STATUS of the VACUUM SYSTEM of the PHOTON FACTORY

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Abstract

The typical beam life time of the Photon Factory was over 1800 minutes at 200 mA of the stored beam current and 2.5 GeV of the beam energy in the usual user run in February 1987. The vacuum system was modified two times in the summer shutdowns in 1985 and 1986 to install radiation absorbers and additional quadrupole magnets. During the shutdown, all the vacuum ducts were left in the atmosphere for three months. After the shutdown, the pressures normalized by the beam currents showed lower values than those before the shutdown at the same accumulated beam current. The performance of the vacuum system of the Photon Factory is reported through the pressure history.

Introduction

The electron storage ring of the Photon Factory in KEK, National Laboratory for High Energy Physics, welcomed the first electron beam in February 1981. The vacuum ducts of the ring were made of aluminum alloy mainly and the rest parts were made of stainless steel. As the stored beam current increased, the temperatures of the stainless steel ducts became higher. In the summer shutdown in 1985, the vacuum system was modified to install the absorbers to protect the stainless steel ducts and the crotches which were between the bending ducts and the radiation exit port to the beam channel from intense synchrotron radiation. In the summer shutdown in 1986 the vacuum system was modified again in order to add the additional quadrupole magnets for low emittance. These modifications needed for the vacuum ducts to expose to air for three months. After the long exposure to air, the ducts were connected and evacuated.

The pressures of the modified ring were lower than the pressures before the modifications on same accumulated current conditions, and these lower pressures were also observed after the second modifications. The ducts irradiated by photons before the shutdown remembered the history of irradiation, and outgassing rates in photodesorption were lower.

In this paper, we report the history of the pressures of the electron storage ring of the Photon Factory.

Before the Improvements

We started on designing the vacuum system of the Photon Factory in April 1979. As the power of the synchrotron radiation is 200 kW per whole the ring at the stored current of 500 mA and the beam energy of 2.5 GeV. Main parts of the vacuum ducts were made of aluminum alloy (A6063), in which cooling water channels were integrated. The aluminum alloy ducts were installed in the bending magnet sections and in the quadrupole magnet sections, and they shared about 80 % of the ring periphery. Rest parts of the ducts were made of stainless steel, i.e., bellows, beam positioning monitors and flanges. They were arranged at the downstream of the quadrupole magnets where photon intensities were lower. The crotch between the beam duct and the light exit port is irradiated 8 times more intense than the duct wall in that section. The crotch was protected by the radiation absorber, which was not welded on the duct but was demountable type with flange. As the beam currents were not so high at that starting time, a temporary absorber was installed at the crotch. It was made of a copper plate simply brazed on the cooling water tube which was made of stainless steel. The stored beam current in the usual user runs was limited in 150 mA, but the current could be increased to 200 mA at general machine study schedule, because the stainless steel parts were heated up for higher beam current.

The pressures in the electron storage ring are measured by 48 Bayard-Alpert type ionization gauges which were mounted on the pumping port. There were the shields for RF wake field and for the stray photoelectrons from the beam duct at these ports. As the pressures on the beam storage conditions depend on the beam current and the accumulated photons, the pressures are normalized by the beam current and plotted against the accumulated beam current (beam dose). Figure 1 shows the pressure changes of the PF ring, where dashed line indicates the pressures of the ring before the summer shutdown in 1985. The pressures dropped steeply at about 50 Ahr of beam dose. At that time we imagined that the newly installed titanium getters worked well and pressures dropped. In March 1984, the ring was leaked to atmosphere accidentally from the beam channel. We stored the electron beam after baking of the ring. As the ducts were exposed to air, we reset the accumulated current and plotted the pressures. The dashed and dotted line indicates pressures after this accident. These pressures were lower than those indicated by the dashed line against the same accumulated currents. The average pressures were below $4*10^{-10}$ Torr at the stored current of 150 mA and the accumulated current of 400 Ahr. The beam life times became longer. They were 900-2000 minutes and depended on the activity of the titanium getter pump.

We decided to improve all the vacuum ducts in order to store much higher currents in usual user runs. The radiation absorbers were installed at the upstream of the stainless steel components in order to make shadows. The shadows protect the stainless steel components from the intense photon incidence.

Improvements of the Vacuum System

First improvement was the install of the radiation absorbers in the vacuum ducts. In case that the radiation absorbers are installed newly in the ring, the distribution of incident photons on the vacuum ducts can change and this may cause different pressure distributions along the vacuum ducts of the ring. We estimated the distributions of outgas caused by photodesorption and of the effective pumping speed at every point along the vacuum ducts by using the one dimensional finite method. The local pressure distributions could be obtained by the convolution of these two distributions. The pressures were normalized by the stored current and by the photodesorption coefficient η (molecules/photon). As the pressure is normalized by the η, the pressure is independent of the duct materials and of the surface treatments. Therefore these normalized pressure curves can indicate the characteristic pressures in the electron storage ring.

Figure 2 shows the characteristic pressures normalized as p (Pa)/η(molec/ph)/I_B(mA) along the vacuum duct in the normal cell of PF and also shows the distributions of incident photons N (ph/s/cm/mA). In the figure, the electron beam comes from right to left. The incident photon distributions depend on the conditions that the beam channels are open or not and the radiation absorber is installed or not. The pumping system has titanium getter pumps, and 30 % of the fleshly evaporated films are assumed to be effective in the calculation. It is clear that the characteristic pressures depend on the photon incident conditions. The results indicate that the installed absorber can cause minor change of the pressures, even if we installed the radiation absorbers in the ring. The calculation method of the local pressure distributions will be submitted elsewhere. The pressure analyses shown in Fig.2 indicate that the pressures in the beam duct are 3-4 times higher than the measured pressures. The pressures shown in Fig.1 were the measured pressures and not corrected by the factor between the beam ducts and the pressure gauge positions.

The absorbers for the crotch were newly designed, which were made of OFHC copper block. The cooling water channels were drilled directly on the block, so the heat flow could be restricted by the thermal conductivity of the copper itself. The absorber had the windows for the radiation, that could pass through the windows and be introduced to the beam channel.

Second improvement was the replacement of the vacuum ducts. The duct at the bending magnet section is called B-duct. Three B-ducts

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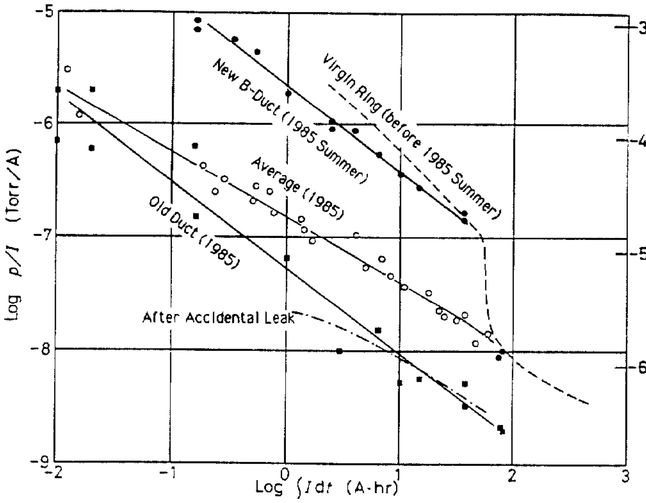

Fig.1 Pressures of the Photon Factory against the beam dose. The pressures are normalized by the stored beam current. Dashed line indicates the average pressures of the virgin ring before the summer shutdown of 1985. Filled circles, filled squares and open circles are the pressures after the first shutdown, and they are plotted after the beam dose was cleard. Filled circles indicate the pressures at the new B-duct installed in the shutdown. Filled squares indicate the pressures at the old duct irradiated already in the virgin ring. Open circles are the average pressures in the improved ring. Dashed and dotted line indicates the pressures after the accidental leak, and they are plotted after the beam dose cleard.

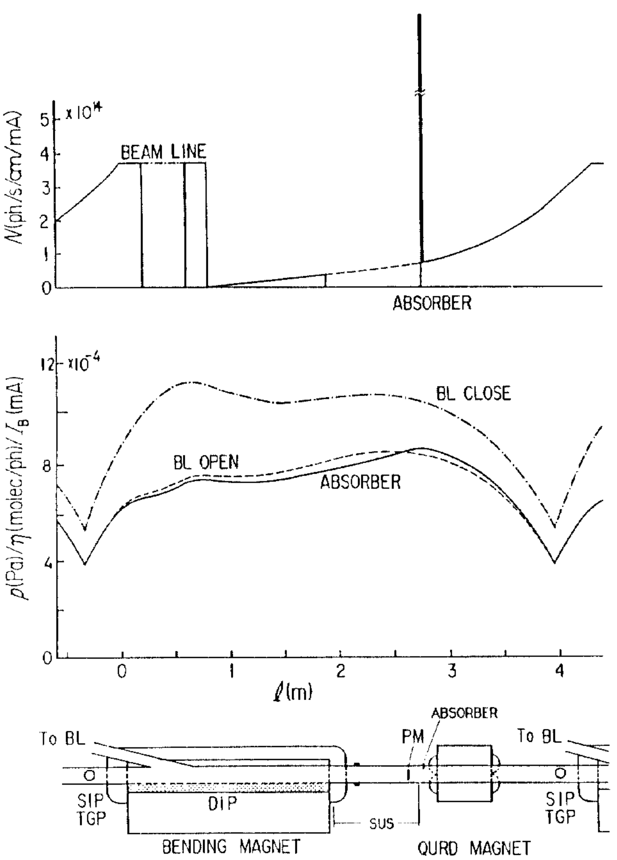

Fig.2 Characteristic pressures of the normal cell of PF. Incident intensities of photons are shown in the upper figure on the unit duct length, where electrons come from right to left. Solid line indicates the intensity on which a radiation absorber is installed at the downstream of the quadrupole magnet and a beam line is opened. Dashed line indicates the intensity without the absorber. Dashed and dotted line indicates the intensity on which the beam line is closed and all the photon emerged from the B-magnet section can irradiate the duct surfaces.

were replaced and they have a wide exit port for the both radiations from the bending magnet and from an insertion device. At the short straight sections, ducts were replaced from usual ones to narrow ducts. Because some octupole magnets and skewed quadrupole magnets were installed newly in that section and the ducts were needed to fit the magnets.

Pressure Characteristics after Improvements

Figure 1 also shows the pressures after the improvements. As whole the vacuum ducts were in atmosphere of the ring tunnel during the shutdown and the duct surface were considered to adsorb many gas molecules, the previous accumulated current was cleared here. Average pressures of the improved ring are normalized by the stored current and indicated by the open circles. The normalized average pressures decreased, as the accumulated current increases. They were lower than those of the old ring, and they became the same values in the old ring over about 50 Ahr. In the same figure, the pressures at the new B-ducts, which were installed in this summer shutdown and virgin for photon incidence, are shown by filled circles. The pressures at the old ducts, which were already irradiated by photons in the ring, are shown by filled squares. It is noticed that the pressures at the new B-ducts of the improved ring were similar to the pressures of the old ring before the improvements. The second remarkable point is that the pressures at the ducts irradiated already in the old ring were lower than those of the new B-ducts in the improved ring and the slope of the pressure decrement of the old ducts was nearly same as the slope of the new ducts. The pressure of the old ducts approached those of the old ring after the accidental leak.

The virgin ducts adsorb many gas molecules on their surfaces. In the accidental leak, the irradiated surfaces were covered by gas molecules and the much clean surfaces of the old ducts were exposed to air for three months. As the gas molecules cover these three kinds of the duct surfaces and the photon stimulated desorption depends on the amount of adsorption, all the pressures must be similar to each other in photon incidence. But the experimental results on pressures showed the different evidence. Pressures of the virgin ducts installed newly in the improved ring changed similarly to those of the virgin ring. On the other hand, though the irradiated ducts were exposed to air for three months, pressures of them in the improved ring were 1/10 or lower than those of new ducts. These pressure changes indicate that the steep decrement of the pressures did not caused only by the increment of the system pumping speeds but the outgassing rates were lower essentially in the old ring at about 50 Ahr. The evidence shows that adsorbed gas molecules can be removed easily by photon irradiation. The vacuum duct of the electron storage ring remember, in other words, the history of photon irradiation. This history is not remembered on the duct surface influenced by adsorption but in the surface layer of the duct. The thickness of the surface layer is considered to be equal to the penetration depth of the high energy photons. The penetrating distance of photons in the metal is defined as the distance at which the number of the survivor photons in the metal is decreased to 10 % of the incident photons. For example, the penetrating distance is estimated to be about 1mm for the aluminum to the radiation from the Photon Factory ring in which the critical energy of radiation is 4 KeV. The incident angle of photons to the B-duct is 7.3°, so the thickness of the surface layer is about 0.1mm. We assume as follows. The surface layer of the vacuum duct is cleaned out by photon irradiation. Gas molecules are adsorbed on the duct surface and diffuse into the clean-out layer by thermal diffusion in the summer shutdown. If the clean-out process was fast and not thermal in the layer, and the diffusion process into the layer was slow and thermal, then the observed results can be understood consistently.

Pressure Characteristics after the 2nd Improvements

In the summer shutdown of 1986, the ring vacuum system was modified to set additional quadrupole magnets newly. These magnets are necessary for low emittance operation. Moreover, a ceramics duct was installed at a kicker of the injection magnets. The vacuum gauges were calibrated by the spinning rotor gauge. All the duct were exposed to air again for two months.

During the leak test followed by the shutdown, an accident occurred. A part of the ring was pumped but a gate valve, which separates the ring duct, was not closed. Unfortunately, the next section

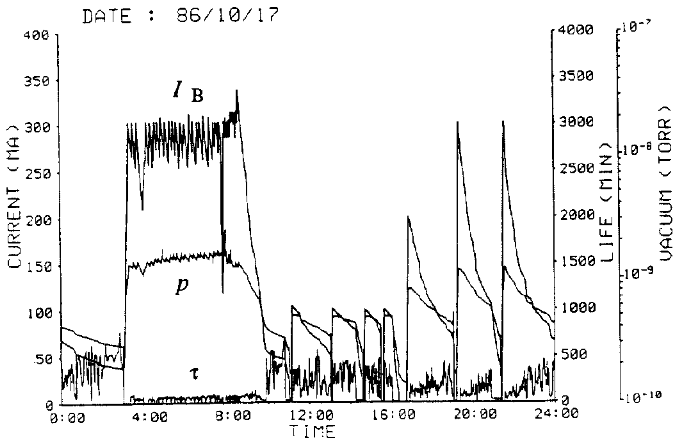

Fig.3 Pressure change on October 10 in 1986 after the accident of polyethylene rushing. Beam current I_B and beam life time t are also shown. The beam was injected frequently at 300 mA in order to clean the vacuum ducts by photons.

was opened to air and people worked. A flange cover for ICF203 made of polyethylene rushed into the vacuum duct of the ring about 30 m over the gate valve. The main part of it was taken away by opening the vacuum ducts. But small flakes and particles were remained, so we searched them by using a fiber scope and sucked out by vacuum cleaner. After baking the average pressure became finally $4*10^{-11}$ Torr and the polyethylene effect seemed very less. When the first electron beam was injected in the ring, the local pressures in the region of the cap rushing were about 100 times higher than those in the other regions. The average pressure and the beam life time were shown in Fig.3 with the beam current, where the accumulated beam current was 10 Ahr. Though the average pressures were kept in $1*10^{-9}$ Torr, the beam life time was less than 200 minutes at the injected currents of 300 mA. These short life time gradually became longer according to the decrement of the local pressures in the cap rushing region. In Fig.4, the latest pressures and beam life time were shown with the beam current, where the accumulated beam current was 225 Ahr. The beam life time became over 2400 minutes at the stored beam current of 150 mA, and the average pressures were below $2*10^{-10}$ Torr. The pressures in the beam duct is estimated to be about three times higher than the measured pressures by the analyses of the characteristic pressure of PF.

The main beam loss mechanism related with vacuum is bremusstrahlung by the residual gas molecules. The cross section σ_B is proportional to $1/(p\,\tau)$, where τ is the beam life time. Figure 5 shows the relation of the cross section against the accumulated current. The initial cross sections were 4 times larger than the latest values, and over 50 Ahr the cross section became to be nearly constant. In the figure, the filled triangles show the cross sections after the 1985 summer shutdown. So this large cross section does not mean the effect that the vacuum system was exposed to air but means that the polyethylene which sucked into the duct accidentally was the source of many heavy molecules and they were released by photodesorption. We tried to detect such molecules by using a mass filter but could not find them. Partial pressures at the injured section seemed not so different from the other sections.

At any time, the present performance of the vacuum system of the Photon Factory is fairly good and the long beam life times shown in Fig.4 can support long irradiation experiments with high current.

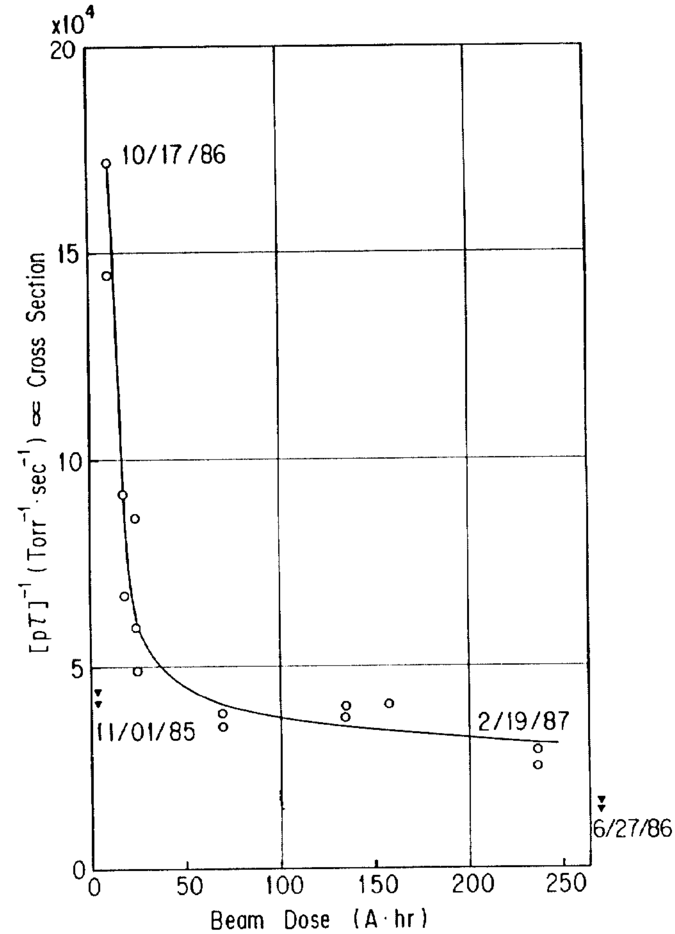

Fig.5 Colliding cross sections with the residual gas molecules. They were expressed as $1/(p\,\tau)$ and plotted the beam dose. Open circles indicate the values after the polyethylene accident in the second shutdown, and filled triangles indicate values after the first shutdown. The short beam life time shown in Fig.3 does not caused by the effect of the air exposure during the shutdown but by the contamination by polyethylene rushing.

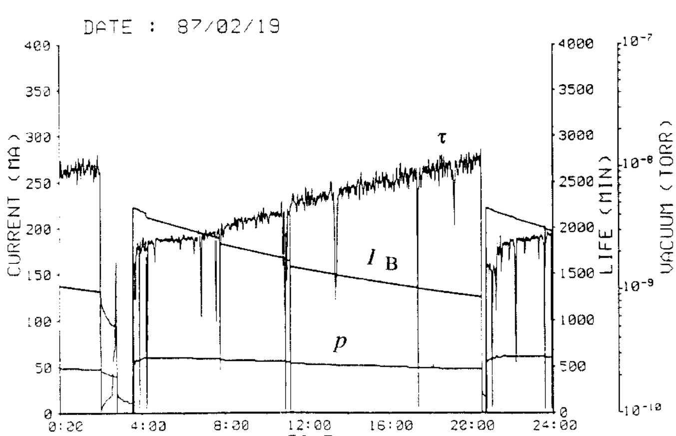

Fig.4 Pressure, beam life time and the beam current on February 2 in 1987. Injected beam current was 225 mA, and average pressure of the ring was less than $3*10^{-10}$ Torr. Beam life time was over 1700 minutes at 220 mA of the beam current, and reached 2700 minutes just before the next injection.