Study on low flow resistance ventilation hose with rapid retraction in space cabin

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Abstract. Aiming at the required of high air tightness, low flow resistance, rapid expansion, easy operation on orbit and hygiene in the space cabin, a low flow resistance ventilation hose which can be retracted quickly in the cabin is proposed. The ventilation hose is composed of metal support ring, air tight composite material, quick connection connector and clamp. After sewing the adhesive tape into a cylindrical tube, it is hot-melt welded with the titanium ring. The pipe body and the quick connection joint are connected and fixed by clamps. After structural design and test verification, a hose with an extension length of 10 meters can shrink to 0.42 meters. the air tightness is 0.96 L/min and the flow resistance is 120Pa. The ventilation hose has the advantages of reliable technology, compact structure, light weight and convenient use in orbit. It provides a new technical way and equipment for the ventilation system in manned spacecraft.

1. Introduction

The ventilation system in the space cabin involves products such as fan systems, purification systems, piping devices, etc., and all parts work together [1-5]. The ventilation hose provides certain air flow for the astronaut activity area and instrument area in the space module to meet the ventilation requirements [6-7]. At present, the hoses on the market can be roughly divided into four types according to the production process: steel wire wound composite hose, clamp bite composite hose, screw extrusion plastic hose and corrugated bite metal hose. The existing hose has the following shortcomings: there is no unified production standard, industry standard, test standard and quality standard; There is no unified connection mode, including hoop connection, adhesive tape bonding, steel wire binding, inner hose binding, outer sleeve binding, etc., which can not realize rapid connection and disconnection; Unable to meet the hygienic requirements, mainly including flame retardancy, combustion products, antibacterial and mildew prevention, harmful gas overflow and other requirements; It is composed of metal materials such as steel wire, steel sheet and steel strip and non-metallic materials with high density. It has large weight and volume and is inconvenient for transportation and operation; Poor air tightness and large flow resistance, unable to meet the requirements of air tightness and low flow resistance [8].

According to the requirements of high air tightness and low flow resistance of air flow in space sealed cabin, rapid connection and disconnection of pipeline, easy operation on orbit and hygienic requirements, a low flow resistance ventilation hose which can be retracted quickly in the cabin is...
proposed in this paper. It is operated by astronauts to quickly connect the ventilation interfaces under different working conditions to establish the ventilation system of the combined cabin.

2. Scheme Design
The ventilation hose is composed of metal support ring, air tight composite fabric (adhesive tape), quick connect connector and clamp, as shown in Figure 1. The metal support ring is a titanium ring, which mainly plays a supporting role to ensure the stable shape of the hose and easy to shrink the pipeline. The adhesive tape is wrapped outside the metal support ring and is composed of air tight composite material and composite TPU adhesive film, which plays the role of air supply and sealing. The quick connect connector is made of aluminum alloy and is divided into quick connect male and quick connect female. The quick connect connector is glued to the hose and fixed with a clamp.

![Figure 1. Structure of ventilation hose](image)

In order to meet the weight and pressure requirements of the hose, stainless steel metal ring and titanium alloy metal ring are selected for comparative pressure test. Fix metal rings of the same size on the same horizontal plane in parallel, the ring is perpendicular to the horizontal plane, and the spacing between the two rings is 10cm. Place a 3.5kg weight on the two metal rings. When the weight is deformed to the bottom, remove the weight and measure the diameter of the metal ring in the bearing direction. It can be seen from table 1 that stainless steel metal ring and titanium alloy metal ring have good deformation recovery. Both can bear the weight of 3.5kg and can be restored to the original state after bearing pressure. Titanium alloy has the characteristics of light weight, high strength, high thermal strength, good corrosion resistance and low density, so titanium alloy metal ring is selected. The metal ring structure is a separate ring, which can be integrated through the mold, safe and reliable, accurate and stable size.

| Texture of material | Diameter before bearing (mm) | Diameter after recovery (mm) | Bearing weight (kg) | Weight (g) |
|---------------------|------------------------------|-----------------------------|---------------------|------------|
| stainless steel     | 183                          | 183                         | 3.5                 | 15         |
| titanium alloy      | 183                          | 183                         | 3.5                 | 8          |

Air tight composite fabric (adhesive tape) is composed of base cloth and polyurethane film. The flexible textile base cloth is used as the reinforcing material to ensure the strength and stability of the hose, and realize the purpose of light weight loss, soft and easy folding. The key factors affecting the properties of the base cloth are microstructure, gram weight and fiber composition. The plain weave structure is selected as the organizational structure of the base cloth. Plain weave structure has flat surface, compact structure, many interleaving points, high strength, good wear resistance, and is flat and easy to compound with adhesive film. Gram weight is one of the important factors to consider when selecting the main base cloth of the hose, but a heavier base cloth will increase the weight of the hose. Select the base cloth with an area density of 150 g/m² and a strength greater than 600N as the
main material. Polyester fiber can be flame retardant finishing to make it flame retardant. Polyester fiber is widely used and is a relatively mature product. Therefore, polyester base cloth is selected as the main material. Polyurethane adhesive film has special adhesion, processing and bonding with relevant materials, has excellent adhesion, and will not delamination and blister. Polyurethane film also has excellent environmental protection properties such as antibacterial, hydrolysis resistance, UV resistance and low temperature resistance. Polyurethane film and polyester base cloth are compounded by dry compounding technology. Dry compounding technology adopts adhesive with good affinity with high molecular aramid fiber, improves the bonding process, improves the waterproof performance and peel strength of the product, and increases the stability of the product.

![Figure 2. Structural diagram of air tight composite fabric (adhesive tape)](image)

The main body of air tight composite fabric (adhesive tape) is formed by sewing to ensure that the product has good appearance effect and connection strength. The hose is a rectangular adhesive tape sewn into a cylindrical round pipe, and the structural diagram of the connection joint is shown in Figure 3. The main material joints shall be covered with auxiliary adhesive tape to reduce the risk of air leakage at the joints.

![Figure 3. Schematic diagram of sewing air tight composite fabric (adhesive tape)](image)

After the hose is processed, it needs to be connected and fixed with the titanium wire ring skeleton by hot melt welding. Its structure is shown in Figure 4. Before the titanium wire ring is installed into the cloth hose, PU adhesive is used to coat it to form a polyurethane coating on its surface. The polyurethane coating on the inner surface of the cloth hose is fused with the polyurethane coating on the outer surface of the titanium wire ring skeleton by hot melt welding, so that the titanium wire ring skeleton has certain constraints in the axial direction. The peel strength of hot melt welding coating shall not be less than 1000 N/m.
The quick connect connector is divided into quick connect male and quick connect female, which is used to realize the quick connection and separation between the ventilation hose and the fan. In view of the long operation time and cumbersome locking of the existing similar devices, the quick disconnect pipeline joint structure is introduced in the design process to help astronauts realize the rapid plugging and unplugging of on orbit pipelines, solve the operation difficulties during pipeline docking, and meet the certain sealing requirements of the ventilation system. Quick connect male and female connectors are shown in Figure 5. Four bosses are uniformly arranged on the quick connect male head and four L-shaped grooves are uniformly arranged on the quick connect female head. When the joint is installed in pairs, the butt rotation operation shall be carried out by identifying the alignment and in place marks on the female head. When the male and female heads are matched and locked, the end face of the female head will compress the C-shaped rubber gasket fixed in the male head groove, so as to meet the air tightness requirements after the device is connected with the target product. The joint and the hose are first bonded by adhesive and then fixed by clamp externally, so as to ensure the air tightness at the interface and prevent the separation of the pipe body from the metal joint.

After the ventilation hose shrinks, put it into the cargo bag, fix it on the bulkhead or instrument board in the cabin, and go up with the cabin. When in rail use, take out the hose from the package, connect one end to the power fan, and stretch the other end to the position requiring ventilation. After use, disconnect the hose connector and shrink it into the package.

3. Test verification
In order to verify the retractable function, air tightness and low flow resistance of the ventilation hose of the structure, a ventilation hose with a length of 10m is selected for experimental verification.
3.1. Compression length
The tension state and compression state of the hose are shown in Figure 6. The length of the hose after complete stretching is 10m, the measured length after shrinkage is 0.42m, and the shrinkage ratio is 4.2%.

![Figure 6. Comparison of tension and contraction of ventilation hose](image)

3.2. Air tightness test
Stretch the hose to a free state, and fill the inlet and outlet with high-purity nitrogen through the tooling. After testing, when the pressure in the pipeline is 1kPa, the air leakage of the product is 0.96L/min.

![Figure 7. Air tightness test of ventilation hose](image)

3.3. Flow resistance test
Under normal temperature and pressure, the pipeline is in the maximum extension state without bending, connected to the outlet of power fan, and the hose outlet is free. The flow is 8m³/min, the measured value of pipeline flow resistance is 120Pa.
4. Conclusion

In view of the requirements of high air tightness and low flow resistance of the ventilation pipeline of large space cabin, as well as the functional requirements of rapid installation and easy storage, a high air tightness rubber film composite pipeline in space cabin is proposed in this paper, which is based on polyester polyurethane composite materials with air tightness, flame retardant, antibacterial and mildew proof functions. The test results show that the ventilation hose is easy to retract, has good air tightness and low flow resistance. This method has the advantages of reliable technology, compact structure, light weight and easy to use in orbit. It provides a new technical way and equipment for the ventilation system in manned spacecraft. In order to improve the overall air tightness of the ventilation pipeline, a higher air tightness adhesive film and pipeline are being developed. Subsequently, the material, structure and process of the ventilation hose can be optimized to make it have higher air tightness, lower flow resistance and easier on orbit operation.

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