Study on Improving the Sealing Reliability of Fluid Connector

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Abstract. Aiming at the problem of sealing reliability of fluid connector products commonly used in hydraulic system, this paper studies the static seal and the sliding seal. The factors affecting the sealing such as spring force, sealing ring and life of spring are considered one by one and the sealing effect is tested. The results showed that improved fluid connector can ensure that the hydraulic system is in the state of not even air intake or oil leakage while connecting and disconnecting at any time. The connector has been successfully applied to a certain model of launch vehicle.

1. Introduction

The fluid connector is an important part of the hydraulic system. It is suitable for the places where the hydraulic system needs to be connected or disconnected, without air intake or oil leakage. When connected, the system works normally; After disconnection, the system becomes two parts, and each part is sealed to the outside.

In actual use, only the 1-0 part and 2-0 part are inserted together, then the hydraulic system can be connected. When 1-0 and 2-0 are disconnected, the system is disconnected. 1-0 and 2-0 become normally closed check valves respectively without liquid overflow, so as to realize the rapid and convenient connection and disconnection of the hydraulic system. It is necessary to ensure the reliability under the condition of multiple connection and disconnection. The oil leakage of the fluid connector will affect the oil storage capacity of the connected system, which will cause a large amount of oil leakage and loss of working ability in serious cases. Therefore, the amount of oil leakage of the fluid connector is an important indicator to measure whether the product is reliable, and directly determines whether the product is qualified. It is critical that the product does not leak when it is connected and disconnected under the use environment. [1][2]

In this paper, the disconnection process of fluid connector LJQ8C used in a project servo system is taken as an example to study its reliability.

2. Technical indicators and working principle

2.1. Technical indicators

LJQ8C fluid connector requires that the application medium is aviation hydraulic oil, the working temperature is -45°C~250°C, the use of this environmental conditions can not leak, and both ends are self-sealing. Specific indicator is leakage of 0.02ml, under the working pressure of 0.5~30MPa.
2.2. *Working principle*

The fluid connector is suitable for the places where the hydraulic system needs to be connected and disconnected. It is composed of two parts, in which the 1-0 part is fixed on the servo system and the 2-0 part is fixed on the metal hose end. After connection, the two parts are connected and the oil circuit is connected. The flow direction of the liquid is shown in Fig. 1. After disconnection, it shuts down by itself to close the oil circuit. [3]

![Fig. 1 structure schematic of LJQ8C](image)

After connection, the oil circuit is connected, and the system works normally; After disconnection, the system becomes two parts, each part is sealed to the outside. When the 2-0 part is disconnected from the 1-0 part, the 1-0 part of the valve component overcomes the friction of the sealing ring under the action of the spring force, and returns in time to fit the pressure glue surface of the valve core to achieve the reliable sealing to the outside of the 1-0 part and the 2-0 part respectively.

Because the 2-0 part is connected to the hose and the 1-0 part is connected to the system, the leakage amount when the fluid connector is disconnected mainly considers the leakage amount of the 1-0 part connected to the system. Therefore, the leakage amount is closely related to the timeliness of the 1-0 valve seat return. The more timely the valve seat component is returned, the less leakage will be caused when the valve is disconnected.

The spring force and the friction of the sealing ring are the main factors that affect the return of the valve seat assembly. Therefore, it is necessary to effectively match the spring spring force and the friction of the sealing ring. In the case of long-term storage, it is also necessary to consider the working life of the spring, so that 1-0 and 2-0 connection will not be particularly laborious while disconnecting to form a timely return force to ensure that there is no leakage. Carry on the experiment to verify the examination, and solve this kind of problem.

3. Materials and Methods

3.1. Design of sealing ring friction force and spring force

The factors affecting the reliability of connection and disconnection are mainly spring force, friction of sealing ring and sealing pressure, so we design for the above factors.

3.1.1. Friction of sealing ring

The calculation of O-ring friction is shown in Figure 2 below.
For the valve core equipped with O-type rubber ring, the sliding friction $Q$ can be calculated according to the following formula.

$$Q = \pi D' F'_0 + F_0$$  \hspace{1cm} (1)

Where $D'$ -- outer diameter of the valve core (mm)

$F'_0$ -- friction generated by the initial elastic compression of O-ring on the contact surface per unit length. For rubber with HS of 80~90, when the precompression amount is 14%~15%, $F'_0 = 0.33 N/mm$;

$F_0$ -- friction of O-ring under fluid pressure (N).

$F_0$ is calculated according to the following assumptions.

(1) The deformation of the O-ring under the action of precompression and fluid pressure is similar to that of a rectangle. In this case, consider the contact width $C$ approximately as one side of the rectangle.

(2) The cross-sectional area of an O-ring with a diameter $d_0$ is the same as that of a rectangle with sides of length $C$ and $(D' - d_1)/2$.

(3) The maximum specific pressure of the O-ring on the side wall of the cylinder is equal to the working pressure of the fluid $P$.

According to the above assumptions, the calculation of $F_0$ has sufficient accuracy in practical application.

According to the above assumptions, the calculation of $F_0$ is as follows:

$$F_0 = \pi D' P C \mu_0$$  \hspace{1cm} (2)

Since the cross-sectional area of the O-ring is $0.785 d_0^2$, then $0.785 d_0^2 = C \left( \frac{D' - d_1}{2} \right)$. When the compression rate is 15%, $D' = d_1 + 1.7d_0$, so $0.785 d_0^2 = 0.85Cd_0$, then $C = 0.92 - d_0$. Substitute it into Equation (2) to get:

$$F_0 = 0.92 \pi D' d_0 P \mu_0$$  \hspace{1cm} (3)

Substitute $F_0$ and $F'_0$ into the equation (1). And figure out as follows:

$$Q = \pi D'(0.33 + 0.92 d_0 P \mu_0)$$  \hspace{1cm} (4)

Where, $\mu_0$ --the friction coefficient of rubber against metal;

$d_0$ -- the cross-sectional diameter of the O-ring.

By substituting the relevant parameters, we can get $Q = 55.9 N$.  

Fig. 2 Calculation diagram of O-ring friction force
3.2. Spring elasticity
The separation force is the key to the fast leak-free disconnection of the fluid connector, which mainly depends on the spring force which can overcome the friction of the O-ring. From the structure of the product, it can be seen that the decision of the separation force of the product is mainly the spring force of the two reset springs that push the block in the plug and socket, and the decision of the separation force of the product is the spring force of the spring in the plug locking sleeve.

According to Article 6.1 in GB/T23935-2009 "Cylindrical Spiral Spring Design and Calculation", the calculation formula of spring elasticity is as follows:

$$F = \frac{Gd^4}{8D^3n}f$$

Where: $G$ -- cutting modulus; $d$ -- spring diameter; $D$ -- spring median diameter; $n$ -- effective number of spring; $f$ -- spring deformation.

The fluid connector is made of carbon spring steel wire class C, GB/T4357-1989, and its cutting modulus is $78 \times 10^3$ MPa. After calculation, the spring wire diameter is 2mm, the effective number of turns is 4.5, the total number of turns is 6.5, and the pitch is 5.7mm. As shown in the figure below, the working force of the spring in the state of separation is 116N. It can overcome the friction of the sealing ring.

According to the above selection of spring material and size, the ultimate life analysis of the spring shows that the stress does not tend to the limit after the spring is compressed for 10,000 times, and it can withstand the specified compression times (see Figure 5).

![Fig. 3 parameters of the spring](image)

3.3. Sealing pressure
The sealing pressure has a direct effect on the sealing reliability of the fluid connector. [4] When the sealing pressure is too small, it is easy to cause leakage, and when the sealing pressure is too large, it is easy to cause damage to the sealing pair. Therefore, in the design of sealing structure, the choice of appropriate sealing materials and sealing pressure is directly related to the reliability of the contact sealing and sealing performance.

The forces on the valve seat assembly are integrally balanced, including fluid pressure, spring force, and ring friction. [5]

$$F_s = F_i + F_p - f = \pi db q_p$$

$$q_p = \frac{F_i - F_p}{\pi db} = 4.56$$
Where, \( F_s \) is the support force of the valve core to the valve seat, N; \( F_t \) is the pre-tightening force of the spring, N; \( p_F \) is the fluid pressure of the valve core, N; \( d \) is the aperture of the valve core, m; \( b \) is the width of the sealing pair, m; \( q_F \) is the sealing pressure, Mpa.

According to the characteristics of nitrile rubber material, check the sealing pressure of the valve port. According to the general design specifications of valves for aerospace, the sealing pressure of valve port must meet the following requirements:

\[
\frac{5}{\text{min}} \leq q_p \leq \left[ q \right] = 5
\]

Where: \( q_{\text{min}} \) is the minimum sealing pressure to keep the seal, Mpa; \( \left[ q \right] \) is the permissible sealing pressure of the material, Mpa.

Calculate the minimum sealing pressure of the valve port according to the sealing pressure formula:

\[
q_{\text{min}} = \frac{0.098 C + K \Delta P}{10 \sqrt{b_0}} = 4.14 \text{ MPa}
\]

Where: \( \Delta P \) is the pressure difference between the two ends of the valve port sealing pair, MPa; \( b_0 \) is the width of the sealing pair, \( 1 \times 10^{-3} \text{ m} \); \( C \) is the coefficient related to the sealing surface material and structure; \( K \) is the influence coefficient of medium pressure on the sealing pressure.

For NBR composites, \( C = 4 \) and \( K = 0.6 \). The pressure difference between the two ends of the valve port is 0.6MPa, the minimum sealing pressure is 4.14MPa, the pre-tightening force of the spring is 65N, the sealing pair width is 1mm, and the actual pressure of the sealing pair is 4.56MPa. Therefore, the actual pressure of the sealing pair of the valve seat (4.56MPa) is larger than the minimum pressure of the sealing under the pressure difference of (4.14MPa), which is smaller than the permissible pressure of the sealing material (5MPa). Therefore, it can meet the requirements of use.

### 4. Test Verification

According to the actual use, check the sealing performance and connection and disconnection performance of the fluid connector.

![Sealing test while disconnect](image1)

![Sealing test while disconnect](image2)

![Sealing test while connect](image3)

Fig. 4 sealing test of SMT8C

Under the pressure of 0.5MPa and 23MPa for 15 minutes, respectively, we observe the sealing situation of 1-0, 2-0 and 0-0. And then we observe the results of sealing test, in the situation of 1-0 part and 2-0 part of SMT8C to be connect and disconnect, under the pressure of 0.5MPa for 15 minutes, respectively.

The results are shown in the table below.
Table 1  Results of Sealing test of SMT8C fluid connector

| Tested product number | Sealing | Connection and disconnection |
|-----------------------|---------|-----------------------------|
|                       | Low pressure sealing | High pressure sealing | Performance |
|                       | No leaks | No leaks | Disconnection Performance |
| 1 001# 1-0 | No leaks | No leaks | No leaks |
| 2-0 | No leaks | No leaks | No leaks |
| 2 002# 1-0 | No leaks | No leaks | No leaks |
| 2-0 | No leaks | No leaks | No leaks |
| 3 003# 1-0 | No leaks | No leaks | No leaks |
| 2-0 | No leaks | No leaks | No leaks |
| 4 004# 1-0 | No leaks | No leaks | No leaks |
| 2-0 | No leaks | No leaks | No leaks |
| 5 005# 1-0 | No leaks | No leaks | No leaks |
| 2-0 | No leaks | No leaks | No leaks |

At the same time, we observe the sealing situation of the SMT8C fluid connector which was stored with pressure for 28 days. The results are shown in the table below.

Table 2  Results of Sealing test of SMT8C after 28 days of pressure retention

| Tested product number | Sealing | Connection and disconnection |
|-----------------------|---------|-----------------------------|
|                       | Low pressure sealing | High pressure sealing | Performance |
|                       | No leaks | No leaks | Disconnection Performance |
| 1 001# 1-0 | No leaks | No leaks | No leaks |
| 2-0 | No leaks | No leaks | No leaks |
| 2 002# 1-0 | No leaks | No leaks | No leaks |
| 2-0 | No leaks | No leaks | No leaks |
| 3 003# 1-0 | No leaks | No leaks | No leaks |
| 2-0 | No leaks | No leaks | No leaks |
| 4 004# 1-0 | No leaks | No leaks | No leaks |
| 2-0 | No leaks | No leaks | No leaks |
| 5 005# 1-0 | No leaks | No leaks | No leaks |
| 2-0 | No leaks | No leaks | No leaks |

5. conclusions
The reliability of fluid connector is affected by spring force, spring life, sealing ring friction and plastic material deformation. To improve the reliability, the above factors need to be considered comprehensively. In the hydraulic system, oil leakage is a common and difficult to solve problem. In order to clarify the influence degree of each factor, attention should be paid to maintaining a single variable in the optimization process and experimental scheme, otherwise it will bring a lot of work. The successful implementation of this product has great reference significance to the improvement of other similar hydraulic products.

In general, the appropriate spring force, longer spring life, ring parameters that maintain the seal without causing leakage and the appropriate amount of deformation, and the match of spring force and ring friction contribute to the reliability of fluid connectors.

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