INVESTIGATION OF OUTGASSING PROPERTIES OF CuZr AND CuCrZr VACUUM PIPES*

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Abstract

The Hefei Advanced Light Facility (HALF) is the fourth-generation synchrotron radiation light source based on Diffraction-limited Storage Ring (DLSR) with low beam emittance, high brightness and coherent photon flux. According to the physical design requirements of the HALF, the vacuum chamber structural materials should have low outgassing rate, good electrical and thermal conductivity, high strength, and non-magnetic. CuZr and CuCrZr were selected as structural materials for the HALF storage ring vacuum chamber structural materials, taking into account material properties and manufacturing process. In this paper, thermal outgassing performances of CuZr and CuCrZr alloy pipes under temperature rise was investigated for the design and calculation of HALF vacuum systems.

INTRODUCTION

The accelerator develops toward high energy, high beam current, high luminosity, and long beam lifetime. The corresponding requirements for the vacuum environment change from ultra-high vacuum (UHV) to extreme conditions, such as extreme-high vacuum and extreme-low temperature. The fourth-generation light source based on the diffraction-limited storage ring (DLSR) has a huge improvement in brightness and coherence compared to the third-generation light source [1], which also places higher demands on structural materials. Copper is used as the preferred structural material for DLSR due to the low outgassing rate, good electrical and thermal conductivity, high strength, and non-magnetic [2]. Considering the properties and processing technology, CuZr and CuCrZr were selected as the storage ring structure materials of Hefei Advanced Light Facility (HALF) [3,4]. Vacuum material outgassing is the primary source of residual gases in accelerator, among which thermal outgassing mainly affects the static vacuum pressure. The outgassing properties of CuZr and CuCrZr vacuum pipes at different temperatures were tested in this paper to evaluate the reliability of the design for HALF vacuum system and the corresponding calculation of the vacuum pressure.

EXPERIMENT

Experimental Setup

The testing setup used for outgassing properties is shown in Fig. 1. The sputter ion pump (SIP) with nominal pumping speed of 200 L/s was used as the main pump. The turbomolecular pump (TMP) unit served as the roughing pump of the system. The DN40 all-metal angle valves were used to connect the pumping chamber to the TMP unit (MAV1) and to the vacuum pipe (MAV2). The B-A gauges were used as the measuring gauges, and the data measured by the B-A gauge at the pumping chamber (BAG1) were set as P_1, and the data measured by the B-A gauge at the end of the pipe (BAG2) were set as P_2.

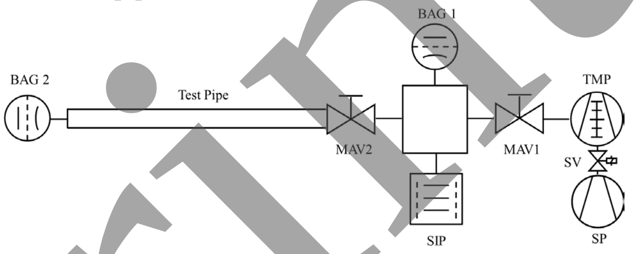

Figure 1: Schematic illustration of pipe outgassing property testing setup.

Experimental Procedures

- System cleaning, installation and leak detection: The rest of the testing setup was cleaned and installed first, followed by the cleaning and installation of the copper pipe. The system leakage rates of CuZr (Φ26 mm × 500 mm) and CuCrZr (Φ22 mm × 500 mm) pipes were below 3×10^{-12} mbar·L/s.
- System bakeout and ultimate vacuum testing: Stainless steel pumping chamber and gauge pipes were baked at 230°C for 48 h, and copper pipes were baked at 180°C for 48 h. The baking curves were set as shown in Fig. 2. After the baking and cooling of the system were completed, the system was left to stand at room temperature for 36 h, while the BAG2 was read as the first ultimate vacuum data.

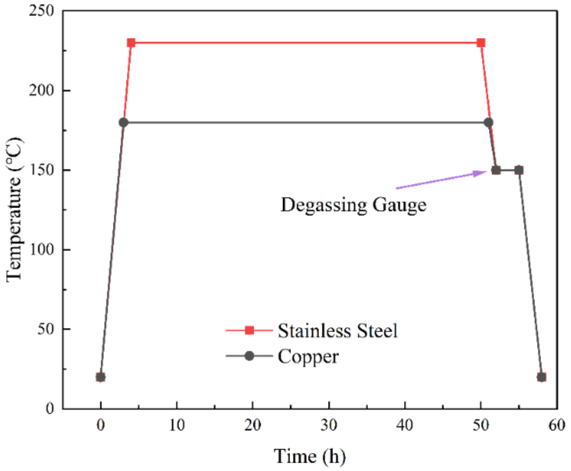

Figure 2: Bakeout procedure for testing setup.

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- Heating-keeping procedure: After the first ultimate vacuum data acquisition, the copper pipe started a new round of heating tests, and the temperature interval was set at 20°C and the holding time at 24 h. The baking curve was set as shown in Fig. 3, with 40/60/80/100/120/140/160/180°C - 24 h heating-keeping treatment, respectively. After the multi-temperature band heating- keeping operation was completed, when the system was cooled down to room temperature and left to stand for 36 h, the BAG2 was read as the second ultimate vacuum data.

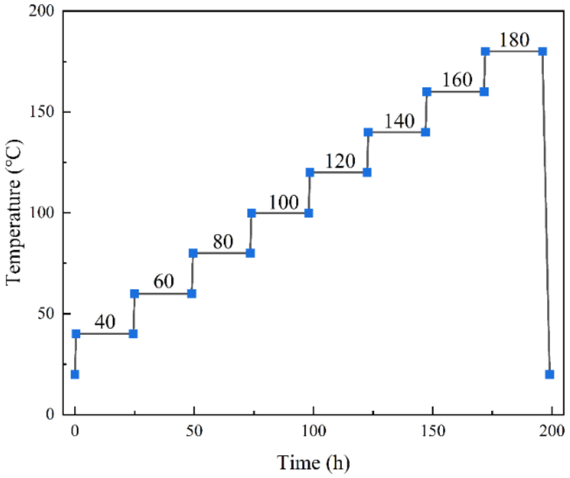

Figure 3: Heating-keeping procedure for copper pipes.

RESULTS

CuZr Pipe

After the first bakeout of the CuZr pipe, the pressure of BAG1 was 1.5×10^{-8} Pa, and the pressure of BAG2 was 3.5×10^{-8} Pa. After a series of heating-keeping, the pressure of BAG1 was 1.5×10^{-8} Pa, and the pressure of BAG2 was 3.3×10^{-8} Pa. The pressure changes during the test are shown in Fig. 4.

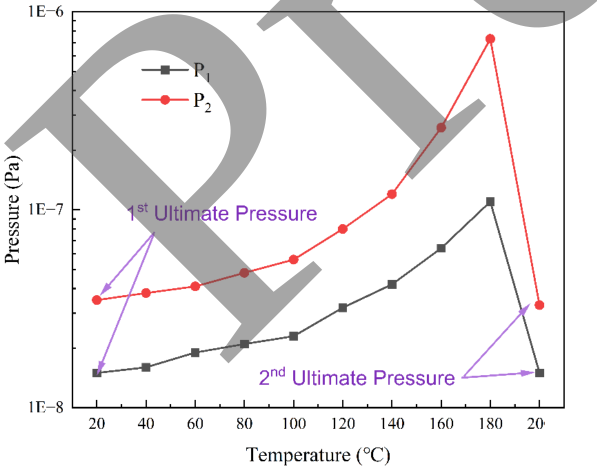

Figure 4: The changes of vacuum pressure in heating-keeping procedure for CuZr pipe.

CuCrZr Pipe

After the first bakeout of the CuCrZr pipe, the pressure of BAG1 was 2.7×10^{-8} Pa, and the pressure of BAG2 was 1.0×10^{-7} Pa. After a series of heating-keeping, the pressure of BAG1 was 1.7E-8 Pa, and the pressure of BAG2 was 5.7×10^{-8} Pa. The pressure changes during the test are shown in Fig. 5.

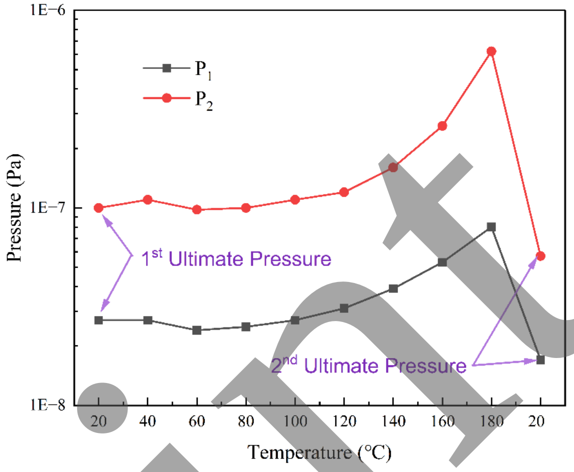

Figure 5: The changes of vacuum pressure in heating-keeping procedure for CuCrZr pipe.

DISCUSSION

In the case of a vacuum system where the gas is in a steady flow, the pressure has the following relationship with the gas load and the flow conductance:

$$\Delta P = P_2 - P_1 \propto \frac{q}{C} \tag{1}$$

where q is the outgassing rate of the component between the two B-A gauges, and C is the pipe conductance between the two B-A gauges.

For the same system, the degree of change in differential pressure was positively correlated with the degree of change in outgassing rate ($\Delta P/\Delta P_0$). Figure 6 shows the maximum outgassing rate relative to the starting outgassing rate during the CuZr pipe test and the CuCrZr pipe test.

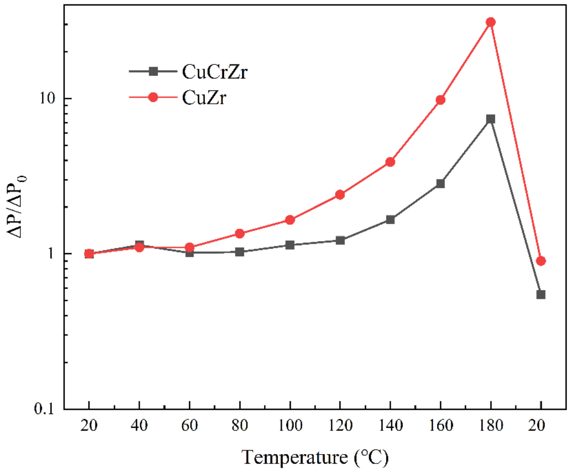

Figure 6: Temperature dependence of the maximum outgassing rate relative to the starting outgassing rate during testing.

In order to estimate the outgassing rate of the system, the test setup is simplified as a series model of the copper pipe with the MAV and the BAG, as shown in Fig. 7, where P_G is the pressure at the connection between the BAG and the pipe, and P_M is the pressure at the connection between the MAV and the pipe.

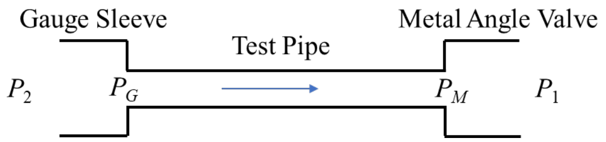

Figure 7: Simplified model for the calculation of the outgassing rate of copper pipes.

Based on the conservation of gas flow, the following equation can be established at a distance x from the MAV:

$$C_V L_V \frac{\mathrm{d}P_x}{\mathrm{d}x} = B(L-x)q_V + Q_{P+G} \qquad (2)$$

where L is the length, B is the cross-section circumference of pipe, V represents MAV, P represents copper pipe, and G represents gauge sleeve.

In order to simplify the calculation, set the MAV, the gauge sleeve and the copper pipe with same outgassing rate, q:

$$q = \Delta P \Big/ \left(\frac{S_V}{2C_V} + \frac{S_P}{2C_P} + \frac{S_G}{2C_G} + \frac{S_G}{C_P} + \frac{S_P + S_G}{C_V} \right) \qquad (3)$$

The estimated maximum outgassing rates during testing of the CuZr pipe and CuCrZr pipe are shown in Fig. 8.

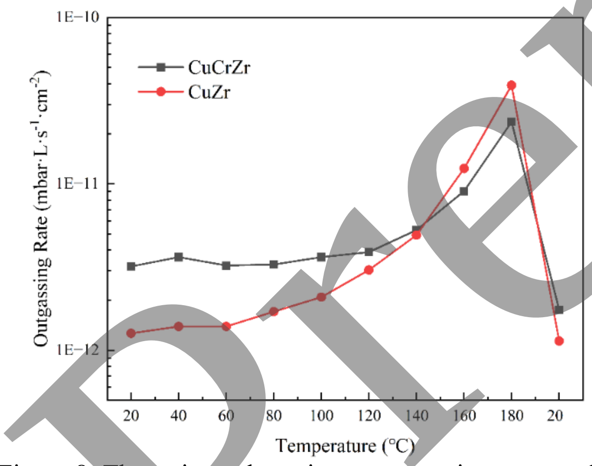

Figure 8: The estimated maximum outgassing rates at different temperatures.

CONCLUSION

Thermal outgassing tests were carried out on CuZr pipe and CuCrZr pipe, and the variation of outgassing rates of the pipes with the temperature were obtained by performed the pipes with the heating-keeping treatment at 40/60/80/100/120/140/160/180 °C for 24 h. The main conclusions are summarised as follows:

1) For CuZr pipe, the change of outgassing rate has less effect on vacuum pressure when the temperature is below 120 °C, while for CuCrZr pipe, the change of outgassing rate has less effect on vacuum when the temperature is below 160 °C and CuCrZr pipe has better degassing effect when baked at 180°C and above;

2) The outgassing rate of CuZr pipe and CuCrZr pipe after baking at 180 °C - 48 h or longer and at higher temperatures is 10^{-12} mbar·L·s^{-1}·cm^{-2} order of magnitude;

3) For systems that have been baked to ultimate vacuum, the thermal outgassing rate of the material can be further reduced by baking again if it is observed that the air pressure at the pump port has not yet reached the ultimate pressure of the ion pump.

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