OPTIMIZATION OF THE ULTRA-HIGH VACUUM SYSTEMS FOR THE 3 GEV TPS SYNCHROTRON LIGHT SOURCE

G. Y. Hsiung#, C. K. Chan, C. C. Chang, C. L. Chen, C. M. Cheng, Y. T. Cheng, S. N. Hsu, H. P. Hsueh, Yingtzu Huang, Albert Sheng, L. H. Wu, Y. C. Yang, NSRRC, Hsinchu, Taiwan
J. R. Chen, NSRRC, Hsinchu; National Tsing Hua University, Hsinchu, Taiwan

Abstract

The Taiwan Photon Source (TPS), a 3 GeV synchrotron light source, provides an ultra-low emittance of electron beam and the consequent extremely high brightness of photons. The vacuum pressure along the beam duct should be ultra-high vacuum (UHV) and even lower for reduction of the impact to the beam from the gas scattering or ion trapping troubles. Most of the outgas comes from the photon stimulated desorption (PSD) back streaming from downstream absorbers during beam operation and large area surface outgas inside the beam duct as well. Due to the anticipate request of the smallest vertical aperture of beam ducts from various insertion devices and the lowest broadband impedance through all the vacuum chambers of electron storage ring, the inner structure design and the surface treatment of vacuum chambers as well as the constraint of the back stream PSD outgas from distributed absorbers and the pumping locations should be optimized to obtain a high quality UHV system for the high stable synchrotron light source through the long period of operation. The optimized design of the vacuum chambers for the TPS will be described.

INTRODUCTION

The vacuum system for the 3 GeV Taiwan Photon Source (TPS) had been designed [1,2] and started the construction since 2010 after confirming the successful manufacturing process for the large aluminium bending chamber to meet the requirement of ultra-high vacuum (UHV) [3]. Since the vacuum pressure along the beam duct of the electron storage ring should be UHV for reduction of the impact to the beam from the gas scattering or ion trapping troubles, and the anticipate lowest broadband impedance through all the vacuum ducts are requested, the geometric structure of the vacuum chambers must be precisely controlled for optimizing the performance. The concepts including the structure inside the chamber, the surface cleaning process, the constraint of the back stream PSD outgas from the absorbers, and the efficient pumping aspects should be optimized to obtain a high quality UHV system for the high stable synchrotron light source through the long period of operation. The optimized design of the vacuum chambers, the components with lower impedance, and pressure calculation for the TPS will be described.

#hsiung@nsrrc.org.tw

DESIGN OF THE VACUUM SYSTEM

The vacuum system for the electron storage ring not only conforms to the basic physical parameters but also achieves the appropriate manufacturing capability that fulfils the UHV performance. The arc-cell vacuum system, ~ 14 m in length, comprises of two bending chambers (B1-ch, B2-ch) and two short straight chambers (S3-ch, S4-ch). Figure 1 shows the schematic drawing of the transection profile for a typical arc-cell. The four chambers with the two bellows are welded to form one piece of vacuum sector, connecting with two sector gate valves (SGV) sealed on both ends. There are 24 arc-cells for the TPS electron storage ring. The vacuum systems for each cell are pre-aligned, welded, assembled, and vacuum baked in the clean room. The vacuum cells sealed in vacuum with SGV will be moved to the tunnel with a carrier for installation on the pre-aligned girder-supports.

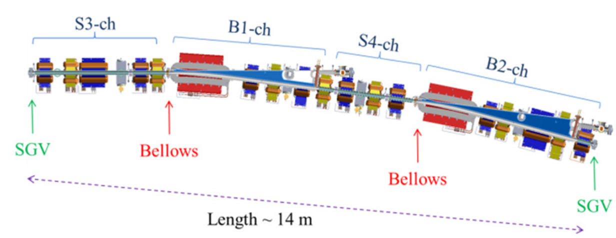

Figure 1: Schematic drawing of the transection profile for a typical 14 m arc-cell vacuum system.

Design Philosophy

The design of the vacuum beam ducts adopts a completely precisely oil-free machining process for the aluminium plates that simplifies the functional structure of beam ducts, and in-house welding to form one piece of 14 m arc-cell sector chamber with smoothest surface. The major advantages of the design contain:

- ***Low impedance*** of the smoothest surface along the beam channel. The structures like holes, gaps, steps, tapers, corrugation, etc. are removed from or reduced the quantity in the chambers.
- ***Precisely oil-free machining process*** for the large aluminium bending chambers. All the manufacturing processes and welding are performed in the clean room with well controlled temperature in 24~25 ˚C, and a relative humidity < 50%. The pure ozonate water cleaning for the aluminium chambers reaches to a lowest rate of thermal outgas < 1×10^{-11} Pa·m/s after vacuum baking at 150 ˚C for 24 h.

ISBN 978-3-95450-115-1

- ***No in-situ baking for the arc-cell vacuum system*** inside the tunnel. All the 14 m vacuum cells will be ex-situ baked to UHV and vacuum sealed in the laboratory to assure the quality prior to the installation. The manpower and maintenance time consuming in the tunnel for in-situ baking can be saved, and the risk of losing the align-precision of BPM and leakage-troubles after baking be avoided.

COMPONENTS WITH LOW IMPEDANCE

The vacuum components along the beam ducts including the sector gate valves, bellows, BPM, flanges, taper chambers, pumping slots, etc. with in-continuous cross section structures will result in the broadband impedance troubles on the beam instability. The design of those components toward the lowest impedance was embedded. Most of them are foreseeable manufacturing with precise machining processes to the dimension < 0.1 mm. On the other hand, the quantities of the components are reduced. The prototyping tests for some critical parts are introduced in the following sections.

Sector Gate Valve

The sector gate valves (SGV) with comb-type rf shield is adopted [4]. The shielding block is made of OFHC copper and precise machined with narrow gaps of 0.5 mm for rf-shielding and gaps of 3.8 mm for pumping. Figure 2 shows the photographs of the SGV and rf shield. There will be two on both ends of each 14 m arc-cell for vacuum sealing.

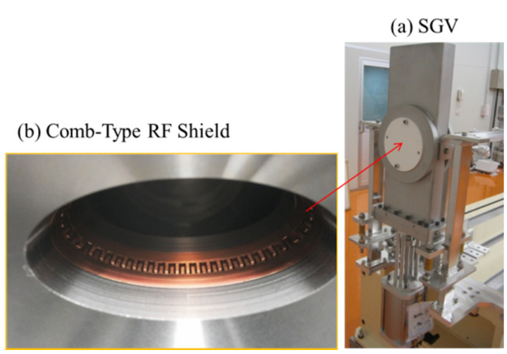

Figure 2: Photographs of the (a) sector gate valve (SGV) and (b) comb-type rf shield.

Bellows

The bellows with rf-fingers in TPS provide the functions of the absorption of tolerance for the beam base girder alignment and the fast orbit feedback correction during the beam operations. Figure 3 shows the photograph and drawing for the bellows. The materials include the non-magnetic titanium (Ti) alloy for bellows (0.15 mm thick), the OFHC copper for rf-fingers (0.2 mm thick), and the bimetallic joint transition between Ti and aluminium (Al) made from Hot Isostatic Pressing (HIP) for welding to the Al beam ducts. The spring loading applied on back side of each rf-finger is higher than 140 grams. The gap between the contact fingers is 1 mm in general for pumping.

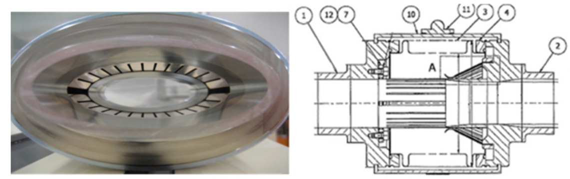

Figure 3: Photograph of the rf fingers and schematic drawing for the bellows.

Beam Position Monitors

Each beam position monitor (BPM) is divided into two parts, upper BPM-flange and lower BPM-flange. Every BPM-flange has two electrodes. There are five BPM assemblies in each arc-cell: three precise machined BPM beam ducts welded one in S3-ch and two in S4-ch, and two machined build-in flanges on B1-ch and B2-ch, respectively, for assembling the BPM flanges. Each BPM flange contains two electrical feedthroughs and electrode buttons. The in-house made electrical feedthrough is designed to match the impedance through the coaxial transmission line circuit [5]. The small gap of 0.4 mm between the electrode button and flange as well as the clearance of 0.025 mm between the flange and the beam duct assure the tolerable minimum impedance. The overall tolerances including the vacuum brazing for feedthrough and the laser beam welding for flange must be < 0.03 mm. With the careful control of manufacturing quality, the reflection coefficient of the BPM flanges measured by the time-domain reflectometer (TDR) is as small as < 5%, as shown in the plot of Fig. 4. In addition to the precise dimension control, every BPM flange has to pass the stringent cyclic thermal shock test of immersing into liquid nitrogen without any leakage, of the rate < 1×10^{-9} mbar·L/s.

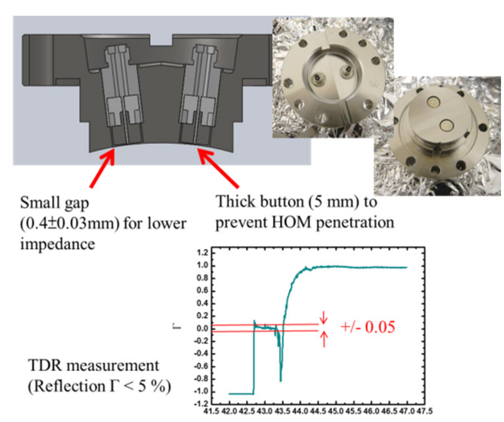

Figure 4: Drawing and photograph for the BPM-flanges, and the reflection coefficient measured by TDR.

PRESSURE DISTRIBUTION

The pressure distribution in the cell vacuum system was calculated with a Monte-Carlo computer program [6].

In the modelling, the thermal outgassing rate of the chamber and the photon-stimulated desorption yield of the absorbers are assumed from the experimental results. The beam-cleaning efficiency for the TPS during the early commissioning stage at the accumulated beam dose of 1 A h and 100 A h is evaluated. Since the thermal outgassing rate for the Al bending chambers is measured lower than 6.4×10^{-10} Pa·m/s [7], which is negligible during the commissioning stage. The major outgas due to the photon-stimulated desorption was assumed to be 80 % H_2 and 20 % CO. The effective pumping speed of various pumps depends on the gas was calculated from the rated speed of pumping assemblies and the conductance of the pumping port. The layout of ten pumping ports and the locations of absorbers for the arc-cell are shown in Fig. 5. The vacuum pumps include four sputtering-ion pumps (SIP, 200 L/s), seven GP500 non-evaporable getter (NEG) pumps, one GP200 NEG pump, and two STP451 magnetic levitation turbo-molecular pumps (TMP) are distributed in those pumping ports. The estimated effective pumping speed closed to the Cu-absorbers can be ~ 1500 L/s for H_2 and ~ 500 L/s for CO [6].

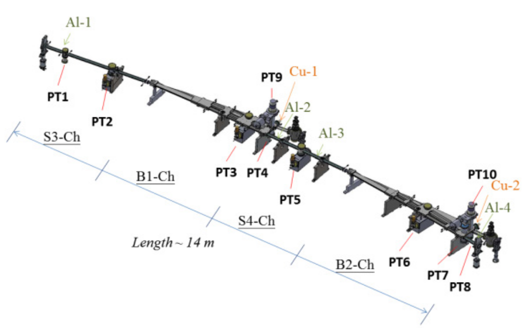

Figure 5: Layout of arc-cell vacuum system. PT1 ~ PT10 represent the ten pumping ports. Locations of four aluminium absorbers, Al-1 ~ Al-4, and two copper crotch absorbers, Cu-1 and Cu-2, inside the vacuum chambers are indicated.

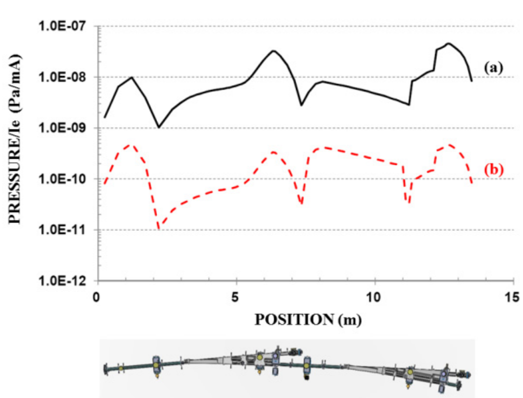

Figure 6: Curves of calculated distributed pressure per beam current, PRESSURE/Ie, for the unit-cell vacuum system at beam dose (a) 1 A h and (b) 100 A h.

The calculated mean pressure P_{av} at 100 A h is 7.7×10^{-8} Pa at beam current 400 mA. The equivalent average pressure rise per beam current, P_{av}/I_e, is 1.2×10^{-8} Pa/mA at 1 A h and 1.9×10^{-10} Pa/mA at 100 A h, respectively [6]. Figure 6 shows the two curves of the distribution of the mean pressure per beam current (PRESSURE/Ie) at beam dose of (a) 1 A h and (b) 100 A h.

CONCLUSIONS

The vacuum system for the TPS has been started the construction since 2010. The requirement of low impedance design for the vacuum chambers and the components is satisfied from the test results of the critical components, e.g. sector gate valves, bellows, BPM, etc. Most of the components must be precisely machined and welded to achieve a smallest dimensional tolerance in 0.1 ~ 0.3 mm. The 14 m arc-cell vacuum system is welded to one piece which minimizes the quantity of flanges and bellows. The aluminium bending chambers are machined oil-free with pure alcohol after with the ozonate water cleaning that produces a lowest desorption rate and benefit the beam cleaning efficiency during the early stage of beam commissioning. The calculated pressure distribution for the arc-cell, adopting the experimental test results, reaches to 7.7×10^{-8} Pa at beam current 400 mA after beam cleaning up to the accumulated beam dose of 100 A h which is satisfied and proves the optimized design concept for the TPS vacuum systems.

ACKNOWLEDGMENT

The authors would give their deep thanks to Dr. Y. Suetsugu (KEK) kindly sharing the Monte-Carlo program for the pressure calculation. Other thanks go to the staff of the vacuum group for their collaboration with the experiments.

REFERENCES

[1] G. Y. Hsiung, et al., "Vacuum Design of the TPS Relates to the Beam Effects", EPAC08, Genoa, Italy, THPP143, p. 3699 (2008); http://www.JACoW.org.
[2] G. Y. Hsiung et al., "TPS Vacuum System", PAC09, Vancouver, BC, Canada, MO6RFP018, p. 387 (2009).
[3] J. R. Chen, et al., "Vacuum system of the 3 GeV Taiwan photon source", J. Vac. Sci. Technol. A28(4), 942 (2010).
[4] Yusuke Suetsugu, et al., "Development of bellows and gate valves with a comb-type rf shield for high-current accelerators: Four-year beam test at KEK B-Factory", Rev. Sci. Instru. 78, 043302 (2007).
[5] I. T. Huang, et al., "Development of a Feedthrough with Small Reflection for the TPS BPM", IPAC2011, San Sebastián, Spain, TUPS029, p. 1593 (2011).
[6] G. Y. Hsiung et al., "Calculation of the pressure in the unit-cell vacuum system of Taiwan Photon Source", Vacuum (2012), doi: 10.1016/j.vacuum.2012.03.017. (In Press)
[7] C. K. Chan, et al., "Cleaning of Aluminium Alloy Chambers with Ozonized Water", Journal of Physics: Conference Series 100 (2008) 092025.

ISBN 978-3-95450-115-1