MANUFACTURING AND VACUUM TESTING OF AN ALUMINIUM BENDING CHAMBER FOR TPS

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Abstract

Taiwan Photon Source (TPS) has a vacuum system of aluminium alloy and a circumference 518.4 m divided into 24 sections. Aluminium material A6061T651 is used for TPS bending chambers. An aluminium bending chamber has as components two half plates, length about 3.5～4.2 m and width～0.6 m, that were CNC machined oil-free, cleaned with ozonized water, and AC-TIG welded in a clean room. Machine deformation < 0.1 mm, welding deformation ±0.3 mm, and leakage rate < 3×10^{-9} mbar L s^{-1} for each bending chamber have been inspected and achieved. Ultimate pressure ~6.2×10^{-10} torr was attained after a baking test at 150 ^{0}C; the rate ~4.47×10^{-13} torr L s^{-1} cm^{-2} of thermal outgassing was estimated from a building-up method.

INTRODUCTION

TPS is a 3-GeV synchrotron storage ring with small emittance under construction in Taiwan. Aluminium alloy is chosen as the material for the vacuum chamber because of its large thermal conductivity, ease of fabrication, small rate of thermal outgassing and other benefits. An aluminium vacuum chamber is composed of two half plates that were CNC machined oil-free, cleaned with ozonized water, and AC-TIG welded in a clean room. The design of a large chamber of triangular shape concentrates the gas load downstream from the chamber, at which large pumping ports are arranged to decrease effectively the average pressure. In this paper, we describe the manufacturing process including machining, cleaning and welding, and a vacuum test with a pumping curve, leakage hunting, and a baking test for ultimate pressure.

LAYOUT

Figure 1 illustrates the layout of a bending vacuum chamber. Of bending chambers of three types in TPS, B1 is for insertion devices, B2 for bending magnets and B3 for IR; the required numbers are 24, 18 and 6, respectively. Inside the bending chamber, an electron beam duct has cross section 30 mm high, 68 mm wide and bending radius 8403.38 mm. The bending angle of the electron trajectory is 7.5°. A bending chamber consists of a 7.5° viewing port for downstream alignment, BPM ports for a beam-position monitor, pumping ports for ion pumps, NEG pumps and turbo pumps, and an absorber port for a crotch absorber in the transverse direction to intercept the heat load. The large triangular bending chamber of length ~4 m for the beam duct was designed for localized pumping near the crotch absorbers in the antechamber to increase the effective speed of pumping, and to decrease the numbers of on-axis pumping ports so as to obtain a small impedance across a smooth surface [1,2]. The crotch absorber located downstream from the bending chamber was designed to take a heat load 9 kW generated by each dipole magnet to protect the transverse areas of the bending chambers downstream.

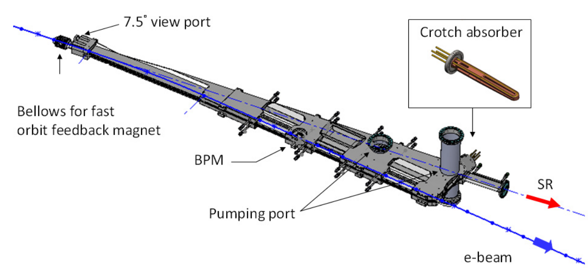

Figure 1: Layout of a B1 bending vacuum chamber

MANUFACTURING

Machining

A6061T651 aluminium alloy plates of length 4000 mm, width 650 mm and thickness 50mm were used to machine the bending chambers. A bending chamber is composed of two half plates that were machined with computer numerical control (CNC) and sprayed with pure alcohol. To minimize machine deformation, rough, intermediate and precise machining, and an aging treatment between machining, were arranged. The overall flatness of a half plate for the bending chamber after machining is less than 0.1 mm/4 m. A special tool was used to machine the surface of the beam-position monitor (BPM) for sealing with a diamond gasket. A roughness of the sealing surface for the BPM less than 0.2 μm was achieved [3].

Cleaning

After CNC machining, the aluminium plates were cleaned in an ozonized water bath; such cleaning provides a content of carbon on the surface smaller than with other cleaning methods [4]. Cleaning involved immersing the aluminium plates in an ozonized (>20 ppm) water bath for 30 min, and then drying under 99.9995 % nitrogen. The other chambers such as pumping tubes and ellipse beam ducts made by extrusion were cleaned with chemical methods. The total content of organic carbon (TOC) in

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the water for the cleaning should be minimized for vacuum cleanliness; the smaller is the TOC content, the lower is the ultimate pressure of the vacuum chambers.

Welding

AC tungsten-inert-gas (TIG) welding was applied to weld the aluminium at NSRRC. After ozonized cleaning, the aluminium plates were transferred into a clean room for welding and vacuum testing. A clean room (class 1000) with temperature 25±0.5 ^{o}C and relative humidity less than 50 % ensures the welding tolerance and surface cleanliness during welding and the vacuum assembly. Welding methods of two kinds were applied – manual welding for pumping ports, curved sides and water pipes, and automatic welding for both straight sides of the chambers. The first welding scheduled was socket welding of the pumping ports with aluminium plates, then circumferential welding of the two plates. Aluminium/ stainless-steel explosion-bonded bimetal-conflate (CF) flanges were used for the pumping-port flanges. It is important to ensure that the bimetal flanges have no leakage before welding with the pumping tubes. A thermal shock test with immersion in a liquid-nitrogen bath for 10 min was undertaken in an inspection to ensure that the explosion-bonded interface is strong and has no leak. The dimensional test and leakage rate were recorded for all pumping ports after welding the pumping ports.

For circumferential welding, two plates were fixed together with a pin rod and then tag-welded to decrease the deformation due to the large thermal expansion of aluminium. Because of the long circumference of TPS, one automatic welding system with six torches developed in NSRRC [5] was applied to weld both straight sides. Six torches welded concurrently, and plates were preheated at ~100 ^{0}C to minimize the deformation during welding. After automatic welding, the vacuum vessel was completed with manual welding of the curved ports and end ports. Maximum deformation ~0.3 mm was measured on the upstream side with a laser tracker after the welding.

VACUUM TEST

Pumping curves, mass spectra with a residual-gas analyzer (RGA) and leak testing are involved in the basic certification of all bending chambers after welding. Leak testing and mass spectra ensure that TIG welding is free of leakage; a leak rate < 3×10^{-9} mbar L s^{-1} was obtained after welding. Pumping curves and RGA spectra are involved in the inspection of the cleanliness of the vacuum surface. Figure 2 shows a pumping curve of chamber R01B2. From the slope of the pumping curve, the cleanliness of vacuum surface was roughly inspected. The slope of the pumping curve is proportional to t^{-1}, as expected for a pumping behaviour dominated by water.

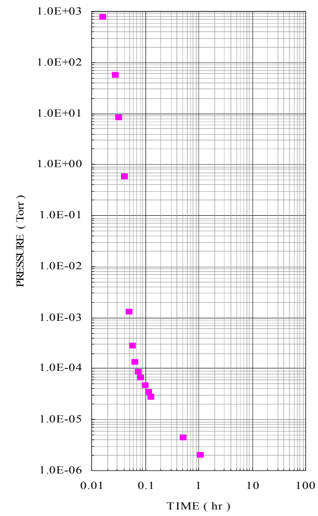

Figure 2: Pressure of chamber R01B2 after welding; the slope of the pumping curve is proportional to t^{-1}.

Baking Test

A baking test was done to inspect the ultrahigh-vacuum performance. Figure 3 displays the baking test of chamber R01B1, including a pumping system at 70 L/s, ion gauge and RGA. After pumping down for 24 h, baking in situ at 150 ^{0}C for 24 h and cooling to room temperature for 24 h, an ultimate pressure 6.2×10^{-10} torr was achieved. A pumping curve of the baking test is shown in Figure 4.

Figure 3: Baking test of chamber R01B1, including a pumping system at 70 L/s, ion gauge and RGA.

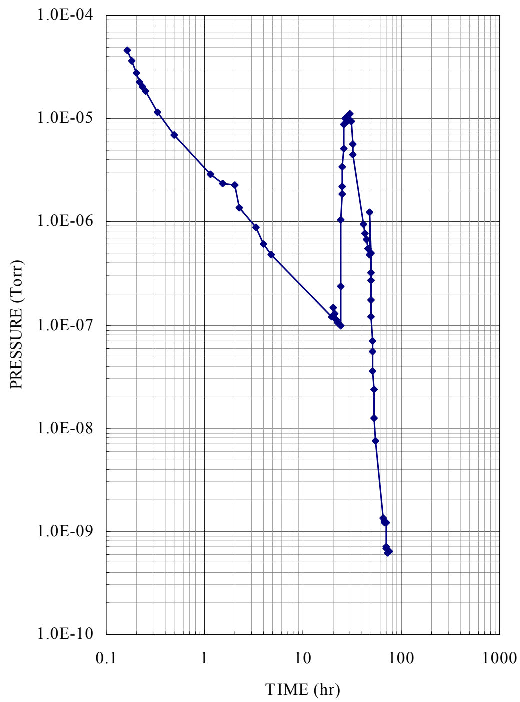

Figure 4: Pumping curve of chamber R01B1 for the baking test. An ultimate pressure 6.2×10^{-10} torr was achieved after the baking test.

Figure 5 shows the mass spectrum from a RGA after a baking test. The major residual gases are H_2, C, H_2O, CO and CO_2.The signals of hydrocarbon and water are still large likely because of an inadequate baking temperature for the stainless-steel material, such as flange blanks, metal angle valves and the RGA tube.

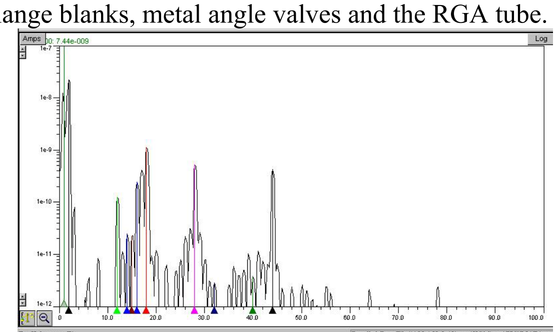

Figure 5: Mass spectrum from the RGA after a baking test. Major residual gases are H_2, C, H_2O, CO and CO_2.

Rate of Thermal Outgassing

Before and after the baking test, the rate of thermal outgassing was estimated with a building-up method. This equation applies to gas flow at equilibrium,

$$Q = S\,P + V\frac{dP}{dt} \tag{1}$$

in which Q is the rate of thermal outgassing, S is the pumping speed, P is pressure and V is the volume of the system. If $S = 0$, equation (1) becomes

$$Q = V\frac{dP}{dt} \tag{2}$$

The rate Q of thermal outgassing was obtained on closing the metal angle valve to isolate the pumping system. A rate q_{20} (q=Q/A, A is the area of the interior surface) ~4.3×10^{-12} torr L s^{-1} cm^{-2} of thermal outgassing before the baking test, and q_{72}~ 4.47×10^{-13} torr L s^{-1} cm^{-2} after the baking test were achieved. Figure 6 displays the building up of the mass spectrum after the baking test.

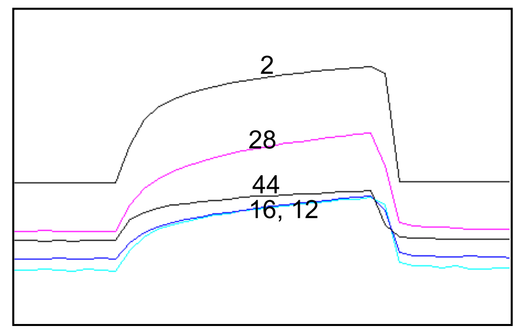

Figure 6: Temporal variation of the mass spectrum after a baking-out test

CONCLUSIONS

Twenty-one bending chambers were completed and maintained in a vacuum environment for the next welding process on site of the cell unit. A welding deformation ~±0.3 mm and leakage rate < 3×10^{-9} mbar L s^{-1} of each bending chamber have been inspected and achieved. An ultimate pressure ~6.2×10^{-10} torr has been attained after a baking test at 150 ^{0}C; the rate ~ 4.47×10^{-13} torr L s^{-1} cm^{-2} of thermal outgassing was estimated with a building-up method.

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