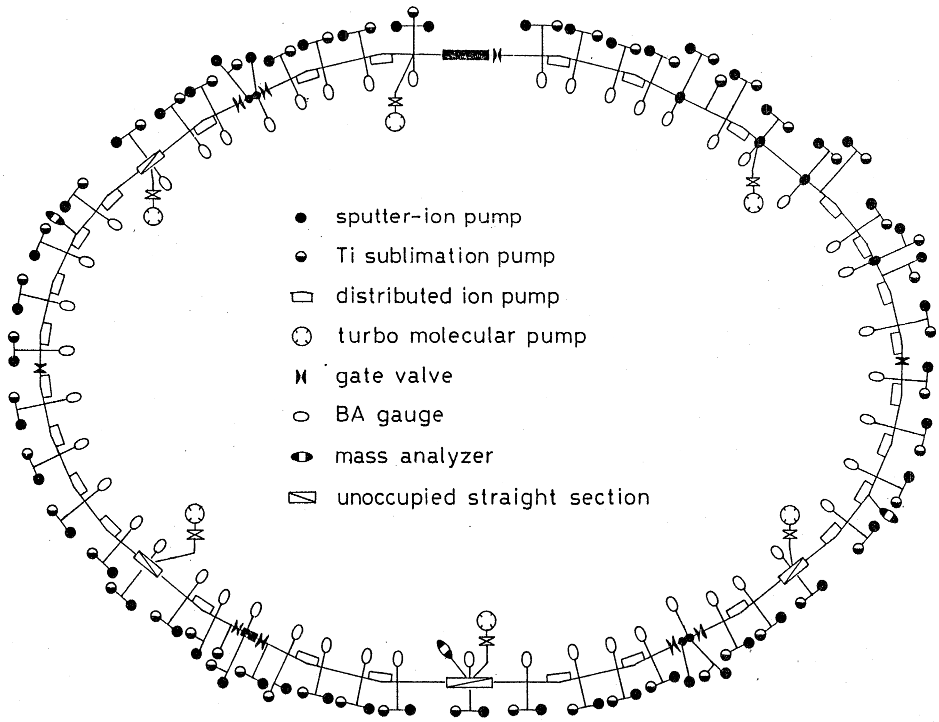

Fig. 1 Schematic illustration of the PF ring vacuum system.

of a 128 ℓ/s sputter-ion pump and a Ti-sublimation pump (TSP). The typical effective pumping speed per pumping port is estimated to be about 600 ℓ/s. Furthermore, 28 sets of distributed-ion pumps (DIPs) with a pumping speed higher than 150 ℓ/s per each are located in the bending sections. The rough pumping is carried out by 6 turbo-molecular pumps. At present, 8 gate valves (VAT 10-100H) with viton seals are used, but, due to the reason as described later, they will be exchanged for all-metal valves with rf shields in March 1985. The system for measuring the pressure consists of 48 BA gauges and 3 quadrupole mass analyzers. The data obtained by the BA gauges are monitored by the CRT display placed in the control room.

RECENT PERFORMANCES OF THE VACUUM SYSTEM

Figure 2 shows the dependences of the pressure, P_{100} averaged in the ring and the beam lifetime, T_{100} for the beam current of 100 mA upon the amount of the time-integrated beam current from the beginning. Although P_{100} decreased gradually down to 1×10^{-7} Torr with $T_{100} = 0.5$ hr before September 1982, it was found to be reduced rapidly by making the ArGDC as well as introducing many Ti sublimation pumps (TSPs), and P_{100} and T_{100} was obtained as 6×10^{-10} Torr and 700 mins, respectively. By the way, P_{100} obtained around 130 Ahrs seems to reach a plateau, but this is thought to originate in the drop of the total pumping speed because 40% of the TSPs had broken down due to the snapping of a filament.

In May 1984, the whole vacuum system of the ring was exposed to air for maintenance with all the broken TSPs being repaired. The system was evacuated again down to the base pressure of 2.5×10^{-11} Torr with a bakeout but without further ArGDC. Although P_{100} went up to 1.5×10^{-8} Torr with $T_{100} = 30$ mins in the first operation of the ring after the last evacuation, the vacuum system was completely restored with $P_{100} = 2 \times 10^{-10}$ Torr and $T_{100} = 1500$ mins. The best operation of the ring, obtained recently, is shown in Fig. 3. The abscissa represents the time elapsed since the end of the injection of the electron beam. The ordinate represents the beam current by a full curve, the pressure by a chained curve, or the lifetime by a dotted curve.

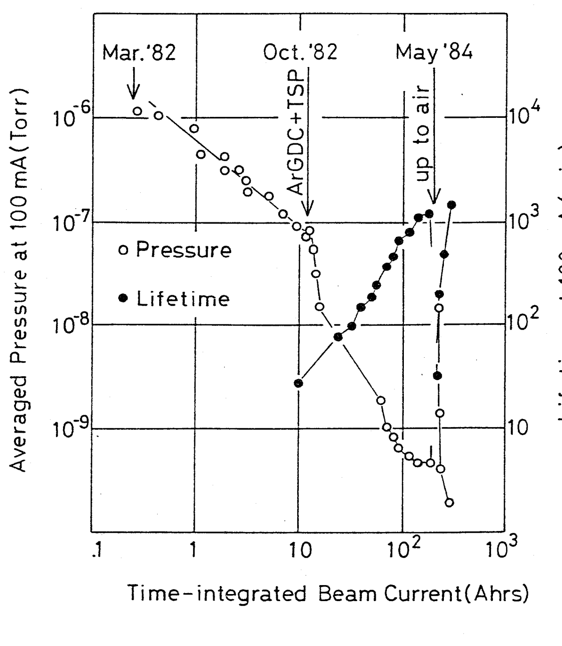

Fig. 2 Decrease of the pressure and improvement of the beam lifetime during the operation of the PF ring.

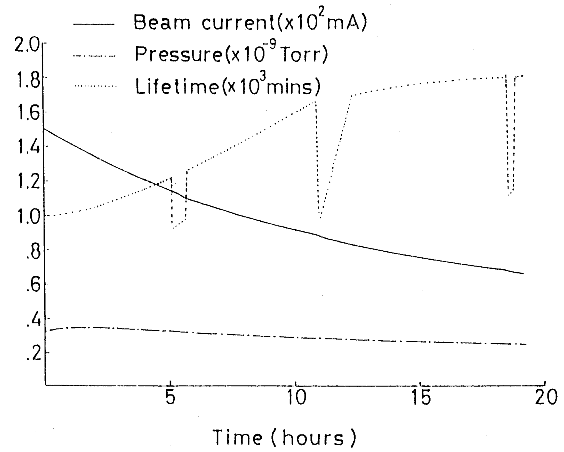

Fig. 3 The best operation of the PF ring.

From the results obtained so far, we concluded that even if the vacuum system, being cleaned with a low rate of the photodesorption, would be filled with air, it may be restored to the original state by a little amount of self-cleaning without an additional ArGDC.

SOME PROBLEMS IN THE VACUUM SYSTEM

Sudden Decay of the Beam Lifetime

We frequently observed a sudden decay of the beam lifetime during the storage of the beam in the PF ring. In the worst case, the lifetime showed a conspicuous decrease from several hundred minutes to a few minutes. The typical example is shown in Fig. 4. The abscissa or ordinate represents the same as described for Fig. 3. As shown in Fig. 4, after 2 hours, the lifetime is found to fall suddenly from 1000 to 100 minutes, while the corresponding pressure did not increase but decreased gradually according to the decay of the beam current. The above phenomenon is thought to have no relation with the beam instabilities with respect to the rf operation etc. because no obvious change in the beam profiles was observed when the sudden beam decay occurred. Furthermore, we also obtained other results related to this phenomenon as described in the following; (1) The frequency of the sudden beam decay was made much lower by applying a negative voltage of 400 V to the stainless steel wire stretched in front of the DIP, which had been prepared primarily for ArGDC, as well as by stopping the operations of all the sets of DIP. (2) The sudden beam decay was initiated just after turning on one of the set of DIP during the storage of the beam.

On the basis of the above results, at first we considered that the sudden beam decay might originate in the scattering by the Ar-ions trapped in the beam and the Ar atoms or ions might be emitted from the DIP. However, this consideration is unreasonable because the pressure averaged in the beam all around the PF ring was estimated to be too low to give such a short lifetime as described below. The emission of Ar from DIP, assumed to result in the sudden beam decay, is thought to occur in only one of the 28 bending sections since it is not natural that most of the sets of DIP installed in the ring may start emissions of Ar at the same time. If the electron beam in the PF ring is assumed to have a circular cross-section of 2 mm in diameter with the current of 100 mA, the density of electrons, averaged in the beam, is estimated to be 7 ×

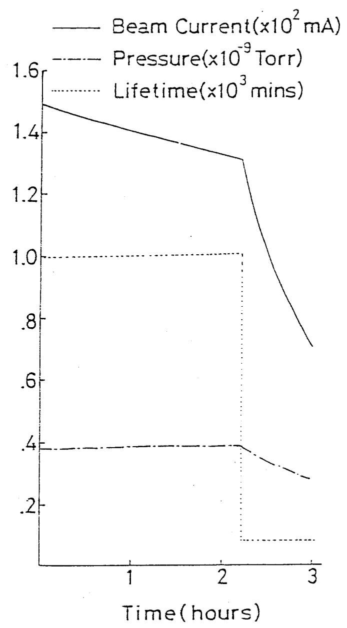

Fig. 4 Sudden decay of the beam lifetime.

10^8 electrons/cm^3 so that the maximum pressure of Ar ions trapped in the beam existing in one bending section 2 m long is calculated as 2×10^{-8} Torr under the assumption of 100% neutralization. Therefore, the Ar-ion pressure averaged in the beam all around the ring of 187 m in circumference is estimated to be 2×10^{-10} Torr, which gives a beam lifetime of 30 hrs.

Hence, we considered another origin. It is well-known that a shower of fine particles is generated in a spark discharge. The sudden beam decay is thought to be caused by the charged fine particles trapped in the beam, which may be generated in the accidental spark discharge occurring in the DIP and charged up by the irradiation of SR. For example, as shown in Fig. 5 where the process of the trapping of fine particles is illustrated, a fine particle of nickel with a globular shape of 2 μm in diameter is assumed to cross the SR beam emitted from the electron beam of 100 mA with an initial velocity around several ten m/sec so that photoelectrons with a number more than 10^3 may be removed from the particle. Since the minimum electric charge required for the particle to be trapped in the beam against the gravity is estimated to be 7×10^{-20} Coulomb being less than the charge of an electron, the possibility of the trapping is very high. The number of Ni atoms contained in the particle is calculated to be 4×10^{11} atoms so that the equivalent Ni pressure averaged in the beam of 2 mm in diameter is estimated to be 2×10^{-8} Torr with the corresponding lifetime of 14 mins, a reasonable value for explaining the sudden beam decay.

We have rarely observed the sudden beam decay in the recent operation of the PF ring because the operations of the DIP become so stable that the spark discharge may not occur frequently.

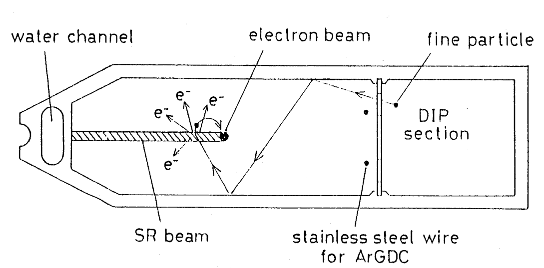

Fig. 5 Process of the trapping of fine particles

Outgassing from the Viton-Sealed Gate Valves

There are 312 buckets in the PF ring because the rf frequency is chosen as 500.1 MHz with the revolution frequency of 1.603 MHz. In the single-bunch operation, the pressures near the gate valves with viton seals showed notable increases while they do not change obviously during the multi-bunch operation where all the buckets were filled equally with electrons. Figure 6 shows the comparison between the beam current dependences of the pressure, averaged all around the ring, in the single-bunch and multi-bunch operations. As shown in Fig. 6, the pressure rise, considered to originate in the outgassing from the viton seals mounted in the gate valves, is found to be more conspicuous in the single-bunch operation. When all the gate valve were disassembled afterwards, we found that the nearest part of each viton seal to the stored beam degenerated with a mosaic shape. The origin of the outgassing is considered to be a heating-up of the viton seal by the wake field generated by bunched beams.

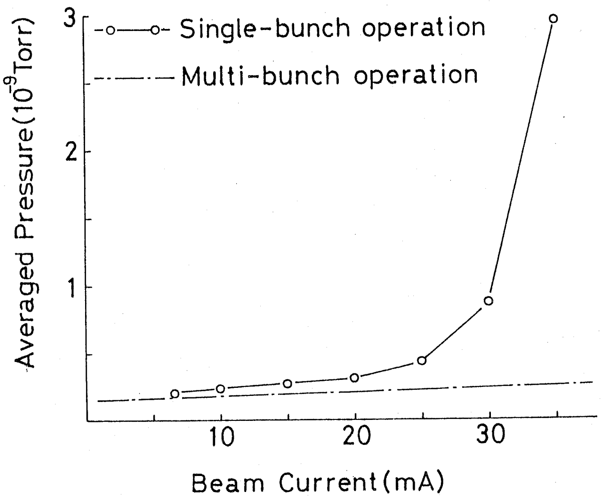

Fig. 6 Beam-current dependences of the pressure in the single-bunch and multi-bunch operations.

In the case of the multi-bunch operation, the Fourier components of the wake field show line-shaped spectra consisting of many higher harmonics with the fundamental frequency of 500.1 MHz so that no absorption might occur in the viton seal if the dielectric-loss spectra of viton did not overlap them. On the other hand, because the wake field generated in the single-bunch operation has quasi-continum spectra extending to several ten· GHz, it may necessarily overlap the loss spectra with an eminent absorption.

All the viton-sealed gate valves being used in the PF ring will be exchanged for all-metal gate valves with shields against the wake fields so that the vacuum performances during single-bunch operations may be improved so much.

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