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# IMPROVED DESIGN OF AIRCRAFT NOSEWHEEL STEERING SYSTEM

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## Abstract

This paper introduces the working principle of the front wheel steering and anti shimmy system of a certain type of aircraft, and analyzes the possible causes of the failure in the field flight. After learning from other mechanical hydraulic servo systems in China, the front wheel steering and anti shimmy system is improved. The improved system separates the steering and anti shimmy oil circuit through the state change-over valve, which eliminates the potential safety hazard of the original system. Finally, AMESim software is used to simulate the improved system, and the results are compared with the test results. The results show that the improved system can meet the needs of steering and anti shimmy of a certain type of aircraft.

**Keywords:** steering; anti shimmying; damp

## 1. Background

In January 2007, during the take-off taxiing of a certain type, the front wheel locked and the pilot use the differential brake system to correct the direction, finally brake tire burst. In March 2012, the aircraft take-off taxiing corrective failure brake tire burst. There are many other accident symptoms like this. The analysis of the causes are in the anti-shimmy state, the booster slide valve isn' t in the neutral position, so that the booster actuator cavity is closed, the front wheel is locked. The pilot try to use differential brake to correct the direction, which leading to the wheel brake burst.

The main accessory of a certain type of aircraft front wheel steering and anti-shimmy system is the front wheel steering and anti-shimmy booster, which combines the two functions of the system. The combination simplifies the system, but also brings problems. Which is the slide valve can play the role of anti shimmy only when it is in the neutral position. In order to ensure the neutral return of the system, the slide valve return spring is set inside the booster, which indirectly leads to the large handwheel control force and has been criticized by the aircrew. Therefore, in this paper, the design of a certain type of aircraft front wheel steering and anti-shimmy system may lead to the front wheel locking and large control force of the booster inner slide valve[1].

## 2. Improved design scheme

The schematic diagram of the improved front wheel steering and anti-shimmy system is shown in figure 1.

The pressure supply mode of the steering system is same as that of the original system.

In the low-speed taxiing stage on the ground, if the pilot wants to steer, turns the "steer / anti shimmy" switch to the "steer" position, turn on the solenoid valve (6), and then connect the steering pressure oil supply circuit. The oil inlet of steering and anti-shimmying booster (7) is connected with high-pressure oil, and the State transition valve (11) overcomes the spring force to switch to the left position function under the action of high-pressure oil. It communicates the steering control oil circuit between the actuator of the booster and the steering control slide valve. The pilot turns the hand wheel to drive the turning slide valve for steering action. The steering return oil fills the compensator (10) with oil through the one-way valve. When the oil filling pressure is reached, the return-oil compensator (8) is opened.

When the hand wheel deflects to a certain position, the front wheel steers to the corresponding position, the oil inlet of the slide valve is closed, the actuator stays at the corresponding position and keeps the deflection angle (corresponding to the hand wheel) for continuous turning. Turn the handwheel to neutral and the front wheel steers to neutral. In the steering state, the front wheel always follows the movement of the hand wheel.

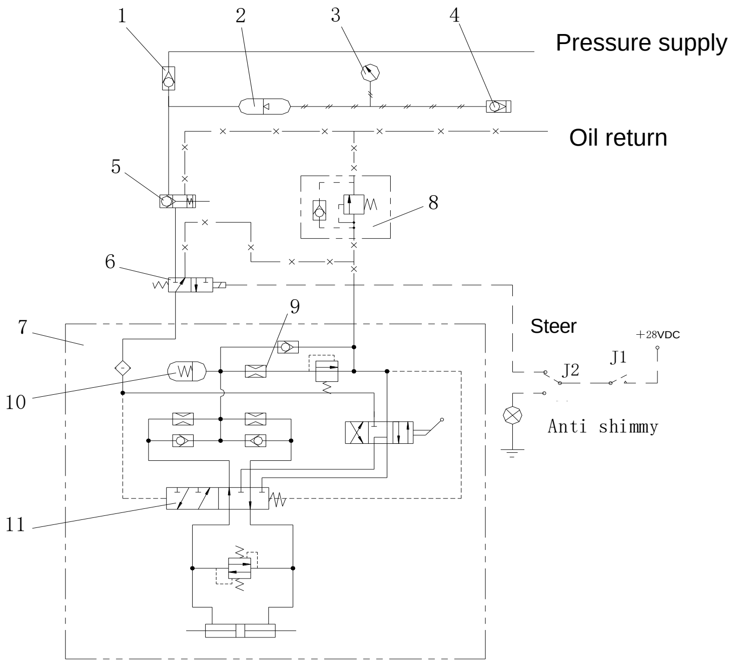


Figure 1 – The Schematic Diagram.

1 Unidirectional valve; 2 Accumulator; 3 Micro pressure gauge; 4 inflation valve; 5 Coordination valve; 6 Hydraulic solenoid valve; 7 Steering and anti-shimmy booster; 8 Anti-shimmy return oil compensator; 9 Throttle; 10 Compensator; 11 State transition valve

Turn the "steer / anti shimmy" switch from the "steer" position to the "anti shimmy" position, turn the power off of the solenoid valve (6), which is in the left position under the action of the return spring, and connect the oil return circuit. The pressure inlet of steering booster (7) is connected with the return oil, and the internal State transition valve (11) is switched to the anti-shimmy position under the action of the return spring, which communicates the two chambers of the booster with the anti-steer oil circuit, and the system is in the anti-shimmy state. At the same time, the oil in the compensator (10) can replenish the anti-shimmy oil circuit through the one-way damping valve to keep the anti-shimmy chamber full of oil.

Since both the supply and return circuits have been cut off by the State transition valve in the anti-shimmy state, the movement of the slide valve has no effect on the displacement of the actuator.

Compared with the original system, the improved front wheel steering and anti shimmying system improves the design of the front wheel steering and anti shimmying booster, and adds a State transition valve to control the oil circuit under different states of steering / anti shimmying. Therefore, a hydraulic solenoid valve is added to the oil inlet circuit to control the working mode of the system. In addition, the hydraulic balancer and solenoid valve on the oil return circuit are canceled, and the compensator, oil return anti charging check valve, overflow valve and throttle valve are integrated in the front wheel steering and anti shimmying booster to ensure that the booster is always filled with oil under the anti shimmy working mode, so as to improve the anti-shimmy performance of the system.

## 3. System simulation calculation

### 3.1 Calculation and comparison of flow area of booster valve port

The flow area of the valve port of the booster spool before and after the improvement is calculated and compared. The calculation of the flow area doesn't consider the fit clearance between the valve core and the valve sleeve[2],[3],[4].

The slide valve core of the improved front wheel steering and anti shimmying booster is a common cylindrical slide valve, and the slide valve sleeve is a groove type, as shown in the figure 2, which is distributed in two places along the circumference. The distance between the working edge of the slide valve and the valve sleeve is 0.25 mm, and the radius of the valve sleeve is 0.165 mm. The transmission ratio between the input stroke of the rocker arm and the axial stroke of the spool valve is 0.6.

Before the improvement, the front wheel steering and anti shimmying booster adopts the form of inclined orifice, and two inclined planes 4° with the spool axis are distributed along the circumference, as shown in the figure 3. The length of the inclined plane along the axial direction is 5.2mm and the diameter of the valve core is 8mm. The overlap area between the slide valve and the valve sleeve is assumed to be 0.5mm.

The calculation results of the valve port flow area of the two types of front wheel steering and anti shimmying booster are shown in figure 4. After improvement, the flow area is increased by about one time.

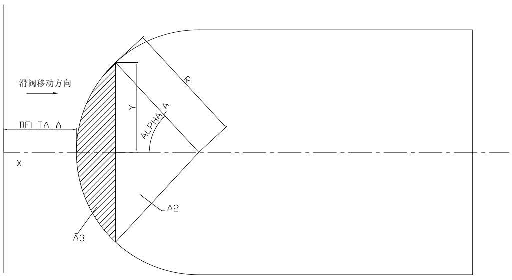


Figure - 2 Cross section of improved booster spool valve

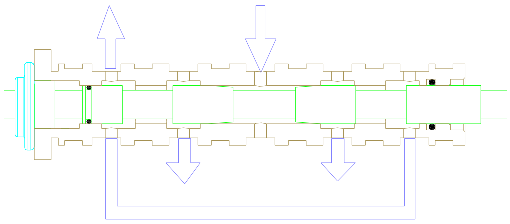

Figure - 3 Cross section of original booster spool valve

## 3.2 Valve port flow calculation

Use the orifice throttling formula for calculation, as shown in Formula (1).

$$Q=Cq*A0*(2*\Delta p/p)^{1/2} \qquad (1)$$

It is assumed that the flow coefficient Cq is 0.7, the oil density is 0.85g/cm3, and the pressure difference is (20.6-1.3) MPa. The results are shown in Figure 5. The results are consistent with the flow area, and the flow rate of the improved valve port is increased by about one time.

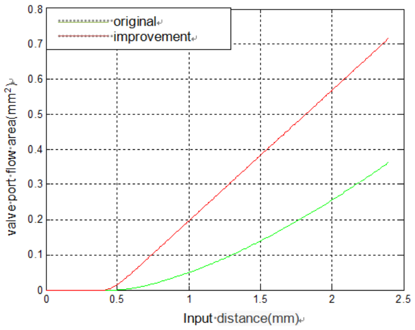


Figure - 4 Calculation results of valve port flow area

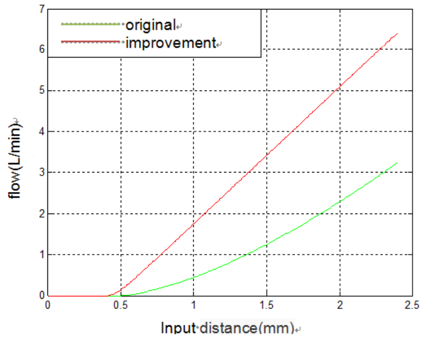


Figure - 5 Valve port flow calculation results

## 3.3 Volume calculation of compensator

In order to improve the anti-shimmy performance of the system, a compensator is added in the hydraulic accessory front wheel steering and anti shimmying booster. Usually, the timing of oil replenishment for compensator is as follows:

When the oil in the system is lost due to temperature change or leakage;

When the front wheel deflection causes the liquid flow velocity to increase (in order to prevent cavitation at the damping valve port due to the increase of pressure drop)[5].

Considering the characteristics of accessories, the proportion of leakage is very small, which can be ignored in transient. When the temperature drops, the oil can be fed into the actuator through the supercharged oil tank. When the temperature rises, the oil in the actuator can be squeezed out from the oil return pipeline, so the volume of the compensator can not consider the temperature compensation; The compensator only considers the change of oil volume caused by the change of pressure drop.

P1 is connected to the left chamber of the actuator and P2 is connected to the right chamber of the actuator.

In the state of swing reduction (instantaneous), there are:

$$\Delta P_1 = P_a - P_b \qquad (2)$$

$$\Delta P_2 = P_b - P_d \qquad (3)$$

$$\frac{\Delta V_1}{V} = \frac{\Delta P_1}{E_y} \qquad (4)$$

$$\frac{\Delta V_2}{V} = \frac{\Delta P_2}{E_y} \qquad (5)$$

$$\Delta V = \Delta V_1 - \Delta V_2 = \frac{V}{E_y}(P_a - 2P_b + P_d) \qquad (6)$$

In the formulas:

$P_a$——The opening pressure of safety valve, taken as $P_a$=25.5MPa;

$P_b$——If the compensator is full of pressure, taken as $P_b$=0.3MPa;

$P_d$——The set value of no negative pressure in the oil chamber, taken as $P_d$=0.1MPa;

V——Volume of actuator oil chamber and pipeline, taken as V=0.226L;

$E_y$——Oil bulk modulus of elasticity, taken as $E_y$=1.5×103MPa/L.

Substitute the data into the formulas to get: $\Delta$V=4.4mL.

## 3.4 system simulation

### *3.4.1 modeling of front wheel steering and anti shimmy system*

According to the system principle shown in figure 1, the simulation model of the improved front wheel steering anti shimmy system is built by using AMESim software, as shown in figure 6.[6][7][8]

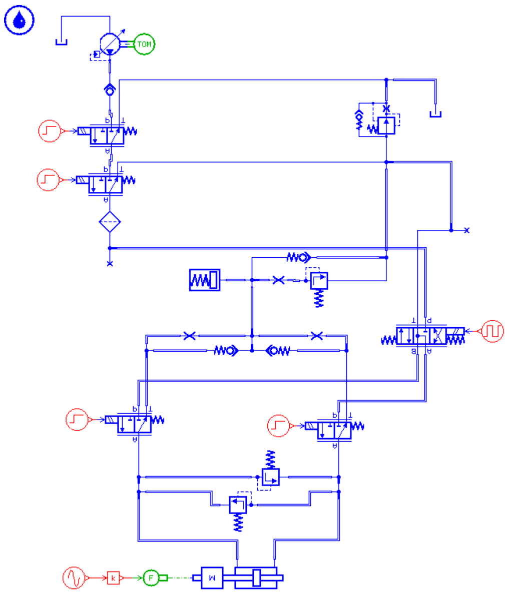

Figure - 6 Simulation model of front wheel steering and anti shimmy system

### *3.4.2 performance simulation analysis of front wheel steering and anti shimmy system*

Based on the two main functions of the front wheel steering and anti shimmy system, the steering performance and anti shimmy performance of the improved system are simulated.

For the steering function, the front wheel steering performance under no-load condition is calculated. For anti shimmy function, the diameter of damping hole is selected Φ 2 mm, the selected frequency is 3 Hz, and the selected angle is 5.6 degrees. The simulation curves are shown in figure 7 to figure 13.

1) Steering performance simulation curve

It can be seen from the steering performance simulation curve that the time required for the actuator to move from one limit position to another limit position is 4s, the movement speed of the actuator is 40mm / s, and the maximum flow is 5.5l/min.

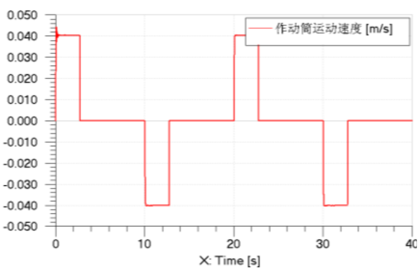


Figure - 7 Velocity curve of actuator

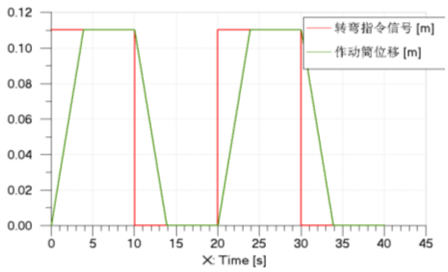


Figure - 8 Command signal and actuator displacement curve

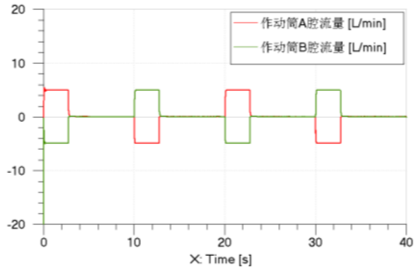


Figure - 9 Two chamber flow curve of actuator

2) Simulation curve of anti shimmy performance

It can be seen from the anti shimmy performance simulation curve that the displacement of the actuator is ± 9mm, the corresponding front wheel angle is ± 5.6 ° and the flow rate of the throttle valve inside the booster is negative, which indicates that the oil in the booster does not flow out from the throttle valve under the anti swing state, and the two cavities of the actuator are always full of oil, which can provide enough anti shimmy damp for the system.

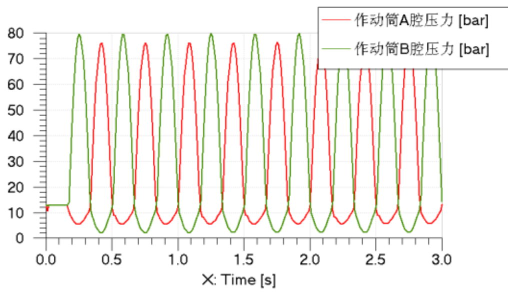


Figure - 10 pressure curve of two chambers of actuator

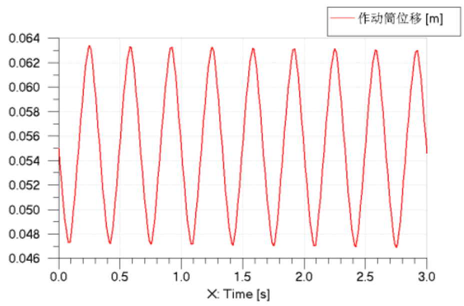


Figure - 11displacement curve of actuator

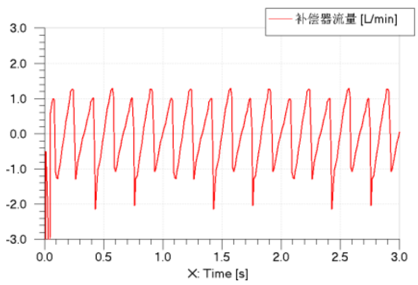


Figure -12 flow curve of internal compensator of booster

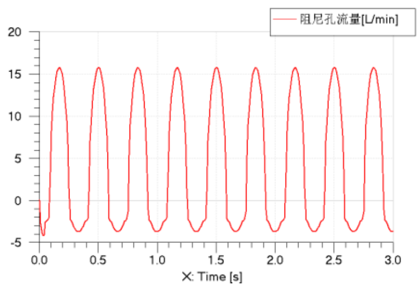


Figure - 13 flow curve of internal damping hole of booster

## 4. Test verification

The improved steering and anti shimmying system has completed the physical comprehensive test. The main contents of the test are as follows: handwheel control force measurement test, steering function test, steering rate test, anti shimmying function test, slide valve blocked on one side test, emergency turning test and system durability test. The test results of steering function are shown in figure14 and figure15.

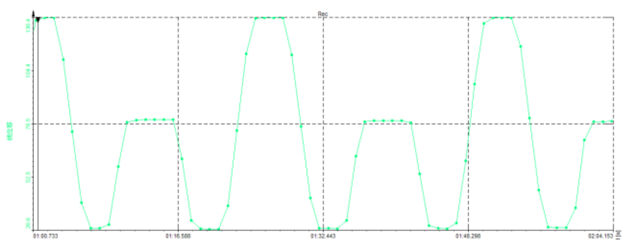

Figure 14 – Actuator displacement curve.

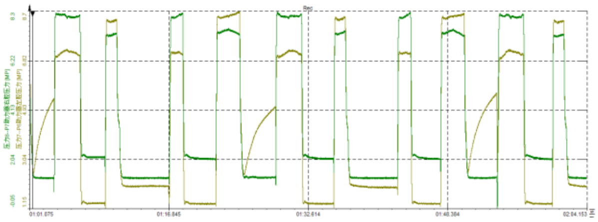

Figure 15 – The curve of pressures of the actuator

As can be seen from the figure, the time required for the actuator to move from one limit position to another is 4s, and the turning time is also 4s in the previous turn function simulation. The oil pressure of the two cavities of the actuator varies with the displacement of the actuator.

## 5. Conclusion

In this paper, analysis the causes of two problems of the steering and anti shimmying system. Complete the design of improved steering and anti shimmying system. The main performance calculation and simulation analysis of the improved system are carried out. The physical test results show that the improved system principle is correct and can meet the needs of aircraft steering system.

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