

# VACUUM DESIGN OF THE TPS RELATES TO THE BEAM EFFECTS

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## Abstract

The concept of the vacuum design for the 3 GeV Taiwan Photon Source (TPS) considers several points of view which relates to the beam effects. The vacuum design of the low outgassing rate and the effective pumping configurations to obtain the lowest average pressure in the electron storage ring is to obtain the longer beam life time and the least of the ion trapping effect and the consequent problem of beam ion instability. The inner structure of the beam ducts provides the lower impedance which reduces the problems of the collective beam instability and the heating dissipation and damage to the vacuum components. The thin wall of the beam ducts and the bellows are designed for the sextupoles that offers the function of fast orbit feedback correction of the beam. The final performance of the third generation light source with low emittance will rely on the original design of vacuum systems for the electron beam. The design philosophy of the vacuum systems for the TPS will be described.

## INTRODUCTIONS

The 3 GeV Taiwan Photon Source (TPS), designed as a third generation synchrotron light source with a low emittance of  $< 2$  nmrad, [1] is to be constructed since 2009. The large size aluminum bending chamber for the beam ducts [2] gains the profits from the localized pumping near the absorbers in the antechamber, smooth and precise machined surface, etc., and provides the lower impedance. The oil-free manufacturing processes for the chambers by pure alcohol and the afterward rinsing with ozonate water [3] produce a clean surface with a thermal outgassing rate as low as  $3.3 \times 10^{-14}$  Torr·L/s·cm<sup>2</sup> and a yield of photon stimulated desorption (PSD) below  $1 \times 10^{-4}$  molecules/photon. However, a request of thin wall chambers in the achromatic sections for the function of fast orbit feedback (FOFB) and the implementation of small gap insertion devices at the straight sections against the rule of thumb. The optimized design of the vacuum systems for achieving the low pressure as well as the low impedance will be described in the following sections.

## OUTGAS AND PRESSURE OF VACUUM SYSTEM FOR ONE UNIT CELL

The vacuum system for the electron storage ring is divided into 24 unit cells separated by the straight sections of  $6 \times 12$  m and  $18 \times 7$  m. Cross section of beam duct is elliptical shape with inner diameters of 30 mm  $\times$  68 mm. The main parameters for the TPS vacuum

systems are listed in Table 1. Figure 1(a) illustrates the layout of the vacuum system for one unit cell. The B1 and B2 chambers, each of  $\sim 4$  m in length, are CNC-machined in pure alcohol, Ozonate water rinsed, peripheral TIG welded in low humidity clean room, prior the assembly.

Table 1: Main parameters for the TPS vacuum systems

Parameters		Values
Beam Energy	E	3.0 GeV
Beam Current	I	400 mA
Bending Radius	$\rho$	8.403 m
Bending Angle	$\theta$	7.5°
Bending Magnet Field	B	1.190 Tesla
Critical Energy	$\epsilon_c$	7.126 keV
Linear Photon Flux	$\hat{\Gamma}$	1.54E+17 photons/s/mrad
PSD Yield at 100 A·h	$\eta$	1.0E-6 molecules/photon
Angular PSD Rate	Q	4.4E-9 Torr·L/s/mrad
Power Loss per Dipole	Pl	7.11 kW
Angular Power Density	Pd	54.3 W/mrad

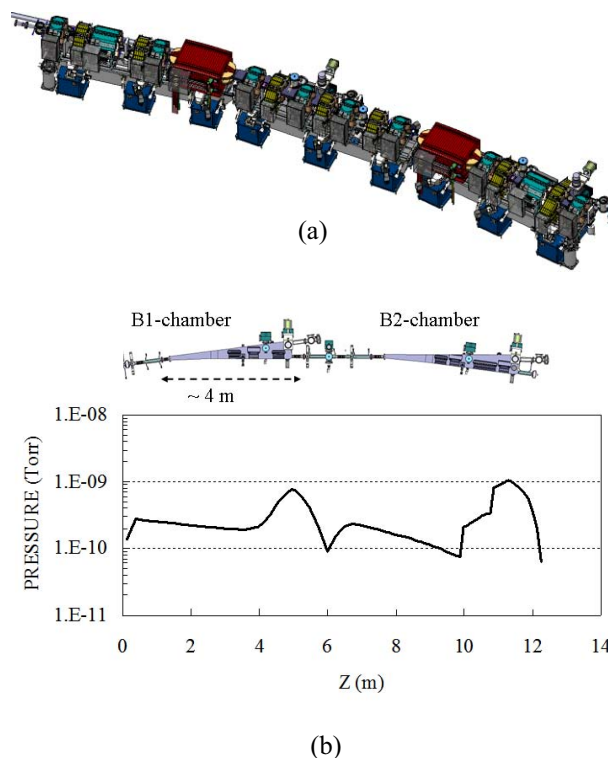


Figure 1: Assembly drawings of B-chambers coexisting with the magnets for one unit cell (a), and the vacuum chambers with pressure distribution simulated with a Monte-Carlo program at 400 mA and 100 A·h (b).

The crotch absorbers, made of OFHC copper, in the B-chambers at about the distance of 2.3 m from the bending magnet source are capable of withstanding the heat load from the irradiation at normal incident angle. It gives a

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lowest outgassing rate of PSD out of the crotch absorbers and the consequent back stream of outgas to the beam duct. The UHV pumps composed of sputtering ion pumps (IP, 150 l/s) and the lumped St-707 NEG pumps (500 l/s) are installed closed to the absorbers and the beam ducts for higher pumping efficiency. The NEG is effective for pumping the major outgas of H<sub>2</sub> and CO, while the IP is helpful for pumping all the gases especially the noble

gases such as CH<sub>4</sub>, and the inert gases, e.g. He, Ne, Ar. The result of simulation for the pressure distribution along the beam duct at beam dose of 100 A·h with a gas composition of H<sub>2</sub> (80%) and CO (20%) are shown in Fig. 1(b). The obtained average pressure of ~ 0.32 nTorr is limited by the insufficient pumping for the higher PSD-outgas near the crotch absorbers in B1 and B2 chambers.

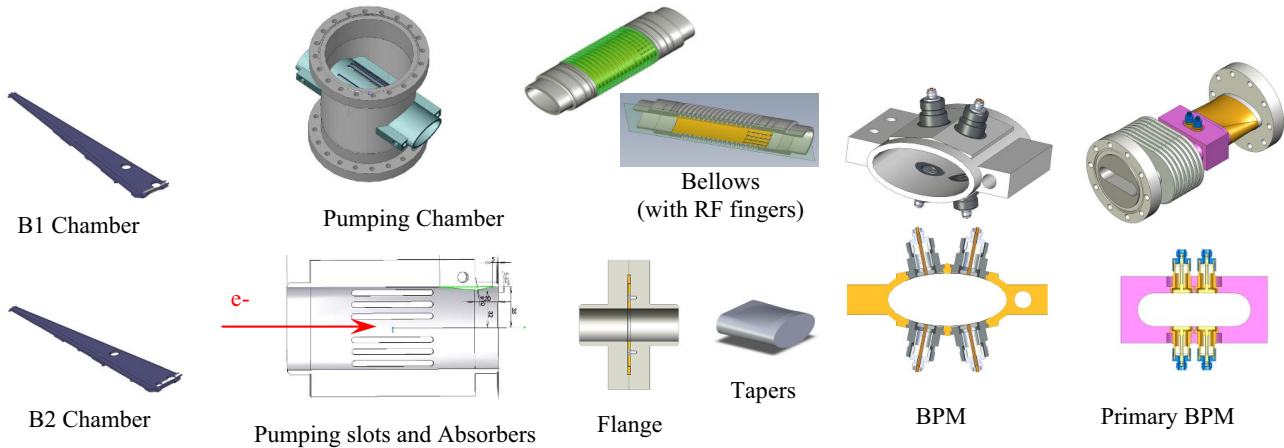


Figure 2: Design drawings of the vacuum parts for the evaluations of the impedance.

## IMPEDANCE OF VACUUM CHAMBER

The impedance of vacuum chambers that influences the electron beam is called broadband impedance. The parts of the chambers, as shown in the Fig. 2, including flanges, bellows, tapers, pumping slots, absorbers, beam monitors, gate valves, etc. have considerable impedance. The RF-contact structures generally fill the discontinuous parts for reduction of the impedance, but the number of thin slits or slots should allow enough pumping of gases inside the shielded RF-contact components. Preliminary calculations [4] have been made for inspecting the impedance of the vacuum parts. In principle, the cross section of the beam duct should vary smoothly. The height for a discontinuity in the chambers must be < 0.5 mm for the standard beam duct, but < 0.3 mm for the ID beam ducts with an inner height of < 20 mm. The variation in the cross section of the tapers should be smooth, with an angle of inclination of < 1/10. The pumping slots are typically placed on both sides of the beam duct, so as not to influence the electron beam transversely.

### Ion Scattering and Beam Life Time

Residual gas molecules in the vacuum system of the storage ring become positively ionized and are attracted by the circulating electron beam. As the mass of ions greatly exceeds that of an electron, the attraction of ions by the electron beam causes an ion-trap effect that can disturb the beam orbit by causing problems of instability. Furthermore, scattering by residual gas molecules causes loss of electrons, decreasing the circulation lifetime of the

beam. The limitation of the gaseous life time is dominant by the inelastic bremsstrahlung scattering of the electron with the nuclei [5], labelled " $\tau_{BS}$ " (see Eq. 1).

$$\tau_{BS} = X_0 / (W \rho c) = 3.2 \times 10^{-8} X_0 / MP \text{ (hour)} \quad (1)$$

in which  $X_0$  (g/cm<sup>2</sup>) is the radiation length,  $\rho$  (g/cm<sup>3</sup>) is the density of residual gases,  $c$  is the speed of light,  $W = [4/3 \ln(\gamma/\Delta\gamma) - 5/6]$ , and  $\gamma$  is the relativistic energy of the electron beam.  $\rho = 5.5 \times 10^{-8} MP$ , with  $M$  (a.m.u) the mass of residual gaseous molecules, so  $P$  (Torr) is the pressure, and if  $\Delta\gamma/\gamma = 1\%$  for instance of TPS. The  $X_0/M$  is 29 for H<sub>2</sub>, 2.8 for CH<sub>4</sub>, 2.0 for H<sub>2</sub>O, 1.3 for CO, and 0.82 for CO<sub>2</sub>.

The solutions for increasing the beam life time are not only to reduce the quantity but also to reduce the higher atomic number of the residual gases in the beam duct. The cleaning of the beam ducts by the ozonate water [3] is helpful for reduction of the carbonaceous gases.

### Ion Trapping

It has been studied the trapped ion effect for the TLS. The calculation of the critical mass (see Eq. 2) [6] is 0.4 a.m.u. or less. Thus the ions of all the residual gases will be trapped by the electron beam.

$$A_{c, x/y} = (N_e \cdot r_P \cdot C_L) / [2n^2 \cdot \sigma_{x/y} \cdot (\sigma_x + \sigma_y)] \quad (2)$$

However, the estimation of Eq. 2 in the case of TPS does not give a critical mass higher than 2 a.m.u. due to the major factor of smaller beam sizes in comparison with those of TLS. Thus all the residual gases will be trapped and the ion instability problem is still essential.

### Fast Orbit Feedback

Regarding the function of the fast orbit feedback system at a bandwidth higher than 300 Hz, the vacuum chambers with thin wall are requested for the sextupole (S-) magnets in which the coils for the fast correction magnets are wound. The non-magnetic Ti-bellows with interior CuBe RF contact shielding will be inserted inside the S-magnets, four for each cell. Figure 3(a) shows the cross section of the bellows with S-magnet which keeps a clearance of 0.92 mm in between. In the case of B-chambers with S-magnets, three for each cell, the chamber wall inside the S-magnets will be machined down to a thickness of 1.5 mm and left a clearance of 1.6 mm in between, as shown in Fig. 3(b). A thin rib of 1 mm in thickness link the thick parts outside the S-magnets is left for strengthening the thin wall against the atmospheric pressure.

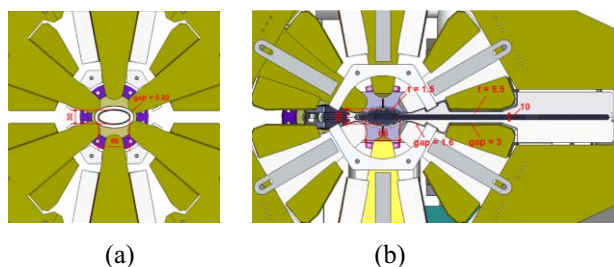


Figure 3: Schematic drawings of the cross sections for the bellows inside the S-magnet (a), and the B-chamber with the S-magnet (b).

### CONCLUSION

Design of the vacuum systems for the TPS adopt the large size of aluminum B-chambers for the benefits of low impedance, localized pumping, precise CNC machining, and oil-free cleaning processes. The quantity of the components including the flanges and the pumping slots are hence reduced. The ozonate water cleaning for the B-chambers and the crotch absorbers able to be irradiated normally that gives a lower outgassing rate of PSD. The composition of NEG and IP are mounted closed to the beam ducts provides a higher pumping efficiency that the dynamic average pressure of  $\sim 0.3$  nTorr be

obtained at beam current of 400 mA and a beam dose of 100 A-h corresponding to a PSD yield of  $1 \times 10^{-6}$  molecules/photon. The ion instability problem is still essential for the low emittance light source that the implementation of the fast orbit feedback system is required. The design of thin wall bellows and the machined thin wall chambers for the correction coils on the sextupole magnets provide the function of fast feedback systems up to 300 Hz.

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