RESIDUAL GAS IN THE 14 M-LONG ALUMINIUM VACUUM SYSTEM OF THE STORAGE RING OF TAIWAN PHOTON SOURCE: TOWARD ULTRA-HIGH VACUUM

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Abstract

In the Taiwan Photon Source project, the storage ring includes 24 sectors (each of length 14 m) of an aluminium vacuum chamber system. The design, manufacture, cleaning, welding and assembly of the vacuum components were undertaken by the NSRRC vacuum group. The ultimate objective is to attain a leak-tight, ultra-high vacuum and a vacuum system with a small rate of outgassing. In this work, we used a residual-gas analyzer (RGA) to analyze the variation of residual gas during proceeding toward ultra-high vacuum. This process, which led the pressure down to ~10^{-11} torr, includes baking, operation of ion pumps, degassing of hot cathode gauges and activation of NEG pumps. When a sufficiently small low pressure is attained, the ion pumps are turned off to test the building up of pressure. The outgassing property and the variation of the residual gas of the aluminium chamber and the ion pumps can be measured.

INTRODUCTION

The vacuum system for the electron-storage ring is divided into six-fold super-period systems; each comprises four long straight sectors, with lengths one 12 m and three 7 m, and four arc-cell bending sectors of lengths 13 ~ 14 m. Each cell of length about 14 m contains two bending (B-) chambers and two short straight (S-) chambers, with a sector gate valve at both ends.

Each cell unit has ten pumping sites: four ion pumps with a NEG pump installed inside each and six NEG pumps in six separate pumping ports. The extractor gauges and the RGA are installed in the four ion pumps. Figure 1 shows the layout of the components in a cell. During the baking, five turbo-molecular pumps were installed on three ion pumps and two pumping gate valves to treat the outgassing. As our vacuum chamber material is aluminium, the target temperature should not exceed 150 °C. The chamber temperature was heated to 150 °C in 8 h, with that temperature sustained for about 18 h, and cooled to room temperature in 8 h. The ion pumps and extractor gauges were degassed, and the NEG pumps were activated before the cooling. When room temperature was attained and the leak test passed, the pressure attained about 2x10^{-11} torr.

EXPERIMENTS

The aluminium chambers were machined completely free of oil, followed by cleaning with ozonized water and welding in a clean room. After two bending (B-) chambers and two short straight (S-) chambers were welded together to form a unit cell of length 13~14 m, all vacuum components, including two sector gate valves (comb-type, rf-shielded, VAT), three extractor gauges (Leybold), four triode ion pumps (Starcell, speed 200 L s^{-1} for nitrogen, Varian), ten NEG pumps (type MK5 SAES getters), five beam-position monitors, two crotch absorbers, two photon absorbers, two front-end valves and two pumping gate valves, were then installed on the cell chamber and pumped before leak testing. After assembly of the components, leak testing and function tests, the unit cells were wound with heating tapes (BriskHeat) and wrapped with aluminium foil and film (Kapton) to preserve the heat. As the thermal expansion due to a sudden alteration of temperature might cause leakage, we heated and cooled the cell at a coherent speed approximately 30°C/h by adjusting the voltage applied to the heating tapes on various parts. To reach the target temperature 150 °C took about 8 h, and 18 h to sustain the temperature. The ion pumps were turned on, and the gauges and the RGA were degassed before cooling and again at about 110 °C. The cartridge NEG pumps were activated at 150 °C after degassing. When the cell cooled to 80 °C, all screws joining aluminium flanges were tightened to torque 100 cm kg. Once it cooled to 40 °C, the cell would undergo the first leak test with the RGA. The second leak test was done at room temperature.

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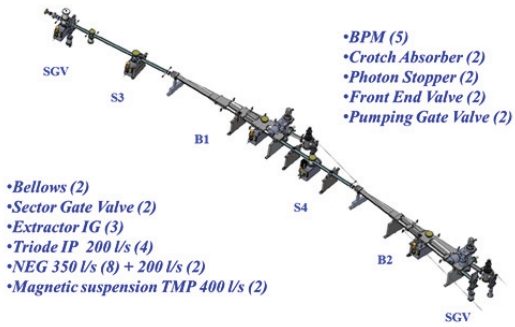

Figure 1: A standard ultra-high vacuum unit cell for the electron storage ring.

RESULTS AND DISCUSSION

Figure 2 shows the pressure variation of cell R20 during baking. A sudden rise of pressure about hour 27 is due to the ion pumps, gauges, RGA degassing and NEG activation. The trend of residual gas and spectrum are shown in Figure 3 and Figure 4. In the first 7 h of heating, the intensity of almost every selected mass rose until the target temperature was attained. The cartridge NEG pumps were then activated at 450 °C for 45 min as suggested by the manufacturer of the SAES getters. During their activation gases desorbed from the getter cartridge; physisorbed gases formed external monolayers covering the surface of the getter material, whereas internally chemisorbed layers were diffused into the bulk of the getter material. Desorbed gases included H_2, H_2O, CO, CO_2, CH_4 and eventually H_2, because of the behavior of the getter material toward this gas (Figure 4).

After activation of the NEG pumps, the chamber was cooled to 110 °C for further degassing. The chamber was then cooled to room temperature at a rate less than 30 °C/h. As aluminium has a thermal- expansion coefficient larger than that of SUS, the screws joining two Al flanges were retightened to the original torque 100 cm kg. The pressure continued to decrease as the chamber temperature decreased.

As the pressure decreased below 10^{-8} torr, all ion pumps were switched on and all turbo-molecular pumps were then isolated with the metal angle valves. When the system cooled to 40 °C, the first leak test was done. The heating power supply was turned off after that leak test, before cooling to room temperature for the second leak test on the next day.

Figure 5 shows the trend of residual gas. Most mass signals related to H_2, H_2O, CO, CO_2 and CH_4 decreased, especially mass 18. The current decreased from 3.77×10^{-9} A to 2.58×10^{-12} A, which indicates that most water had been expelled from the vacuum system, but the current of mass 40, which implies argon, increased during heating and in the early stage of operation of the ion pumps. With the system cooling and the ion pumps acting, the current at mass 40 finally decreased below the initial value.

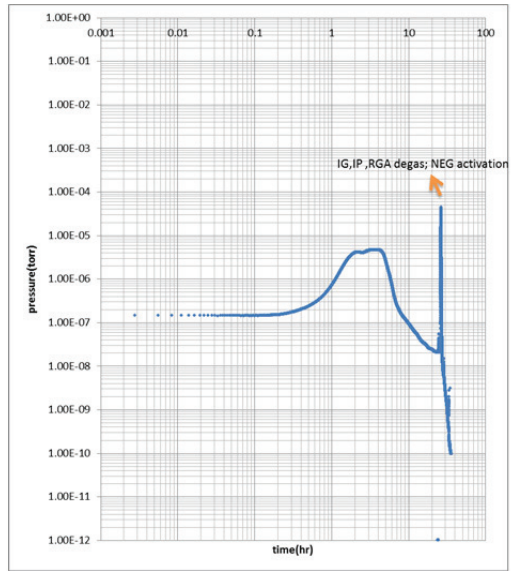

Figure 2: Pumping curves for CELL 20 vs time during baking.

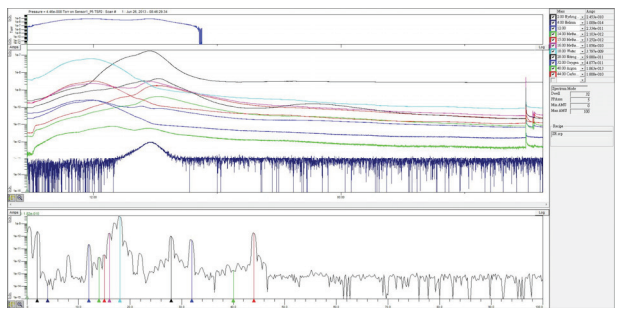

Figure 3: Residual gas trend and spectrum during baking and degassing.

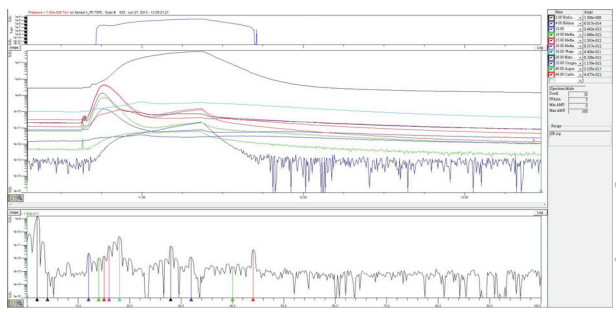

Figure 4: Trend of residual gas and spectrum during activation of the NEG pumps and cooling.

In a vacuum system, the relation between the rate of outgassing and the pumping speed is written as[1]

$$Q = SP + V\frac{dP}{dt} \quad (1)$$

in which Q denotes the total rate of outgassing, SP the amount of gas pumped in a unit period of time, S pumping speed, P pressure, $\frac{dP}{dt}$ pressure change per unit period of time and V volume of the vacuum system;

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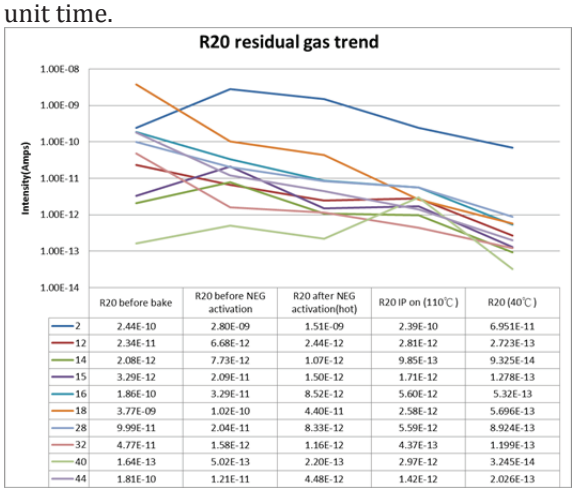
$V\frac{dP}{dt}$ is the change of the amount of gas molecules per unit time.



	R20 before bake	R20 before NEG activation	R20 after NEG activation(hot)	R20 IP on (110℃)	R20 (40℃)
2	2.44E-10	2.80E-09	1.51E-09	2.39E-10	6.951E-11
12	2.34E-11	6.68E-12	2.44E-12	2.81E-12	2.723E-13
14	2.08E-12	7.73E-12	1.07E-12	9.85E-13	9.325E-14
15	3.29E-12	2.09E-11	1.50E-12	1.71E-12	1.278E-13
16	1.86E-10	3.29E-11	8.52E-12	5.60E-12	5.32E-13
18	3.77E-09	1.02E-10	4.40E-11	2.58E-12	5.696E-13
28	9.99E-11	2.04E-11	8.33E-12	5.59E-12	8.924E-13
32	4.77E-11	1.58E-12	1.16E-12	4.37E-13	1.199E-13
40	1.64E-13	5.02E-13	2.20E-13	2.97E-12	3.245E-14
44	1.81E-10	1.21E-11	4.48E-12	1.42E-12	2.026E-13

Figure 5: Variation of the trend of residual gas due to operation of the pumps.

Solving equation 1, we obtain

$$P(t) = \frac{Q}{S}\left[1 - e^{-\left(\frac{S}{V}\right)t}\right] + P(0) \qquad (2)$$

in which $P(0)$ is the pressure at t=0, and $P(t)$ is the pressure at time t. To calculate the pumping speed (S) of the vacuum system, we turned off the ion pumps and recorded the building pressure (Figure 6). Each gauge record was plotted; a linear fit was made for the initial 2 minutes. The slope, which is $\frac{dP}{dt}$, of each curve was fitted as $3.30\text{x}10^{-3}$, $2.36\text{x}10^{-3}$ and $1.01\text{x}10^{-3}$ ntorr/s for IG4, IG5 and IG6, respectively. As the cartridge NEG pumps began pumping after activation, the rate (Q) of outgassing and the pumping speed (S) cannot be calculated from equation 1. Considering equation 2, we obtained instead the pumping speed (S) on plotting the pressure curves as log P versus t; the slope of the curves became S/V. On multiplying the volume, which was about 500 L, of the vacuum system, the pumping speed (S) calculated from records of three separate gauges was 2.42, 2.94 and 3.48 L/s. The pumping mechanism can involve NEG pumping, adsorption on the surface of the vacuum chamber, and the effect of the extractor gauges pumping.

To recognize the gaseous species during build-up, we show the trend of residual gas in Figure 7. The sputter-ion pump is capable of reemitting any pumped gas. In our case, the major gases building up were noble gases (Ar, He) and organic gas. Noble gases are known to be pumped less efficiently than active gases. They become pumped by burial of ions in the cathodes and by reflected neutral burial in the anodes and cathodes. The noble gases pumped on the cathodes were mostly in the area near the anodes at which the sputter building up occurred [2]. When the ion pumps were turned off, the gas became released from the cathodes, which led to a significant building up of Ar and He.

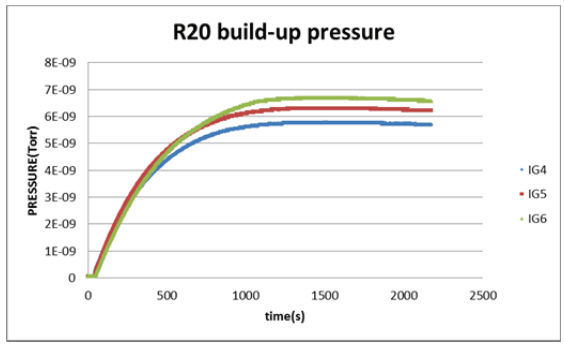


Figure 6: Pressure built up when ion pumps were turned off.

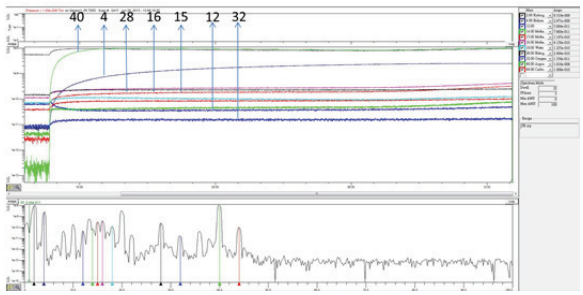


Figure 7: RGA trend after turning off ion pumps for build-up.

CONCLUSION

In Taiwan Photon Source project, the 24 sectors of the 14-meter-long aluminium vacuum chamber system were all baked, transported, and installed on the girders in the storage ring tunnel. The straight sectors connecting two 14-meter-long bending sectors are now being assembled and baked on site. With the experience of baking the bending sectors, we are more confident of baking a large vacuum system, but some questions, such as the source of argon and the disparate building up pressures between cells, must be answered with further study.

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