Study on seal of the hydraulic lock with high pressure-resistance and leakage-free

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Abstract. In order to solve the sealing problem between the two cavities of the servo actuator in harsh environment, the high pressure resistant hydraulic lock with integrated cone soft seal technology is designed by using nonmetal rolling molding and self-balanced technology of a integrated valve core. Its life and sealing effect were tested; the results showed that this new type hydraulic lock has reliable open and shut characteristic as well as reliable sealing effect. It can ensure the servomechanism is fully close anywhere. The new type design has been applied to certain model of carrier rocket.

1. Introduction

Hydraulic lock is an important component of rocket servo control system.

The rocket thrust vector control system consists of servomechanism and engine. It moves follow the control command from the computer to control the rocket attitude. The engine applied in certain rocket has a relatively large eccentric moment. The servomechanism is required to fix the engine nozzle in any position when the engine is at eccentric state. The locking device is added in servomechanism (the hydraulic lock) to solve this problem. As a core component in the servomechanism, the hydraulic lock fixes the piston rod at any position by locking the oil in actuator.

In the servo system, the hydraulic lock needs both excellent open and shut characteristic and reliable sealing effect. It needs to open sensitively and keep the load at the stop position for a long time, that is to say fix the piston rod in any position. The open and shut characteristic of hydraulic lock is important in servomechanism system application.

Figure 1. The gravitational eccentric moment of engine
2. Design of the hydraulic lock with high pressure-resistance

2.1. The working principle of hydraulic lock with high pressure-resistance

The hydraulic lock with high pressure-resistance and leakage-free belongs to hydraulic control valve. It is installed in the hydraulic circuit between the servo valve and actuator in servomechanism. It locks the oil circuit of the servo valve and actuator respectively. As shown in Fig.3, the structure principle of its main components is different from conventional hydraulic lock.

The principle of the conventional hydraulic lock is same as the hydraulic control check valve, that is to say the oil flow moves positively and keeps locked when it is opposite. It can be open by its control pressure when it is opposite [3]. When this type hydraulic lock is locked, the oil circuit is locked under the action of the spring. The external control pressure is needed to act on the valve core to open the oil circuit. The principle is shown in figure 3, when the pressure in the main oil system drops, the pressure acting on valve core from the control cavity in hydraulic lock then decreases, the valve core shuts up rapidly under the action of the spring. The oil circuit of the actuator and servo valve is locked.

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Figure 2. The fixing position of the hydraulic lock

Figure 3. The functional diagram of the hydraulic lock
2.2. **The Structure design of the hydraulic lock with high pressure-resistance**

The new type hydraulic lock consists of housing, blocking, valve core, seal ring, spring, screws, The structure is shown in figure 4. The valve core adopts self-balancing structure to realize the high pressure resistant hydraulic lock, then the pressure on the valve core from actuator can cancel each other out. The hydraulic lock has such futures as light quality and compact structure because of its fission and integral structure.

![Figure 4. The structural diagram of hydraulic lock](image1)

The valve core adopts integral taper sealing structure namely the seal form between the valve core and the shell is contact type. The basic working principle is when the control pressure goes up, it works on the smaller end of the valve core, overcoming the pressure of spring and return oil to open the valve core and then the actuator cavity A and servo cavity B are interlinked. When the control pressure drops, the pressure acting on the smaller end of the valve core is insufficient to overcome the pressure of spring and return oil. The valve core shuts down and then the actuator cavity A is isolated from the servo cavity B.

2.3. **Flow field simulation of the hydraulic lock with high pressure-resistance**

The design of channel structure not only affects the pressure loss in hydraulic lock but also affects the product life and seal reliability, when the maximum velocity present to the cone soft seal and impact it, therefore, we use CFD to optimize the design of channel structure.

The simulation result of pressure loss: inlet pressure 24MPa, output pressure 23.6773MPa, pressure loss 0.33MPa, it can meets the demand. At the same time, the velocity and flow are simulated and optimized, the maximum velocity (33.1m/s) was not in the seal position where the flow less than 9.8m/s, the figure shows as follows:

![Figure 5. The simulation of velocity/flow and the 3D streamline](image2)

3. **Selection of the sealing material**

In the hydraulic lock structure, the seal reliability of valve core (the leakage) is the key of the whole design. When the hydraulic pressure is neglected, the main reason for the leakage can be divided into the rough seal surface and small sealing pressure(big clearance of the seal surface). There are two ways
to improve the seal property: (1) Enhance machining precision to achieve Ra0.4~Ra0.8 μm of the roughness. Increase the waviness of ring direction to achieve labyrinth seal under the sealing force.; (2) Enhance the contact pressure on seal surface namely sealing pressure to cause elastic deformation of the interface which can flatten the profile peak of seal surface and seal well [4].

The working medium of hydraulic lock is aircraft hydraulic oils and the working temperature is −40±3°C ~ 60±2°C. Some hydraulic locks are sealed with “GLYD RING+SEAL RING” which is Iltype seal, it is hard to be installed when the mounting hole is slender. At present, the seal structure of most hydraulic poppet valves is metal hard seal; the valve port will gradually wear down after times operation. It is different to meet the requirement of zero leakage. Therefore, the seal structure of this type hydraulic lock is valve cone soft seal+Il type seal, the sealing material is NBR5080 which has good elasticity and machining performance. It is suitable for molding, injection molding, casting molding and machining [5][6].

The seal structure of this hydraulic lock is the form of vulcanizing the NBR5080 on the valve core. It forms sealing circular-bands by vulcanizing NBR on the groove of valve core to form the sealing pair with the shell. This new structure improves the seal performance by using the elastic detonation of rubber material. The valve core is pushed by spring to make it contact to the shell, it realized the reliable sealing by the elastic deformation of the rubber.

4. Force analysis of the seal cone

The sealing pressure directly affects the sealing performance and the reliability of valve. The sealing pressure is too small will cause leakage, and pressure the general assembly to premature the seal failure. Therefore, the choice of suitable sealing material and pressure is directly related to the reliability and performance of the seal in the design of its structure.

The pressure on the valve core of the hydraulic lock is in equilibrium, it is only subjected to the hydraulic pressure from the control cavity, the spring force, the return oil pressure from the low-pressure cavity and the supporting force from the valve sleeve.

\[
F_s = F_t - F_p = \pi d q_p \quad (1)
\]

\[
q_p = \frac{F_t - F_p}{\pi d} \quad (2)
\]

Fs is the supporting force from the housing; Ft is the initial pressure of spring, Ft = 400N; Fp is the hydraulic pressure from the control cavity, Fp = 140N, d is the aperture, b is the bandwidth of sealing pair, q_p is the sealing pressure.

The sealing pressure at the valve port was checked according to the material properties of NBR. According to the general design code for aerospace valves, the sealing pressure at the valve port must meet the following rules:

\[
q_{\min} \leq q_p \leq [\dot{q}] \quad (3)
\]

Where \( q_{\min} \) is the minimum sealing pressure of keeping seal, MPa; \([\dot{q}]\) is the permissible sealing pressure of the material, \([\dot{q}] = 5\) MPa.
The minimum sealing pressure at the valve port can be calculated according to the following formula of sealing pressure:

$$q_{\text{min}} = \frac{0.098C + K\Delta p}{10\sqrt{b_0}}$$  \hspace{1cm} (4)

Where: $\Delta p$ is the pressure difference at valve port, MPa; $b$ is the bandwidth of sealing pair, m; $C$ is the coefficient related to the sealing material and structure; $K$ is the influence coefficient of sealing pressure due to the medium pressure.

For the NBR, $C$ is 4; $K$ is 0.6; $\Delta p$ is 1.5 MPa; The minimum sealing pressure is $q_{\text{min}} = 2.89$ MPa; the initial pressure of spring is 400 N; the bandwidth of sealing pair is 2 mm and the practical sealing pressure is $q_p = 3.43$ MPa.

$$q_{\text{min}} = 2.89 \text{MPa} \leq q_p = 3.43 \text{MPa} \leq [q] = 5 \text{MPa}.$$  

Therefore, it can meet the requirement.

5. Experimental verification

5.1. The element test

In order to validate the seal reliability of the hydraulic lock with high pressure resistance, the hydraulic lock was tested; the main test item and results are shown in the following table.

| Testing items      | Testing conditions                                                                 | Test result | Test conclusion |
|--------------------|------------------------------------------------------------------------------------|-------------|-----------------|
| Hydraulic sealing  | The actuator cavity was pumped at 24 MPa, the servo valve cavity was closed, 10 min. | 0 drops     | Qualified       |
|                    | The servo valve cavity was pumped at 24 MPa, the actuator cavity was closed, 10 min.| 0 drops     | Qualified       |
| Housing strength   | The control cavity was pumped at 37 MPa, the return oil cavity was pumped at 3 MPa, 5 min. | 0 drops     | Qualified       |
|                    | The control pressure of hydraulic oil increased from almost zero, when at 4 MPa, it opened; when at 5.2 MPa it fully opened. | /           | Qualified       |
| Opening pressure   | The servo valve cavity was pumped in 80 L/min (full opened), the pressure loss between two cavities $\leq 1.25$ MPa | 0.7 MPa     | Qualified       |

5.2. The servomechanism test

The hydraulic lock was installed on the servomechanism for testing. The extend/retract test of actuator and sealing rest were done with the loaded engine. Under the specified test conditions, the
extend/retract of servomechanism was normal and it can hold normally. The results indicated that the open and shut characteristic and sealing of the hydraulic lock can meet the requirement of system operation.

6. Conclusions
In the design of the hydraulic lock with high-pressure resistance and leakage free, it adopted the technology that the NBR5080 and metal were fabricated as one whole body. The hydraulic lock has the properties of compact structure and light weight. The reliability of the servomechanism is improved by simplifying the structure of hydraulic lock, and the function of locking the nozzle for a long time at any position in harsh environment was realized. This structure may be of certain reference significance to the other valves and it will has a wild prospect of application.

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