Vacuum design for the 3 GeV TPS synchrotron light source

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Abstract. The 3 GeV Taiwan Photon Source (TPS) is a synchrotron light accelerator which is designed for a beam emittance of < 2 nmrad at a beam current of 400 mA. The vacuum system for the electron storage ring provides a pressure of < 1 nTorr for the electron beam with long beam life time and small disturbance from trapped ions. Due to the limited space for the pumps and the poor conductance of the beam ducts, the vacuum chambers should be manufactured with a clean surface of very low outgassing rate. Aluminum alloys vacuum chambers and the structures of confined-pumping for the localized photo-desorption are selected to meet the design requirement. The CNC-machining for the bending chambers in pure alcohol spraying, followed by ozonated water cleaning and TIG welding in clean room, provides a clean surface and simple structure which lowers the outgassing rate and the chamber impedance. Combinations of the lumped non-evaporable getters (NEG) and the sputtering ion pumps are located near the absorbers for higher efficiency of localized pumping capability. Either the NEG-strips or interior NEG-coating will be used for the Undulator chambers for providing a good linear pumping feature. The design concept will be described in this paper. Besides, the simulation of the pressure distribution and some test results of outgassing measurement for the aluminum chambers will be discussed.

1. Introduction

The 3 GeV Taiwan Photon Source (TPS), a new accelerator for the synchrotron light source project in Taiwan, is designed for a beam emittance lower than 2 nmrad at a beam current of 400 mA. An optical lattice of 24-cell DBA structure with 6 long straight sections of > 10 m in length and 18 medium straight sections of > 5 m in length has been evaluated for the electron storage ring.[1] The vacuum system for the storage ring not only requests the average pressure lower than 1 nTorr but also the low impedance of chambers that provides a least disturbance environment for the circulated electron beam. A preliminary design for the vacuum system of the electron storage ring depicts the concept of aluminum chambers fulfills the requirements of the TPS lattice.[2] The concept of the large size bending (B-) chamber associated with the antechamber structure provides the confined outgas desorbed from downstream crotch absorbers and the localized pumping against the outgas backfilled to the beam channel. The precise CNC-machining method for the B-chamber provides a smooth inner surface near beam channel which benefits the lower deformation from evacuation as well as the lower
impedance of the chamber.[3] Some of design has been executed based on the existed experiences of the operation for the 1.5 GeV Taiwan Light Source (TLS) for its high reliability and stability performance.[4] To realize the design concept of the vacuum system for the TPS, several experiments have been done and will be described in the following sections of this paper.

2. Design philosophy
Since the broad band impedance from the vacuum chamber will affect the eventual beam performance such as the orbital stability and the beam emittance, the smoothest structure of the chamber near the beam channel is required. The structures like holes, gaps, steps, tapers, corrugation, etc. should be removed from the beam channel. The design philosophy for the electron storage ring adopts the large B-chamber, with reasonable length of about 4 ~ 5 m for machining and handling, which significantly reduces the quantity of the pumping holes, flanges, bellows, and welding joints. Figure 1 illustrates the drawing of a typical bending chamber with bellows-(a) and BPM-(b) be welded, and the flange ports for sputtering ion pump-(c), crotch absorber-(d), and NEG pump-(e) be welded on the chamber as well.[3] The backside of B-chamber will be machined out the materials near the magnets according to shapes of poles and coils to maintain the clearance of 0.6 ~ 3 mm without touching each other. The in-situ baking for the vacuum system inside the tunnel will not be practical due to a big effort of disassembling the magnets, releasing the supports, wrapping the heaters, etc. will consume the manpower, maintenance time, and lose the precision of alignment for BPM. All the cells of vacuum system will be pre-baked and vacuum sealed in the laboratory prior to the transportation and installation into the tunnel. Another ultra-low humidity controlled dry glove box will be employed for connecting straight chambers on both sides of the cells that effort of baking on-site will be saved.

![Figure 1. Cross section plan view of a typical bending chamber which contains (a) bellows, (b) BPM, (c) sputtering ion pump, (d) crotch absorber, and (e) NEG pump. The total length of chamber is about 4 ~ 5 m.](image1.png)

A Monte-Carlo program developed by Dr. Y. Suetsugu of KEK has been used for the pressure simulation.[5] The result of the pressure profile of one cell vacuum system for the 24DBA lattice is shown in figure 2. Combination of the sputtering ion pumps (400 L/s) and the lumped NEG pumps (500 L/s) gives a total effective pumping speed of 2400 liters per cell. The averaged pressure reaches 1 nTorr at 400 mA when the yield of PSD < 5.0×10^6 molecules/electron, which might take about 300 A·h of accumulated beam dose for the commissioning.[6]

3. Manufacturing processes and tests
The major effort for production of high quality aluminum vacuum chambers for the storage ring is to control the manufacturing process. All the processes including the machining, the cleaning, the welding, the assembling, and the installation, should be done in a clean and dry environment for maintaining the clean surface of the aluminum chambers. The processing steps and some test results will be described in the following sections.
3.1. Machining with CNC in ethanol and cleaning with ozonated water

The aluminum bending chamber, about 4 m in length, will be CNC-machined in ethanol environment for production of clean oxide layers which is similar with the process for TLS. However, the final step of cleaning with CFC is secured and will be replaced by another solvent. The ozonated water cleaning has been tested for its capability of removing the carbon from the top oxide layers of aluminum chamber. Several test aluminum samples with various surface treatments are compared. Three kinds of treatment labeled -A, -B, and -C represents the CNC machining in ethanol, followed by chemical cleaning [7], and followed by ozonated water cleaning, respectively. The AES survey spectra shown in figure 3(a) illustrates the treatment-C has least carbon (C) remaining on the surface. The pressure rise per beam current shown in figure 3(b) reveals a lowest desorption of PSD in case of treatment-C as well.[6] The rate of thermal outgassing for treatment-C, not shown in this paper, has measured and reached to < 5×10^{-14} Torr·L/s·cm^2 after baking at 150°C.[6] Those results confirm the aluminum surface cleaned with ozonated water obtains a low carbon contained oxide layer after baking.

![Figure 3](image)

(a) AES survey energy spectra, and (b) pressure rise per beam current of photon exposure, for aluminum test samples with different treatments of -A, -B, and -C.

3.2. Welding for the aluminum bending chambers and for the Beam Position Monitor (BPM)

The large aluminum bending chambers, after cleaning, will be performed the welding process in the clean room controlled with the dust and the low humidity. An automatic welding system has been developed for performing the TIG-welding on the straight edges of the chambers when joining the two heavy aluminum plates (~ 4 m) and be fixed on the movable stage for controlling the distortion. Prior to the welding for flanges on each piece of the halves, the BPM feedthroughs will be welded on the chamber by another laser beam welding system for assuring the precise fitting.

3.3. Assembly and baking

In order to save the time for assembly and baking works inside the tunnel, it is not proposed to do the in-situ baking on site. All the assembly works for the cells in arc-sections, with sector gate valves sealed on both ends, will be done in the clean room prior to the installation. The ultimate pressure and leakage will be inspected after baking in the laboratory that proves the vacuum performance b achieved. The assemblies of long straight sections can be done the same way as well, but will be purged with a super dry nitrogen gas to the atmosphere prior to the installation in the tunnel.

3.4. Installation and supporting

The assembly of the cells, ~ 14 m in total length, will be manipulated by a movable cart for transportation from laboratory to the storage ring building. Then a crane can lift the assembly of cell to the tunnel and position to the right supports which have been pre-aligned to a precision of < 1 mm. All
the magnets for the storage ring can be opened the upper halves for setting the assemblies of cells and closed afterward. The supporting system for the vacuum chambers will set the fix points near the BPM and longitudinal movable points on other sides of chambers. Basically, the vacuum chambers will be supported without touching the magnets. However, for assuring the precise position of BPM, the support for BPM is to be fixed on the same girder for the magnets. A setup of experiment for measuring the impact of vibration on the girder results from the cooling water for the vacuum chambers through the supports to the girder has been performed. To compare the impact of the turbulent flow of water to the chamber, the cooling pipes are welded to the chamber at entrance angles of 45° on one side and 90° on the other side. An accelerometer is mounted either on the chamber or on the girder for measuring the vibration amplitude. Figure 4 shows the typical vibration spectrum. The broadband vibration modes were excited near 240 ~ 280 Hz and higher harmonics are measured as well. However, no vibration is measured on the girder when the water flow rate increased to 10 L/min.

![Figure 4. Typical vibration spectrum measured on the vacuum chamber with cooling water flowing. The spectrum in 0 ~ 500 Hz shown in the lower diagram is enlarged from a total frequency band in 0 ~ 5000 Hz shown in the upper diagram.](image)

4. Conclusions
Design of the large size aluminum bending chamber for the TPS provides a low impedance of structure and low rate of surface outgas. In-situ baking for the chambers in the tunnel is not practical for the sake of tight clearance between the chambers and the magnets. Thus the ultra-low humidity controlled installation system is necessary for connecting the vacuum systems on-site. The moving cart and the crane are necessary for transporting and lifting the whole cell in vacuum during the installation. All the efforts give the highest reliable hardware systems and shortest time for maintenance works inside the tunnel. The stable beam orbit with a low emittance feature of TPS will be revealed as well eventually.

5. References
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Acknowledgments
Authors would like to thank to Dr. Y. Suetsugu (KEK) for his kindly sharing the program for pressure simulation. Other thanks give to Mr. T. T. Tzeng (NSRRC) for collaboration on girder vibration test.