Change of Vacuum Pressure at the Photon Factory 2.5-GeV Storage Ring

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Abstract

In this report we discuss the pressure changes of the Photon Factory 2.5-GeV electron/positron storage ring since 1986. Local pressures along the ring circumference were measured by 48 B-A type ionization gauges. The beam lifetime largely depends on the pressure of the storage ring. The pressure normalized by the stored beam current is a good parameter for descibing the vacuum performance. The normalized pressure decreased as the time-integrated beam current increased, and the beam lifetime increased as the normalized pressure decreased. The normalized pressure was reached at below 1×10^{-12} Torr / mA, and the product of the beam current and the beam lifetime reached 1200 A min. This is the highest value for any electron/positron storage ring in the world.

I. INTRODUCTION

The Photon Factory 2.5-GeV electron/positron storage ring (PF ring) is a dedicated synchrotron-radiation source. The beam energy is 2.5 GeV and the beam current 350 mA for the initial stored beam current in normally scheduled user runs. A high beam current and a long beam lifetime are requested for experiments using synchrotron radiation. A beam lifetime longer than 3400 minutes at 350 mA of the stored beam current was achieved.

The beam lifetime depends on the pressure in the vacuum chamber of the storage ring and on the components of the residual gas molecules [1].

The local pressures of the ring were measured using B-A type ionization gauges. The ring is 187 meters in circumference. Forty eight B-A type gauges were mounted at each pumping port at about every 4 meters. The pressures of the PF ring during a user run are in the ultra-high vacuum region.

The measured vacuum pressures are transferred to a micro-computer and displayed as a bar graph on a CRT. The arithmetic mean of the 48 vacuum pressures is called the "averaged-pressure P_{av}". P_{av} is used as the typical pressure of the PF ring in this report.

The vacuum pressure (p) of the storage ring is given by

$$p = Q\, S_{eff}^{-1}, \tag{1}$$

where Q is total outgassing and S_{eff} is the total effective pumping speed of the ring. The pumping speed in the PF ring does not change very much during operation. The vacuum pressures depend on the outgassing from the vacuum chambers of the ring. The main outgassing in the storage ring is by photodesorption (ΔQ) and is given by the following relation [1]:

$$\Delta Q = K\, \eta\, N, \tag{2}$$

where N is number of incident photons [photon/sec], η is the photodesorption coefficient [molecules/photon] and K a constant for the unit conversion from the number of molecule to the amount of gas. The photodesorption coefficient (η) is thus deduced from the pressure rise (Δp) of the ring by

$$\eta = \Delta Q\, (KN)^{-1} = \Delta p\, S_{eff}\, (KN)^{-1}. \tag{3}$$

The number of incident photons (N) is given by[1]

$$N = 8.08\times10^{17} I_B E, \tag{4}$$

where I_B is the stored beam current [mA] and E is the beam energy [GeV]. Thereror, η can be written as

$$\eta = \Delta p S_{eff}\, (K\times8.08\times10^{17} I_B E)^{-1}. \tag{5}$$

When the pumping speed and beam energy E are constant, $\Delta p / I_B$ is proportional to η. Since the base pressure without a stored beam is much less than the pressure rise due to photodesorption, Δp is almost equal to p during the usual user operation of the PF ring.

We have used the vacuum pressures normalized by the stored beam current (p/I_B) to evaluate the vacuum pressures of the storage rings.

II. CHANGE OF AVERAGED PRESSURE

The normalized pressure (P_{av}/I_B) is plotted in Fig.1 against the time-integrated beam current. We set the starting point for October, 1986 in this plot.

Some of the vacuum chambers of the ring were exposed during every long shutdown for both improvements and maintenance. The normalized pressure was high at the beginning of operation just after the long shutdowns. The pressure decreased as the time-integrated beam current of each operation increased. The lowest value of the normalized pressure during each operation has gradually been decreasing with the total time-integrated beam current, as shown in Fig.1. A normalized pressure below 1×10^{-12} Torr/mA was achieved during every recent operation. Estimating η by equation (5), the value 1×10^{-12} Torr / mA is equivalent to about 1×10^{-6} molecules/photon.

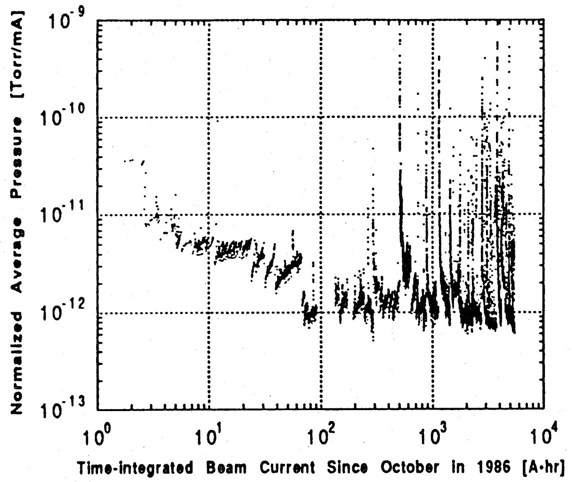

Fig.1 Change in the averaged normalized pressures in the PF 2.5-GeV storage ring since October, 1986.

III. BEAM CLEANING EFFECT

The pressure decrease described above was due to the fact that the surface of the vacuum chamber was cleaned by photodesorption. This effect is called the beam-cleaning effect. An example of this effect due to photon irradiation is shown in Fig.2 and 3.

Figure 2 shows the change in the local normalized pressure in a chamber of the ring during one operation term. The chamber had not been replaced and had been irradiated by a large number of photons. Also, the chamber had not been vented nor replaced during the shutdown just before operation. The normalized pressure was kept very low during the operation.

During the following shutdown, the chamber was replaced with a new one. After it had been baked, the pressure in the new chamber reached the 10^{-10} Torr range before operation.

Figure 3 shows the change in the local normalized pressure in a new chamber during operation. Although the normalized pressure was very high at the beginning of operation, it decressed with the time-integrated beam current, reaching about 1×10^{-11} Torr/mA at the end of the operation. However, its value was higher by about one order than that during the previous operation. Since the beam cleaning effect remained on the surface layer irradiated by the synchrotron radiation[2], a lower normalized pressure can be achieved relatively soon in a chamber used for a long operation time.

IV. CHANGE OF BEAM LIFETIME

The beamlife time (τ) can be expressed as $1/\tau = \alpha p$ [3]. Here, α is a constant related with the atomic number (Z) of residual gas molecules, and is approximately proportional to Z^2. We can reduce $I_B\tau$ to,

$$I_B\tau = S_{eff}\,(\alpha\eta K\times 8.08\times10^{17}E)^{-1}. \tag{6}$$

We can also evaluate the beam lifetime using $I_B\tau$, which is independent of the stored beam current. When $I_B\,\tau$ is large, it is clear that the product of α and η is small. We used $I_B\tau$ to evaluate the vacuum quality as well as the beam lifetime. The change in $I_B\tau$ in the PF ring is shown in Fig.4. The horizontal axis is the fiscal year from 1985 to 1992.

The long beam lifetime shown in Fig.4 mainly resulted from a decrease in the normalized pressure. Also, the beam lifetime was improved by modifying the ring optics [4]. Positron storage started in 1988 instead of electron storage. The positron beam has been stably stored without accidental current decay by micro-dust trapping, which had occurred during electron storage [3]. The recent typical operation status is shown in Fig.5, for the daily change of beam current, beam lifetime and averaged pressure. The positron beam is injected regularly once a day. A high beam current above 250 mA is maintained by the long beam lifetime during user runs.

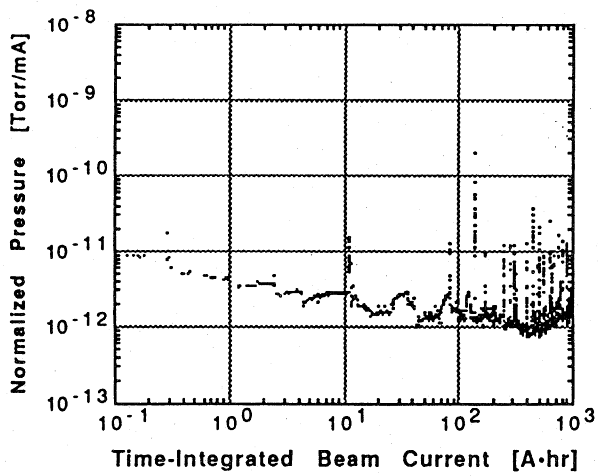

Fig.2 Change in the local normalized pressure in an old beam chamber.

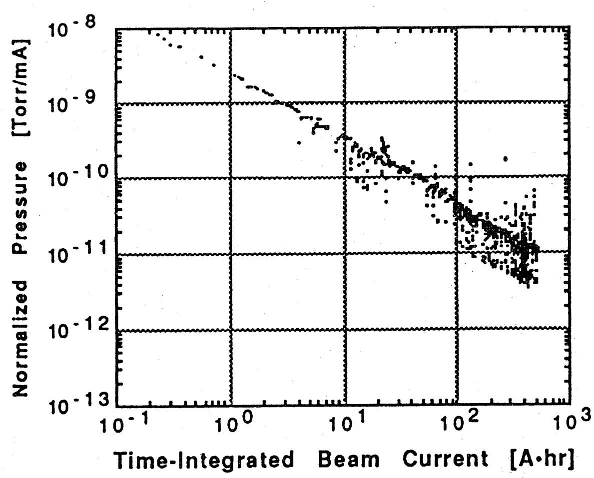

Fig.3 Change in the local normalized pressure in a newly installed beam chamber.

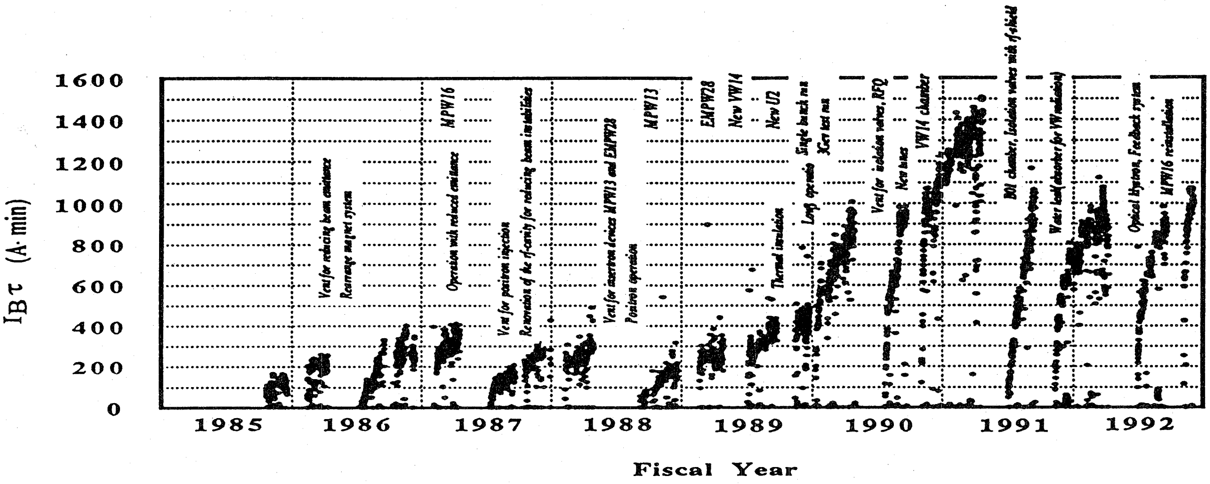

Fig.4 Change of $I_B\tau$ since October, 1985. The main upgrades are indicated in the figure.

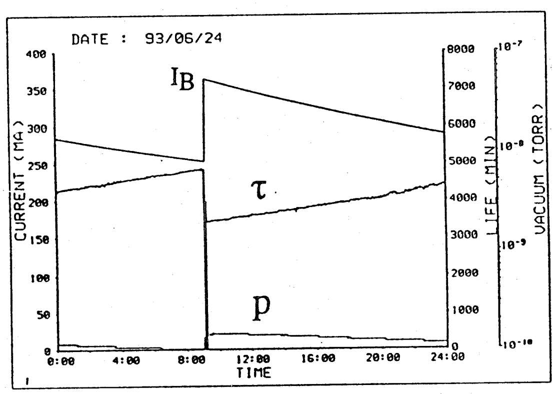

Fig.5 Change in I_B, τ and p during a typical one-day operation of the PF ring.

The high $I_B\tau$ is due to stable operation. More stable operation depends on a lower fault rate of the ring. The fault rate of the PF ring is less than about two percent of the operation time. The beam-cleaning effect has progressed quickly.

V. VACUUM DATA STORAGE

A great amount of pressure data have been recorded on about one hundred 8" floppy diskettes (2D type) and 5" floppy diskettes (2HD type). Unfortunately we could not recover the some files in 1983 to 1985. So we now record all the raw data in a hard disk unit, 5" floppy diskettes, 3.5" floppy diskettes and magnetic-optical diskettes. The calculated and processed data are recorded in floppy diskettes. Duplicate multiple recording is very important to guarantee long period record of the data.

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