FEASIBILITY STUDY FOR HIGH PERFORMANCE VACUUM CHAMBER

Y. Tanimoto[#], KEK, Tsukuba, Japan

Abstract

For longer beam lifetime, many accelerators have employed ante-chamber type of beam ducts to reduce photon-induced desorption gas around the beam orbit. Still more reduction, however, can be expected if an X-ray transparent membrane, such as beryllium thin film, is installed between the beam chamber and the ante-chamber because X-rays from the stored beam pass through the membrane while gas molecules desorbed in the ante-chamber are shut out by the membrane. Similarly, photoelectrons and secondary electrons traveling from the ante-chamber to the beam chamber are also shut out by the membrane; this function is expected to mitigate beam-photoelectron instability in positron storage rings. Feasibility study for this type of vacuum chamber has been started at Photon Factory (PF), and the result of the first-stage experiment will be presented.

INTRODUCTION

The ante-chamber type of beam ducts have widely been employed in many electron/position storage rings since early 1990s [1][2][3][4]. The most advantageous point of this type of beam duct is to geometrically distance the sources of photon-induced gas desorption from the beam orbit. A simplified diagram of the ante-chamber type of beam duct is shown in Fig. 1.

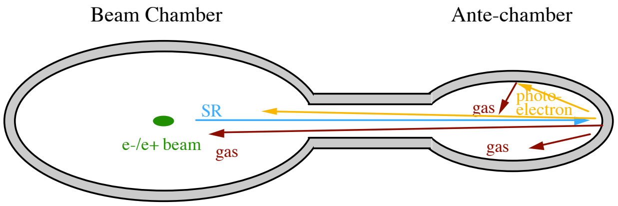

Figure 1: Conceptual diagram of the ante-chamber type of beam duct.

This structure also enables effective evacuation of the photon-induced desorption gas by equipping distributed NEG (Non-Evaporable Getter) pumps along the ante-chamber channel, or lumped pumps with TSPs (Titanium Sublimation Pump) and/or SIPs (Sputter Ion Pump) near photon absorbers in the ante-chamber. These assets conduce to the reduction of the beam loss from gas scattering and consequently prolong the beam lifetime.

In addition, the ante-chamber beam duct is expected to reduce the photon-induced electrons around the beam orbit. In the KEKB-LER positron storage ring, maximum stored current is limited by the electron cloud instability due mainly to the photon-induced electrons. As one of the solutions of this problem, the ante-chamber beam duct was examined and its effectiveness for the reduction of the electrons in the beam chamber was ascertained [5].

From the point of view of the reduction of gas flow into the beam chamber, it is important to reduce the conductance of the channel between two chambers. However, the vertical clearance should be wide enough for the passing synchrotron radiation (SR), and this would limit the conductance reduction. One of the improvement schemes for the ante-chamber's limitations is to install an SR transparent membrane as a partition as illustrated in Fig. 2. In this type of beam duct, the photon-induced gas molecules yielded in the ante-chamber can not enter the beam chamber.

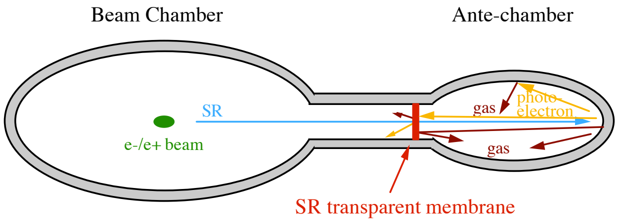

Figure 2: Conceptual diagram of the beam duct with an SR transparent membrane.

The beam chamber, therefore, can be kept in good vacuum even with high current beams stored. On the other hand, the ante-chamber does not have to be kept in vacuum as long as the vacuum sealing of the membrane is sufficiently tight.

The same as the gas dynamics is applicable to the photon-induced electrons. Since the photon-induced electrons yielded in the ante-chamber can not enter the beam chamber, electron clouds around the beam orbit would be rarefied. This will mitigate the photoelectron instability for positively charged beams.

R&D PROGRAM

Many problems, however, need to be solved to realize this type of beam chamber.

- Find suitable material for the membrane (high transmissivity, high strength, high thermal conductivity, low gas desorption yield, low cost, etc).
- Examine its performance (SR transmissivity, thermal property, photon-stimulated gas desorption yield, photoelectron yield, etc).
- Design its configuration.
- Establish its manufacturing (welding, cooling, etc).

Material candidates for the membrane have to be transparent to the wide range of SR and have to possess the low gas desorption yield property. From a comprehensive point of view, beryllium can be the first candidate because of its excellent properties, especially its high transmissivity to X-rays. Actually, beryllium is widely used for the window in X-ray beam lines, and its manufacturing is already well established.

[#] yasunori.tanimoto@kek.jp

Then, the first key subject of this R&D is to ascertain the beryllium performance on the SR irradiation. The chief concern is the dynamic pressure rise in the beam chamber side due to the photon-induced gas desorption by the relatively low energy photons that can not pass through the membrane.

EXPERIMENTAL SETUP

For the first step of this R&D program, SR irradiation experiments for beryllium thin film has been conducted since the autumn of 2007. The SR from a bending magnet of the PF ring is used as the incident photons for these experiments. The PF ring stores 2.5GeV-450mA beams and the critical photon energy is 4keV. The experimental equipments are installed at the vacuum group dedicated beam line, BL-21.

The sample beryllium thin film was brazed to a copper substrate, and the copper was welded to water-cooled stainless steel by electron beam welding (EBW). The thickness of the beryllium film is 0.2mm, and its size is 10mm(H) × 18mm(W).

The schematic diagram of the experimental setup is illustrated in Fig. 3. The SR passing through a 5mm × 5mm slit hits beryllium window at normal incidence because of the simplicity of data analysis. The primary chamber and the ante-chamber are isolated by the beryllium window, and each chamber is equipped with an SIP and a Bayard-Alpert gauge (BAG). Prior to the SR experiment, the system was baked out at 200˚C for 2 days.

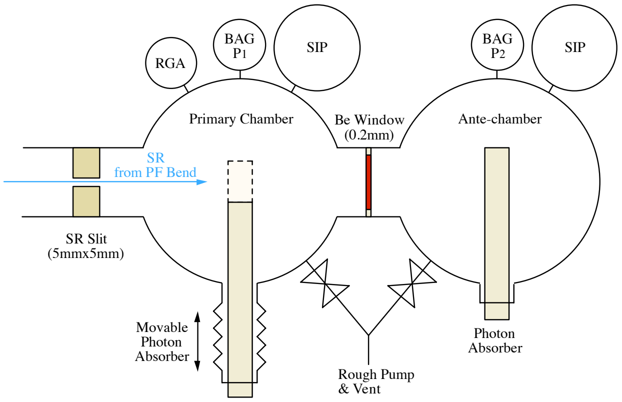

Figure 3: Schematic diagram of the experimental setup.

Although using a water-cooled removable beryllium window is the best way to measure the effect of the membrane, a movable photon absorber was installed instead for the simplicity of the system. Therefore, one experiment is comprised of the following two steps. Firstly, the movable absorber is inserted for the SR scrubbing around the primary chamber. Secondly, after the adequate photon dose, the absorber is retracted and the SR starts to hit the beryllium window. In other words, the first and second step simulate the "conventional" (not ante-chamber type) beam duct and the membrane type beam duct, respectively. On comparison with these results the effect of the membrane can be measured.

RESULT AND CONSIDERATION

After the thermal baking, the pressures in the primary chamber (P_1) and the ante-chamber (P_2) reached 4.5×10^{-7} Pa and 2.5×10^{-7} Pa, respectively. The reason why P_2 was lower than P_1 is that a modification was applied to the primary chamber after one SR experiment, and even during the modification the ante-chamber was kept in vacuum.

The progress of the dynamic pressure rise normalized by stored current as a function of photon dose in the recent SR experiment is shown in Fig. 4.

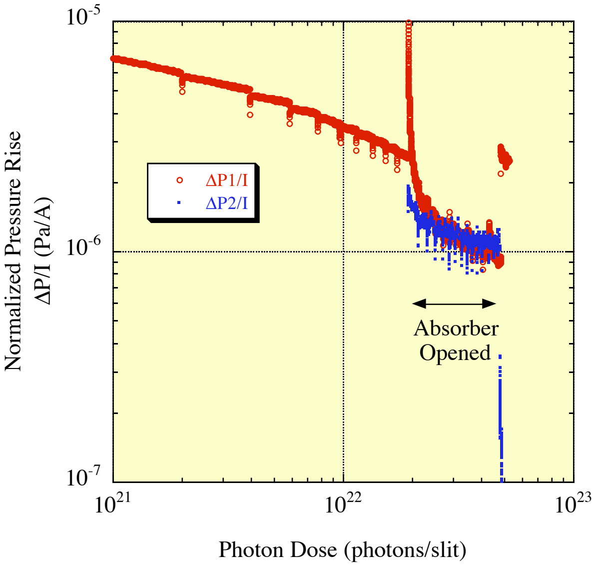

Figure 4: Result of the SR experiment.

When the photon dose reached 4.8×10^{22} photons/slit, $\Delta P_1/I$ with the movable absorber opened was $9.3\pm0.5\times10^{-7}$ Pa/A. And then, after the absorber was re-closed, $\Delta P_1/I$ increased to $2.5\pm0.2\times10^{-6}$ Pa/A (at that time static pressures for P_1 and P_2 reached 3.2×10^{-7} Pa and 2.4×10^{-7} Pa, respectively). In this experiment, therefore, the 0.2mm-thick beryllium film could reduce the pressure in the primary chamber by 63% while the SR was irradiating the beryllium window.

With regard to the pressure rise for each chamber, $\Delta P_1/I$ was $9.4\pm0.6\times10^{-6}$ Pa/A and $\Delta P_2/I$ was $1.1\pm0.2\times10^{-6}$ Pa/A during the photon dose range of $4.5\sim4.8\times10^{22}$ photons/slit. Although the vacuum condition for each chamber is not exactly the same, this result also indicates that the greater half of the incident photons that affect the gas desorption passed through the membrane.

For further quantitative evaluation of the X-ray transmissivity of the beryllium thin film, the calculated photon flux for this experiment, namely, incident, transmitted, and absorbed photon flux spectra, are shown in Fig. 5. The data of mass absorption coefficient of beryllium was approximately calculated with the data from the references [6] and [7].

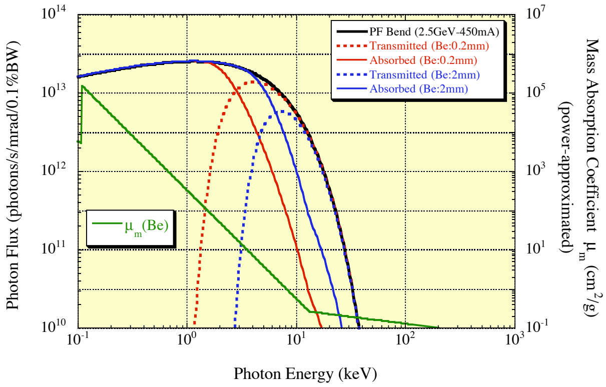

Figure 5: Calculated photon flux from PF bend.

By integrating these flux spectra with respect to the photon energy, the percentage of the transmitted photons through the 0.2mm-thick beryllium is calculated to be only 14% of total incident photons. Therefore, the result from the experiment indicates that the low energy photons are less effective for the gas desorption itself or the photons that penetrated to a certain depth in the membrane do not affect the gas desorption.

FUTURE PLANS

For further investigation on the photon energy dependence, it would be useful to carry on the SR experiments with different energy photons. In KEK, another light source, the 6.5GeV Photon Factory Advanced Ring (PF-AR) is available for these experiments. The critical photon energy of the PF-AR is 26keV. The calculated photon flux from the PF-AR bending magnet is shown in Fig. 6. The calculated percentage of the transmitted photons through the 0.2mm-thick beryllium is 45%.

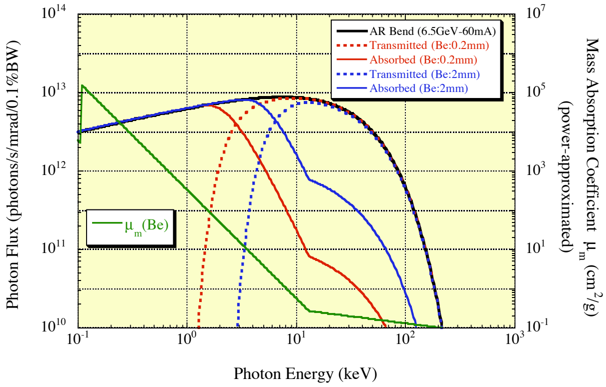

Figure 6: Calculated photon flux from PF-AR bend.

Investigation on the incident angle dependence is one of the key subjects because, in the practical design, the SR would irradiate the membrane with various incident angles. As the effective thickness increases due to the oblique incidence, the number of photons passing through the membrane decreases.

The photoelectron yield measurement is also of great interest. A simple modification to the current setup, i.e., installing insulated electrodes to both chambers, enables this experiment. There would be a strong possibility that the dependence of the photoelectron yield on incident photon energy is different from that of the gas desorption because their yielding mechanisms are totally different.

For the practical application of the membrane to accelerators, various engineering difficulties must be resolved. Some junction methods, such as brazing, HIP (Hot Isostatic Pressing), EBW or friction welding, as well as the thermal tolerance with SR irradiation should be examined. As mentioned above, the ante-chamber does not have to be kept in vacuum. This affords a simplified design that the membrane can be attached on the chamber wall or photon absorber wall. Although the purpose was to diffuse the heat density, beryllium-attached copper was actually used for crotch absorbers at CESR [8].

SUMMARY

The vacuum chamber utilizing an X-ray transparent membrane is expected to reduce the photon-induced gas and electrons around the beam orbit. In order to prove its feasibility, the first-stage experiment on the beryllium membrane has been started. The fact that the better performance than expected from the transmissivity calculation was observed is leading to the large potentialities of the beryllium membrane for high performance vacuum chambers.

ACKNOWLEDGMENT

The author would thank S. Asaoka for the offer of the beryllium window and K. Tsuchiya for the photon flux data of the PF and the PF-AR. The experimental equipments were prepared with the aid of H. Sasaki and the Mitsubishi Electric System Service staff for the PF light source division.

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