Design and Verification of Urine Collection Hose Assembly Used for Environment Control and Life Support System

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Abstract. The urine collection hose assembly is u sed in the urine collection subsystem of the environmental control and life support system (ECLSS) of the space station to connect the products or components in the urine collection subsystem and transmit the working medium. This paper introduces the design scheme and verification test of urine collection hose assembly. The urine collection hose adopts the design scheme of stainless steel wire armored polytetrafluoroethylene hose. Through the verification test, the results show that the scheme can meet the performance requirements of the space station toilet collection subsystem hose assembly.

Keywords: Space station; Environmental control and life insurance system (ECLSS); Urine collection hose; Polytetrafluoroethylene.

1. Introduction

Environmental control and life support system (ECLSS) is an important system of manned spacecraft with the most manned space characteristics, and it is an indispensable guarantee condition directly related to the life safety of astronauts. Its basic function is to control the closed cabin environment of spacecraft and provide water, oxygen, food and other necessary substances and other life support for astronauts [1]. Urine treatment is one of the important links in the environmental control and life insurance system of the space station. The individual products and components of the environmental control and life insurance system are connected through hoses. The urine collection hose assembly is used in the urine and urine collection subsystem of the environmental control and life support system (ECLSS) of the space station. The significance of urine collection is to collect the urine excreted by astronauts in the space station for treatment and purification, and extract water from the urine for electrolytic water oxygen generation or astronauts' domestic water, so as to realize the recycling and reuse of water in the space station [2].

According to the special working conditions of the environmental control and life support hose of the space station, this paper proposes a design scheme of urine collection hose assembly based on polytetrafluoroethylene hose.

2. Scheme design of urine collection hose assembly

2.1 Analysis on performance requirements of urine collection hose assembly

Compared with the common hose assemblies on the ground, the performance requirements of the urine collection hose assembly of the stool collection subsystem of the space station are as follows:

2.1.1 The working medium is special and not easy to replace on orbit

The working medium of the urine collection hose is astronaut urine, urine pre-treatment agent, urine and urine pre-treatment agent mixture, drinking water containing silver ions, drinking water and urine pre-treatment agent mixture, air, etc. Once the hose assembly is used, there is a working condition that the corresponding working fluid remains in the hose and is stored for a long time. Since the hose assembly is used in the space station, the compatibility between the hose and the internal working medium needs to meet the requirements of 15 years.

2.1.2 Complex performance index constraints

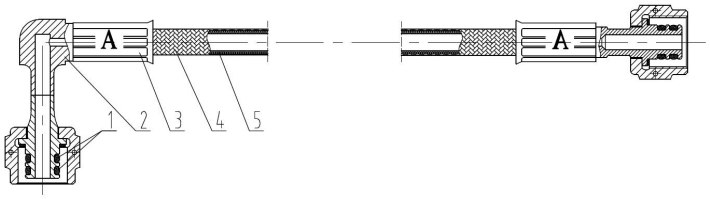
Table 1. Performance index constraints of urine collection hose

Project	Index constraint
Drift diameter	DN4
Leakage rate pa.m3/s	Not greater than 1 × 10-4
Withstand voltage	Not less than 0.1MPa, keeping pressure for 5min
blast	Not less than 0.2MPa
Pullout force	Not less than 200N
Bending radius	Not more than 51mm
quality	Unit (m) mass not greater than 150g
Cleanliness	Q/W925A D2
Bending fatigue	100 times

2.1.3 The non-metallic pipes used need to meet the non-metallic material test items and test requirements of the space station

In order to ensure the control of harmful gas concentration, fire prevention and microbial control in the sealed cabin of the space station, it is necessary to control the flame retardant characteristics, combustion products and other indicators of non-metallic materials in the cabin. Since the urine collection hose assembly is a product in the cabin, if non-metallic pipes are used and the total weight exceeds 0.5kg, the pipes must pass the flame retardant and combustion product test in the ground state.

2.2 Design of urine collection hose assembly



1-seal ring 2-connector assembly 3-buckle sleeve 4-stainless steel wire reinforcement layer

5-PTFE inner pipe

Fig. 1 Product structure of urine collection hose

Polytetrafluoroethylene hose assembly is usually composed of polytetrafluoroethylene (PTFE) inner pipe, stainless steel wire reinforcement layer and metal connector (including nut, sleeve and connector) [3]. The urine collection hose adopts the design scheme of stainless steel wire armored polytetrafluoroethylene hose. The specific structure is composed of polytetrafluoroethylene inner tube, stainless steel wire reinforcement layer, connector assembly and buckle sleeve, as shown in Fig. 1.

2.2.1 Material selection of inner pipe

Since the working medium of the urine collection hose is highly corrosive, the main components are shown in Table 2 to Table 4. The material of the pipe body is in direct contact with the working medium, so the pipe should not only meet the strong acid resistance and corrosion resistance, but also have the excellent characteristics of long life, light weight, small bending radius and good air tightness. Because the working medium contains concentrated sulfuric acid, the common metal bellows pipes do not meet this working condition. According to the investigation and analysis of

common non-metallic materials that can be used to make hoses, polytetrafluoroethylene (PTFE) can meet the working conditions of urine collection hoses.

Table 2 . Main components of urine

Component	Water	Inorganic salt	Urea	Uric acid
Concentration (proportion)	95%	1.1%	1.8%	0.05%

Table 3. Main components of urine pretreatment agent

Component	Sulfuric acid H2SO4	CrO3	Water
Concentration (proportion)	98%	a small amount	the rest

Table 4. Composition and concentration of defecation gas

Component	Ammonia	Hydrogen sulfide	Methylhydrol	Methamine	Phenol	Ethylphenol	Indole
Concentration (mg/m3)	234	117	10	20	205	32	1.31

Polytetrafluoroethylene has high chemical stability and can resist the corrosion of all strong acids, bases, oxidizing agents, reducing agents and various organic solvents; Polytetrafluoroethylene has a wide temperature range. It can be used in the temperature range of -180 ℃ ~+250 ℃ for a long time under normal pressure. After being treated at 250 ℃ for 1000h, its mechanical properties change little; Polytetrafluoroethylene has excellent aging resistance and radiation resistance. It is not only stable in size under low and high temperature conditions, but also free from microbial invasion under wet conditions. It also has high protection against various kinds of radiation [4].

According to 1.1.3, it is necessary to carry out space station non-metallic material test on polytetrafluoroethylene (PTFE) pipes.

The determination results of combustion products are as follows: the concentration of CO in the combustion products of the sample is 227ppm, the concentration of NOx is 2.5ppm, the concentration of HF is 90ppm, and no HCl, SO2, HCN and other gases are detected.

The results of vertical combustion test are as follows: the average flame burning time is 0s, the average coke burning length is 14mm, and there is no drop.

The result of horizontal combustion test is: the evaluated combustion rate =0mm/min.

By comparing the test qualification standards of non-metallic materials in the space station, the pipes meet the test requirements of non-metallic materials in the space station. Therefore, this polytetrafluoroethylene (PTFE) pipe is selected as the inner pipe of the urine collection hose.

2.2.2 Design of stainless steel wire reinforcement layer

Considering the relatively hard material of PTFE inner pipe, the risk of "collapse" and irrecoverable when subjected to excessive bending, as well as the hidden dangers of bumps and scratches on the outer surface affecting its life, PTFE inner pipe can not be directly used as outer pipe. According to the different bearing capacity of the product, the reinforcement layer can be mainly divided into two structures: "braided" structure and "winding + braiding" structure. The stainless steel wire materials of each layer are the same [5]. The "braided" structure has the advantages of good fixation and light weight, and is mainly used for hose assemblies with small specifications and high pressure levels or large specifications and low pressure levels. The "winding + braiding" structure has the advantages of good adhesion to the outer surface of the inner pipe and

uniform arrangement of steel wires, which is mainly used in hose assemblies with high pressure levels. Therefore, the design principle of the reinforcement layer is to use the reinforcement layer with the least number of layers and the most reasonable structure on the premise of meeting the hose technical indicators. Considering the weight reduction requirements of space station products, the stainless steel reinforcing layer of urine collection hose adopts the lightest braiding method among medium and low pressure hoses. The reinforcing layer is woven with stainless steel wire. The weaving process parameters are shown in Table 5.

Table 5. Braiding parameters of stainless steel wire reinforcement layer

Structure	Number of shares Mm × root	Ingots spindle	Stroke Mm	Outer diameter after weaving Mm
Single series	Φ 0.2 × 4	24	14.4 ± 0.8	Φ 6.9 ± 0.2

2.2.3 Metal connector design

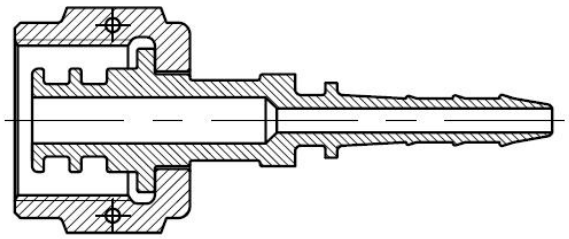


Figure 2. Structural diagram of plunger connector assembly

The metal connectors at both ends of the hose and the hose achieve the effect of fixed connection through part deformation, that is, the so-called buckle [6]. The structural form of metal joint is shown in Figure 2. The form of crimping end interface is barbed joint. The crimping structure of the connection between the metal connector and the hose mainly plays two roles: one is to prevent the metal connector and the hose body from falling off during use, and the other is to ensure that the hose assembly remains sealed during use under long-term pressure, so as to prevent the leakage of media at the connection between the connector and the pipe body [7]. According to the compatibility test results with the working medium, the joint material in contact with the working medium is titanium alloy TA2, and the outer nut material is TC4.

3. Main validation test of urine collection hose assembly

3.1 Performance test

Carry out the required performance test on the urine collection hose. The test items and test results are shown in Table 6.

Table 6. performance test results of urine collection hose

Test items	Index value	Inspection value	Conclusion
Leakage rate pa.m3/s	Not greater than 1×10^{-4}	1.4×10^{-5}	Qualified
Pressure test	Not less than 0.1MPa, Keeping pressure for 5min	0.1MPa high purity nitrogen, Pressure maintaining for 5min	Qualified
Blasting test		> 0.2MPa	Qualified
Pullout force			

Bending fatigue	Not less than 0.2 MPa Not less than 200N 100 times	≥ 200N Leak detection after 100 times 2.6 × 10^{-5}	Qualified Qualified

3.2 Environmental test

According to the product design and construction specifications of the space station, environmental tests such as vibration, impact, acceleration, ground storage and transportation temperature, and alternating humidity and heat were carried out on the identified parts of the urine collection hose. Taking the vibration and impact test as an example, the test process is introduced. The vibration and impact test of urine collection hose shall be carried out in the order of X direction → Y direction → Z direction, and the stress loading shall be carried out in each direction in the order of acceptance level sinusoidal vibration (30%) → identification level sinusoidal vibration → acceptance level random vibration (30%) → identification level random vibration → impact response spectrum test.

Table 7. Sine vibration test conditions

Test direction	Frequency (Hz)	Acceptance - Test magnitude	Qualification - Test magnitude	Sweep rate	Frequency sweep times
X, Y, Z	4~10	14.7mm (0~p)	22mm (0~p)	4oct/min (acceptance) 2oct/min (identification)	1 time (from low frequency to high frequency)
	10~17	3.6g	5.4G		
	17~60	8g	12g		
	60~100	3.8g	5.6g		

Table 8. Random vibration test conditions

Test direction	Frequency (Hz)	Power spectral density (acceptance)	Power spectral density (identification)	Root mean square acceleration (GRMS)	Test time
X, Y, Z	10~50	+3dB/Oct	+3dB/Oct	6.11g (acceptance) 9.68g (identification)	60s/ direction (acceptance) 180s/ direction (identification)
	50~300	0.1g2/hz	0.25g2/hz		
	300~2000	-12db/oct	-12db/oct		

Table 9. shock response spectrum test conditions

Test direction	Frequency (Hz)	Order	Number of impacts
X, Y, Z	100~650	+8dB/Oct	3 times / direction
	650-3000	400g	

A total of 4 acceleration sensors 1#, 2#, 3# and 4#, are installed for vibration, of which 1#, 2# are located on the special tooling as control points, and 3#, 4# are located on the surface of the hose product as measurement points. The test installation status is shown in Figure 3. Two acceleration sensors 1# and 2# are installed in the impact test, of which 1# is located on the special tooling as the

control point, and 2# is located at the connection between the hose product and the tooling as the measurement point. The test installation status is shown in Fig. 4.

Fig. 3 Installation status of urine collection hose for sinusoidal vibration and random vibration test

Fig. 4 Installation status of positive impact test of urine collection hose

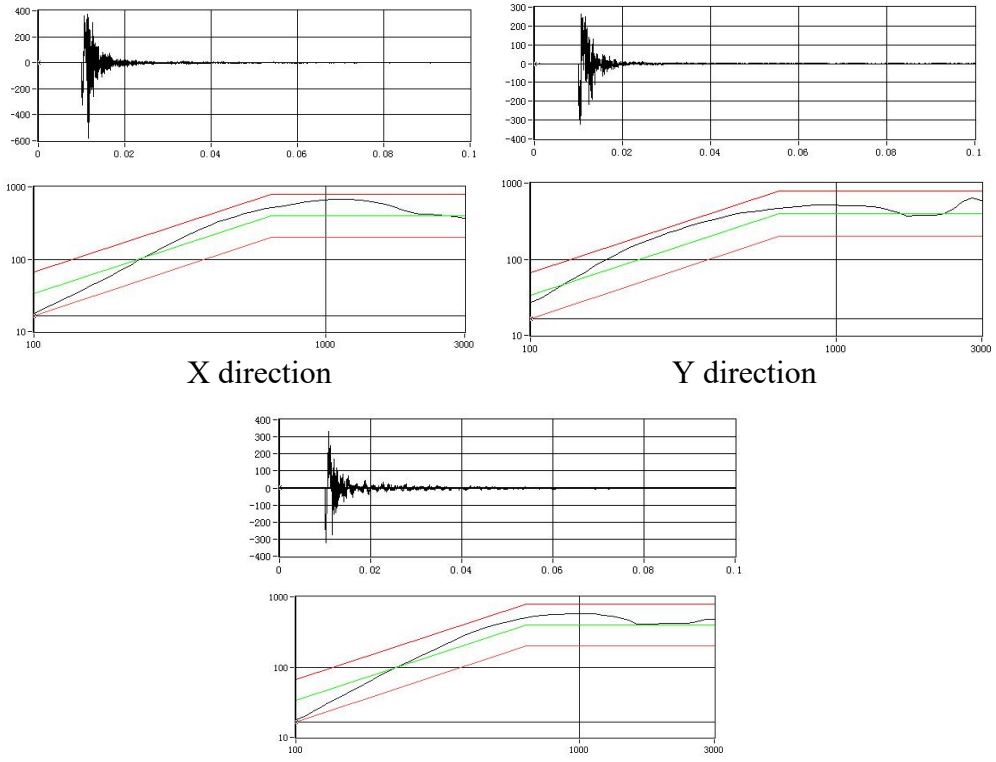


Fig. 5 Control record curve of shock response spectrum test loading

As shown in Fig. 5, after the completion of all environmental test items, the hose leakage rate meets the design requirements, that is, the urine collection hose assembly passes the identification level environmental test.

4. Conclusion

The design scheme of urine collection hose assembly based on polytetrafluoroethylene (PTFE) hose proposed in this paper has passed the performance test and space station product environmental test, and can meet the needs of the space station urine collection subsystem for the use of hose assembly. The design scheme has reference significance for the design of the environmental control and life support system (ECLSS) hose assembly of the space station and other manned spacecraft on long-term missions.

5. Acknowledgments

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References

[1] Zhou Kanghan, Fu Lan, Han Yongqiang, Li Junrong. Research and Progress on Regenerative Environmental Control and Life Support Technology [J]. Aerospace Medicine and Medical Engineering, 2003,12

[2] Yang Qi, Zhang Wenrui, Yu Kunkun. Research and Progress on Urine Treatment Technology for Space Stations [J]. Vacuum and Low Temperature, 2014,6

[3] Zhang Liang, Han Li. Design of fire resistant polytetrafluoroethylene hose assemblies [J] .Rubber Industry, 2017,2

[4] Ge Xiaofei. Research on PTFE inner tubes for aerospace applications [D] .Fudan University: chemical engineering, 2013

[5] Zhang Yuanchun. Main pump outlet of a certain type of aircraft Φ Design Improvement of 14mm High Pressure PTFE Hose Assembly (Part 1) [J] .Shanghai Chemical Industry, 2012,10

[6] Zheng Lixin, Zhang Yuanchun. Development of high-performance polytetrafluoroethylene hose assemblies. [C] The 17th National Academic Conference on Composite Materials, 2012

[7] Zhang Yuanchun. Design of metal joints for high-pressure polytetrafluoroethylene hose assemblies. [J] Shanghai Chemical Industry, 2010,6