Rapid Decompression Technology for the Oxygen Supply System

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Abstract. To ensure the safety of the pilot, the design scheme of a ground experiment platform for testing the performance of oxygen supply system under rapid decompression was presented. Detail design process of the subsystems such as vacuum system, rapid decompression system and temperature control system was introduced. Numerical simulations were carried out for the latter two subsystems. The results show that, the requirements both for the temperature uniformity of the experiment cabin and for the rapid decompression time can be achieved, based on the design of the present work which is very valuable for constructing the rapid decompression test platform of oxygen supply system.

1. Introduction
When the cabin is structurally damaged at high altitude, the air pressure in the cabin drops sharply. Rapid decompression, which occurs in less than a second or even tens of milliseconds, is often called explosion decompression [1]. Rapid decompression is extremely harmful [2-5]. In order to ensure the safety of pilots, when the cabin explodes and decompresses, the oxygen supply system [6-7] should first ensure that the expiratory valve is free for a short time to release the pressure on the lungs, and then quickly pressurize the body surface and mask to avoid the occurrence of explosive hypoxia [8]. In order to study the working performance of the oxygen supply system and ensure the life safety of the pilot, the ground simulation explosion decompression test of the oxygen supply system is needed.

2. Overview
A design technology of a rapid decompression test platform for oxygen supply system was introduced in the present work, which is mainly used for the comprehensive dynamic performance test of oxygen supply system by simulating the rapid decompression process. The test platform consists of vacuum system, rapid decompression system and temperature control system. Its main functions are as follows:

Environmental pressure: altitude > 25000m, control accuracy > 30m (0-8000m), + / -100m (8000-18000m)

Cabin temperature: 55 ℃ ~ room temperature, temperature uniformity: within 2 ℃

Rapid decompression: time for explosion decompression: less than 100ms; time for rapid decompression: 210ms-500ms.

3. Vacuum system
The main equipment of the vacuum system includes screw dry pump unit, vacuum valves and control valves, vacuum pressure measuring instruments, mufflers and other devices. The schematic diagram is shown in Figure 1.
The pressure relief channel is set up between the cockpit and the vacuum reserve cabin, and the vacuum valve is set in the middle to ensure the pressure safety before the pressure relief. The vacuum system is equipped with a screw dry pump unit, which is used to pump air out of each compartment. The pump unit is connected with each compartment through regulating valves. Pressure measuring instruments are installed in each section to measure the pressure in real time. When the cabin pressure or lifting pressure rate needs to be maintained and controlled, the valve can be adjusted through the feedback system to control the flow rates of air extraction and air intake. Therefore, the constant maintenance and control of the final required pressure or lifting pressure rate can be realized.

The pumping speed required for the vacuum system to reach the set pressure is determined by the following equation (1):

$$P_g = P_0 + \frac{Q_L}{S_{eff}} + \frac{Q_e}{S_{eff}}$$

Equation (1)

$P_g$ represents the maximum vacuum that the cabin can reach, Pa. $P_0$ represents the limit vacuum for the pump, Pa. $Q_0$ represents the air load of the vacuum chamber (including leakage $Q_L$ and gas release of material surface $Q_e$), PaL/s after a certain period of time. $Q_L$ represents process gas load of vacuum chamber. $S_{eff}$ represents the effective pumping speed of the pump near the suction port of the vacuum chamber, L/s.

In the above equation (1), the ultimate vacuum of the vacuum cabin is always lower than that of the vacuum pumping unit, i.e. $P_0 \ll P_g$. Under the condition of a certain effective pumping speed of the pump near the suction port, the ultimate vacuum of the vacuum cabin under no-load condition is proportional to the leakage and air output of the vacuum cabin.

In the case of loading, assuming the exhaust flow in the cabin is 700L/min at room temperature and the exhaust pressure is 0.3Mpa. The leakage gas load of the vacuum container itself is negligible compared with the product load flow. At this point, the design height of the vacuum cabin is required.
to be 25000m, and the height is converted to the pressure of about $2.5 \times 10^{3}$ Pa. According to the basic law of ideal gas and equation (1), the extraction speed required to maintain the dynamic vacuum degree of the vacuum system is:

$$S_{eff} = \frac{PS_T}{P_T}$$

(2)

The vacuum unit adopts the combination of roots pump and dry pump to pump air. Therefore, the pumping speed also needs to meet the requirements of vacuum reserve tank pumping time. The pumping speed can be calculated according to the following formula:

$$S_r = \frac{3V_t}{T} K \times L_g \frac{P_1}{P_2}$$

(3)

$T$ represents pumping time, h; $S_r$ represents effective pumping speed of dry pump, m$^3$/h; $V$ represents volume of the chamber, m$^3$; $P_1$ represents pressure at the beginning of pumping, Pa; $P_2$ represents the air pressure reached after time $t$, Pa. $K$ represents correction factor, whose value is shown in Table 1.

| Pressure/Pa | $K$ |
|-------------|-----|
| $10^5 \sim 10^4$ | 1 |
| $10^4 \sim 10^3$ | 1.25 |
| $10^3 \sim 10^2$ | 1.5 |
| $10^2 \sim 10^1$ | 2 |
| $10^1 \sim 10^0$ | 4 |

By calculating the requirement of pumping speed under the ultimate pressure and pumping time, ensure that the vacuum system can still meet the pressure control requirements under the maximum working condition of the product load, and the pumping time of each cabin can be achieved.

4. Rapid decompression system

The rapid decompression system is used to realize the rapid decompression and blasting decompression of the cabin. The glass blasting method is adopted in this scheme, which has the advantages of reasonable structure, easy operation and convenient for using. The system consists of tempered glass and mounting flange, blasting mechanism, opening adjustment valve, vacuum butterfly valve and cleaning mechanism. The schematic diagram of system composition is shown in Figure 2 below:

![Figure 2. Schematic diagram of rapid decompression system](image)

In order to realize rapid decompression, the blasting glass is set at the blasting decompression interface. The glass is installed on the side of the vacuum storage tank, and sealed by fluoro rubber ring. The blasting actuator is set up on the side of the cockpit of the blasting decompression interface. The actuator is driven by the cylinder and the tip collider is installed at the end of the cylinder pusher. When the blasting started, the crash needle is pushed by the cylinder to crush the tempered glass. According to the properties of the toughened glass, the whole glass will break up quickly. With the help of the huge pressure difference on different sides of the window, the glass will break to the side
of the vacuum reserve. After the blasting is finished, the cylinder drives the impact needle back automatically.

![Tempered glass](image1)

**Figure 3.** Break device and glass window

As shown in Figure 3, the pneumatic system of the blasting mechanism is mainly composed of air filtration combination, control valve and cylinder. Electromagnetic directional valve controls the direction of cylinder movement. Two-way throttle valve and one-way throttle valve regulate the cylinder speed.

The control of rapid decompression time is realized through the electric opening valve in the decompression channel, and the throat area during the decompression process of the pressure relief channel is controlled by adjusting the opening of the valve to adjust the decompression time. Fluent was used to simulate the dynamic process of rapid decompression of the cockpit and the vacuum reserve tank. The calculation results are shown in Figure 4.

![Pressure vs. Time](image2)

**Figure 4.** Pressure in environment cabin

5. **Temperature control system**

The temperature control system is mainly used to adjust the temperature in the environment test chamber, which consists of air conditioning unit and heat sink unit. The air conditioning unit consists of a fan, an electric heater, an evaporator and a refrigeration unit. The temperature control system is mainly used to adjust the temperature of the test space under normal pressure and low pressure. The heat sink unit is composed of heat sink and heat sink refrigeration unit, which is mainly used to adjust the temperature uniformity of test space under low pressure environment. The system flow diagram is shown in Figure 5 below.
The system adopts the combination of active temperature control and passive temperature control to adjust the space temperature in the environment cabin. The active temperature control method is to use the air through convection to exchange heat with the test piece in the test box, transfer heat to evaporator or electric heater, and use the fan to complete the circulation heat exchange process. The passive temperature control method is to complete the heat transfer between the test piece and the heat sink by using heat sink to radiate heat in the test chamber space. The combined heat sink and air circulation temperature control method can effectively solve the problem of temperature uniformity in the test chamber under low pressure.

The design and calculation of temperature control system mainly include the power design of heating system and refrigeration system. The calculation method is as follows:

1) Power calculation for heating system

In the cabin, its cooling load is mainly composed of inner tank load \(Q_n\), air load \(Q_k\) in the test chamber, heat dissipation of maintenance structure \(Q_w\), air conditioning unit load \(Q_t\) and load of test device \(Q_f\). Since the maximum temperature is normal temperature, the final heating power is determined by the power of temperature rise period. The heating power required in the heating stage is calculated by the following calculation formula:

\[
Q_{heating} = Q_n + Q_k + Q_w + Q_t + Q_f
\]  

(4)

2) Power calculation for refrigeration system

In the cabin, its thermal load includes inner tank load, air load in the test box, heat dissipation of maintenance structure, air temperature regulating unit load, load of test device, heat dissipation of motor and associated heat \(Q'\), and heat load of exhaust gas \(Q_q\). The refrigeration power required in the cooling phase and the refrigeration power required in the stabilization phase are calculated as follows:

\[
\begin{align*}
Q_{cooling} & = Q_n + Q_k + Q_w + Q_t + Q_f + Q' \\
Q_{stabilization} & = Q_w + Q' + Q_q \\
Q_{refrigeration} & = \max \{Q_{cooling}, Q_{stabilization}\}
\end{align*}
\]  

(5)

Fluent was used to simulate the temperature distributions of the environment chamber. The obtained temperature contours and velocity contours are shown in Figure 6.
6. Results

In order to ensure the safety of the pilot's life in the environment of rapid decompression, a design scheme for the rapid decompression test platform of the oxygen supply system was provided in this paper, the design methods of the vacuum system, the rapid decompression system and the temperature control system of the test platform were introduced in detail, and simulation verification for the rapid decompression and temperature control system were carried out. The main conclusions are as follows:

(1) A rapid decompression method of glass blasting was designed. Combined with the adjustment of the opening degree of the pressure relief valve, different rapid decompression time can be controlled.

(2) The temperature control method combining active temperature control and passive temperature control was proposed, and the temperature uniformity of the environment chamber was verified by numerical calculation.

In summary, by using the design advocated in this paper, the temperature uniformity of the test system and the requirements of rapid decompression time were realized, which provides a reference for the design of rapid decompression test of oxygen supply system in the future and has certain guiding significance.

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