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Outgassing analysis of the 14-m-long arc-cell vacuum chambers of the Taiwan Photon Source

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ABSTRACT

An overall outgassing analysis of the large, 14-m-long, ultra-high-vacuum aluminum arc-cell chambers of the Taiwan Photon Source (TPS) was performed using residual gas analyzer (RGA). Pumping primarily by ion pumps (IP) and non-evaporable getter (NEG) pumps, the cells obtained pressures of 6.4×10^{-9} Pa on average, and the main residual gas was H_2. The pressure build-up method was adopted to investigate the outgassing of the vacuum chambers. Because active gases (H_2, CO, CO_2) were primarily pumped by NEG pumps, the increased vacuum pressure here mainly resulted from the inert gas. Therefore, the residual gases measured after switched off the ion pumps were CH_4 and Ar. After the ion pumps were baked separately, the outgassing of CH_4 was considerably diminished and the lowest achievable vacuum pressure was improved. The outgassing of Ar was primarily responsible for the long-term pressure build-up. Moreover, vacuum pressure measurements and residual gas analyses were performed *in situ* while a cell chamber was being transported. The vibration of the arc-cell vacuum chamber caused the pressure to rise abruptly; in this case, the outgassing gas measured during transportation was CH_4. Once the arc cell was installed, the original level recovered because of the pumping effect of the ion gauges.

1. Introduction

Construction of the Taiwan Photon Source (TPS) began in 2010, and it is in operation in 2016. The TPS is a medium-energy electron storage ring operating at 3 GeV. The vacuum chambers of the TPS storage ring are constructed of an aluminum (Al) alloy because of its high thermal conductivity, absence of magnetism, low residual radioactivity, and ease of machining [1]. The TPS consists of 24 aluminum arc-cell vacuum chambers in the electron storage ring. Each arc-cell chamber is 14 m in length, including two straight chamber sections (S3 and S4) and two bending chamber sections (B1 and B2), as shown in Fig. 1. The straight chamber sections were constructed from extruded aluminum alloy and subjected to chemical cleaning in a sequential process [2]. The bending-chamber components were manufactured using computer numerical control (CNC) alcohol machining and cleaned with ozonated water [3,4]. Then, the sections were assembled and jointed using tungsten inert gas (TIG) welding. A residual gas analyzer was installed in the arc-cell vacuum chamber to observe the outgassing of residual gases. According to previous research [5], ozonated water effectively removes residual carbon from the surfaces of aluminum alloys, and the thermal outgassing rate of such alloys has been found to decrease to 6.7×10^{-12} Pa m s^{-1} after baking. Each cell was assembled in the laboratory with two sector gate valves and then pumped by turbo pumps and dry pumps, followed by a 24-h bakeout. After bakeout and 24 h of pumping, pressures of less than 1.0×10^{-8} Pa were achieved at room temperature for all cells. Once the vacuum pressure of the 14-m-long aluminum vacuum chamber had achieved UHV levels, the four ion pumps were turned off to investigate the outgassing and to analyze the residual gas using the pressure build-up method [6].

When the civil engineering of the tunnel was finished, the vacuum chambers were just installed in the tunnel. As the arc-cell chamber was transported from the assembly laboratory to the TPS tunnel, the four ion pumps were turned off and the end valves were closed. After arc-cell chambers were installed in the tunnel, the dummy chambers and short straight sections were connected between two cells chambers. These connected chambers were

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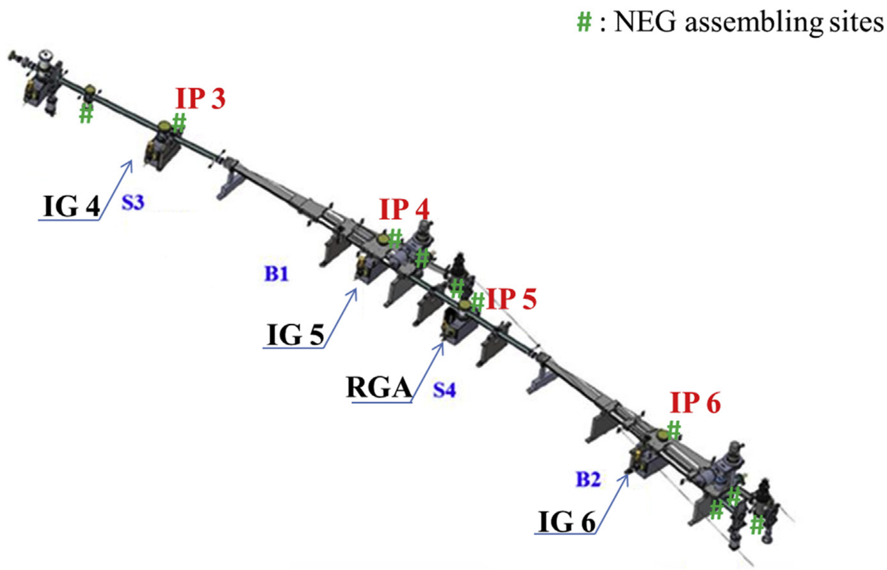

Fig. 1. Locations of vacuum chamber sections and vacuum components in one 14-m-long aluminum arc-cell chamber of the TPS.

pumped and then baked in the tunnel.

This paper focuses on the overall outgassing analysis of the long cell chambers, including pressure build-up tests, additional baking tests, and during the transport. Here, the active gases (H_2, CO, CO_2) were primarily pumped by NEG pumps. Thus, the measured outgassing rate (Q) primarily came from the inert gas, such as CH_4 and Ar.

The purpose of this analysis was to determine which types of residual gases were measured and to investigate possible methods of decreasing the outgassing of these gases. Here, the outgassing of the R05 cell and the R24 cell were analyzed and compared. Moreover, the types of gases produced during cell transport were observed. Vacuum system is described in detail below.

2. TPS cell vacuum system

For one aluminum vacuum chamber, which is 14 m in length [6], as depicted in Fig. 1, the components of the vacuum assembly include two sector gate valves (SGVs), two gate valves for isolating turbopumps, bellows, beam position monitors (BPMs), extractor ionization gauges (IGs), non-evaporable getters (NEGs) (1.2 $m^{-3}\ s^{-1}$ for hydrogen and 0.5 $m^{-3}\ s^{-1}$ for CO), ion pumps (IPs) (0.2 $m^{-3}\ s^{-1}$ for nitrogen), crotch absorbers, photon stoppers, front-end valves, angle valves, a residual gas analyzer (RGA), and turbomolecular pumps (TMPs), backed by dry pumps. The vacuum components were assembled in a clean room (class 10,000) under dust and humidity controlled environment to minimize the outgassing rate from the chamber's inner surfaces. The photon stopper chambers, composed of stainless steel, were pre-baked to 260 °C prior to assembly. The RGA spectrum was continuously recorded during pumping. In all experiments in this study, the following species were recorded: m/e = 2, 4, 12, 13, 14, 15, 16, 18, 28, 32, 40, and 44, associated with H_2^+, He^+, C^+, CH^+, CH_2^+, CH_3^+, CH_4^+/O^+, H_2O^+, N_2^+/CO^+, O_2^+, Ar^+, and CO_2^+, respectively. The current *I* that is reported here represents a RGA spectrum rather than a partial pressure. The RGA trends were recorded by ion currents and the ratios of ion currents were calculated in order to compare the relative variations of residual gases.

3. Methodology

The baking process (150 °C for 24 h) for all 24 cells was performed in the laboratory to achieve ultra-high vacuum (UHV), with pressures of less than 1.0×10^{-8} Pa. The build-up method was adopted to analyze the outgassing for the long cell chambers. This method has been found to be practical and effective in evaluating the performance of vacuum chambers after the baking process [6].

The outgassing rate of a vacuum system can be estimated using the following equation [7]:

$$Q = S \cdot P + V \cdot dP/dt \tag{1}$$

where Q is the total outgassing rate (Pa $m^3\ s^{-1}$), S is the pumping speed ($m^3\ s^{-1}$), P is the pressure (Pa), and V is the volume of the system (m^3).

In our case, when the ion pumps are turned off, the initial pumping in the vessel is not in a steady state. The NEG pumps are primary pumps. Therefore, to analyze the outgassing rate (Q) of a large ultra-high-vacuum system and to simplify the problem, we just estimated the V·dP/dt values [6].

It is assumed that $S = S_{NEG} + S_{IP} + S_{IG} + S_{wall}$, where S_{NEG} is the pumping speed of the NEG pumps ($m^3 \cdot s^{-1}$), S_{IP} is the pumping speed of the ion pumps ($m^3 \cdot s^{-1}$), S_{IG} is the pumping speed of the ion gauges ($m^3 \cdot s^{-1}$), and S_{wall} is the pumping speed of the vacuum chamber wall ($m^3 \cdot s^{-1}$).

Because the ion pumps are inactive during the pressure build-up period, $S_{IP} = 0$, and equation (1) can be rewritten as follows:

$$Q - (S_{NEG} + S_{IG} + S_{wall}) \cdot P = V \cdot dP/dt \tag{2}$$

Next, the individual pumping speed is discussed.

(1) S_{NEG}: The NEG pumps are already operational after baking activation. The NEG pumps primarily pump H_2, CO, and CO_2 [8]. For all 24 cells, the activation current of the NEG pumps was continuously measured using a current meter, the RGA spectra were continuously acquired, but the actual temperatures of the NEG pumps were not measured, while the NEG pumps were activated. The RGA spectra suggested that the